EXPERIMENT STATION
OF THE
KANSAS STATE AGRICULTURAL COLLEGE
MANHATTAN

BULLETIN No. 127--JUNE 1904
(Issued March 1905)

FARM DEPARTMENT

A.M. TEN EYCK, B. AGR., Agriculturist

The Roots of Plants

PREVIOUS ROOT STUDY. In 1897 Prof. C.C. Georgeson, at that time agriculturist at this Station, and J.E. Payne, assistant, made "Investigations of the Root Development of some Forage Plants," the results of which were published in Station Bulletin No. 75. Although a large amount of work was carefully done in digging out and tracing the roots of several plants, and valuable drawings and notes were made which gave a good idea of the root growth of some plants, yet no sample showing the root system of any plant was secured and photographed.

In the preparation of the current bulletin a different method of studying the roots has been used, by which samples of the plant have been secured and preserved, showing the natural root system as it grew in the soil of the Station farm. The method of sampling was in part original with the author of this bulletin, who, as an assistant to Prof. F. H. King, in Wisconsin, in 1892, prepared the first samples in this manner of which a record has been published. These samples were exhibited at the World's Fair in 1893, and cuts of the same were published and discussed by Professor King in the Ninth and Tenth Annual Reports of the Wisconsin Agricultural Station, and also in his book, "The Soil." Professor King did not continue his studies, but others in different states have made investigations, and in 1898 and

1899 the writer continued this work at the North Dakota Experiment Station and published Bulletins Nos. 36 and 43 of that station, which were largely a study of the root development of wheat, flax, potatoes, and corn, although some study was also made of the roots of sugar-beets and of some of the grasses.

The work published in this bulletin is therefore not entirely new, being in part a repetition of some of the work done at the North Dakota Experiment Station, and by the permission of the director of that station some cuts of samples prepared at that station by the author are published in this bulletin. The study of the roots of Kafir-corn, sorghum, soy beans, cowpeas, alfalfa and some of the grasses may be called *new work,* and the cuts published in this bulletin were made from the photographs of the original samples, now being exhibited at the St. Louis Exposition or held in the agricultural museum at this Station. The comparison of the root growth of level-planted and lister-planted corn is also new work.

PREPARATION OF THE ROOT SAMPLES. The method of preparing the root samples though simple is somewhat expensive, and requires some hard and painstaking work on the part of the investigator. It is always interesting, however, to the experimenter to investigate and uncover the secrets of nature, even if it is done in mud and water. Briefly, the samples are prepared as follows: A trench two feet wide and several feet deep is dug about a block of earth in which is the growing plant (or plants), the roots of which it is desired to secure as a sample. Over this block of earth is fitted a cage, made by covering the sides of a wooden or iron frame of the proper dimensions with common wire poultry netting. When the cage is properly fitted so that the top part of the frame rests firmly on the surface of the ground, plaster of Paris, stirred to a thin paste with water, is poured into the top of the frame about the base of the plants and allowed to set and harden. Small steel rods (Nos. 10 and 12 galvanized iron wire, straightened and cut into pieces about two inches longer than the width of the cage, sharpened at one end and looped at the other) are now run through the blocks of earth one way, or better two ways, when the cage is square, and made secure at one end. Water, by means of a small force- or spray-pump, is now applied, and the earth is slowly washed away, leaving the roots suspended on the wire rods.

The cages used were made out of two-inch White pine, some being fourteen inches square on the inside, while others were fourteen inches wide and varying in length from four to five and one-half feet. A width of fourteen inches made as thick a block of earth as the rods could be shoved through easily, and with a thicker block it was found that the earth could not be readily removed in washing out the roots.

This plan of taking root samples succeeds well in loam and clayey soils which are not too sticky to wash, but in light, sandy soils which are likely to cave, the method will not work so successfully. One of the advantages of the method is that it requires no artificial preparation of the soil previous to planting the crop, and the samples secured in this way show the actual development and distribution of the roots which take place under natural field conditions.

THE SOIL IN WHICH THE ROOTS GREW. Nearly all of the root samples were taken from the upland soil of the Station farm. This is a limestone soil, rather poor in humus, and varies some in texture, being of the nature of a sandy loam in places; but usually the surface six to twelve inches may be described as a rather fine compact loam, with a subsoil usually containing a little more clay than the soil, so that it is often quite tough and hard to wash. Any special character of the soil observed in washing out the roots will be mentioned in the description of the samples.

CORN ROOTS.

(Lister *versus* level planting.)

In the study of corn roots, the purpose was not only to exhibit the root development of the plant, but to compare the root systems produced by the level and lister methods of planting. The corn was planted May 19, on new spring plowing. Part of the ground was listed in furrows about six inches deep, and all of the corn was planted with a check-row planter, in hills three and one-half feet apart each way. The variety of corn used was the Kansas Sunflower, a rather late maturing sort and a medium grower. The first set of samples were taken July 18–23, sixty days after planting. The corn stood about five feet high at that date, and had been cultivated for the last time ten days previous to taking the samples. It was the plan to cultivate shallow, in order not to injure the roots of the corn, but through an error, at the third cultivation, June 30, a six-shovel cultivator was used, and it is possible that the cultivation was sufficiently deep to destroy some roots.

Plate 1 is an illustration of the sample of the level-planted corn taken sixty days after planting. It shows the development and distribution of the roots between the hills of corn in adjacent rows. At the first observation, one is surprised at the large number of roots and their extensive growth. At this stage the corn has filled the soil with its roots, not only beneath the hills but between them, until the entire space was fully occupied to the depth of two and one-half feet, and some roots reached a depth of more than three feet. The roots are thrown off from the base of the stalks in quite uniform whorls, arranged one above the other, the whole forming a root-crown which in this sample measured ten to twelve inches in diameter near the surface of the ground.

From the illustration two classes of roots are easily distinguished: Those that curve out from t h e crown and strike more or less directly downward into the soil, i. *e*., the main vertical roots, and those that spread out from the root-stem in a horizontal plane, near the surface of the ground, the main lateral roots. In this sample the lateral roots curve downward as they leave the crown, and then extend out in an almost horizontal plane, the roots from opposite hills meeting and interlacing, when they curve more or less abruptly downward, often ending two or three feet beneath the opposite hill. In their horizontal course these roots have given off many vertical branches, which have penetrated the subsoil and reached a depth almost equal to that of the primary vertical roots directly beneath the hill.

In this sample the main roots were about four inches from the surface of the ground midway between the hills, at eight or ten inches from the hill they were three inches beneath the surface, and at four or five inches from the hill the outer roots of the root-crown reached the surface, and many large brace roots extended two or three inches above the ground. The bulk of the lateral roots lie between three inches and twelve inches from the surface. Some small, fibrous roots were observed above the main lateral growth, showing that the small feeding roots grow upward as well as downward and to the sides. This upward growth was more noticeable in the samples taken at maturity. Some of the main roots strike out at an angle, gradually curving downward with the branches from the horizontal roots. The vertical as well as the horizontal roots give off numerous branches, the branches in turn give off other branches, and these produce smaller fibers and root-hairs, so that the whole soil at this stage of growth, to the depth of two and one-half feet, served as a feeding-ground for the crop.

Plate 2 shows the root system of the corn which was planted in lister furrows. The sample was taken sixty-five days after planting. The early part of the season was very wet and rather unfavorable to the growth of listed corn, and the stalks of corn in these two hills were not quite so large as those in the hills of the level-planted corn; also, the roots of the listed corn appear to be less numerous and have made somewhat less growth than the others, although having much the same general arrangement and distribution in the soil. The main difference in the two root systems appears in the difference in the location and form of the root-crowns. While the root-crown of the level-planted corn rises to the surface of the ground in a compact, fibrous mass, from which the roots curve downward and outward into the soil, the root-crown of the listed sample is located fully three inches deeper in the ground and is less compact and fibrous, and the lateral roots extend directly from the root-stem in an almost horizontal direction, the depth at the hill being practically the same as the depth midway between the hills. Thus, although the lateral roots of the listed corn were found within four inches of the surface, midway between the hills, yet the average depth of the roots was greater than in the level-planted corn, in which the lateral roots rise nearer the surface at the root-crown.

It is the general experience of farmers who practice the lister method of planting that listed corn stands drought better than level-planted corn. This study of the root systems offers a suggestion as to the reason why: It is evident that the listed corn could have been cultivated deeper and closer to the hill at the last cultivation, without injuring the roots, than the level-planted corn. The root-crown forms deeper in the soil and, as cultivation progresses, the furrow is gradually filled until, at the last cultivation, the ground is left practically level, with three or four inches of mellow soil over the roots close up to the hill. The root-crown and the main roots of the corn are well covered and the whole soil is completely protected by a deep soil mulch, which conserves the soil moisture and protects the corn roots from the extreme heat of the summer sun much more than could be the case if the root-crown rose to the surface as it does in the level-planted corn. Although the root-crown and the main lateral root system of the listed corn lie deeper in the soil than in the level-planted corn, yet there was apparently no loss of feeding-ground for the roots, since it was observed in washing out the sample that the soil above the main roots was filled with numerous slender, hair-like roots, branches from the main roots, which seemed to feed almost to the surface of the soil. These small roots were either broken off in washing, or, having no support, sank down upon the main lateral roots when the earth was removed. *

Plate 3 is an illustration of the sample of listed corn showing the root development at maturity, 125 days after planting. The stalks averaged about eight feet in height. The ears were nearly ripe, but the stalks and leaves were green and the roots were still alive and apparently growing when the sample was taken. At maturity the

---

* Later study in the spring of 1904, after this bulletin was prepared for publication, indicates that, when the middles between the listed rows are unplowed and hard, the lateral roots actually rise nearer the surface as they extend outward from the root crown. Thus the depth of the lateral roots midway between the rows may be less with the listed corn than with the level-planted corn, when the latter is planted in a deep, mellow seed-bed.

roots had reached a depth of fully four feet, and some were traced to the depth of five feet, but it was very difficult to wash them out to that depth because of the tenacious, clayey character of the deeper subsoil. Comparing this sample with those taken earlier in the season, it will be observed that the amount of root growth was greatly increased. The arrangement of the root system is much the same as that of the earlier sample of listed corn already described, but the root-crown has greatly increased in size and density and appears a little nearer to the surface, although midway between the rows the roots are slightly deeper than was observed in the first sample taken.

Plate 4 shows the root system of the level-planted corn at maturity. This sample was taken a few days later than the listed-corn sample just described. It should, however, have been taken before the other, because it was the riper corn. The ears were fully ripe and the leaves and stalks were beginning to turn brown when the sample was taken. In this sample the roots reached fully as deep into the ground, but the number of roots and the fibrous growth was less than in the sample of listed corn. The root-crowns lie near the surface but midway between the rows; the lateral roots are deeper than in the sample taken earlier, those from the hill on the right being nearly six inches beneath the surface. Compared with the sample taken earlier in the season, this seems to be an irregularity in growth, or it may be that the roots of this hill received some injury from the cultivator. The apparently thinner and less fibrous growth of the roots in this sample may also be due partly to the fact that the corn was overripe and the roots broke and washed away more easily than did the roots of the listed corn.

In taking the sample at maturity, it was observed, both in the listed and level-planted corn, that the soil above the main roots was filled with a fine fibrous growth of roots to within one-half inch of the surface. Thus the fact that the main roots lie several inches from the surface does not prevent the crop from feeding in the more fertile surface soil. That the roots of plants may readily grow upward in the soil is evidenced by examining celery after it has been banked for several weeks. When digging celery last fall, the writer found the soil full of the slender, white roots of the plants twelve inches above the root-crowns.

SOIL MOISTURE CONSERVED BY LISTING CORN. A comparison of the soil moisture found in adjacent plots of listed and level-planted corn last season showed little difference in the amount of moisture in the soil of the two plots during the first part of the season. The level-planted corn was laid by July 2, part of it receiving shallow cultivation and part being cultivated deep. The listed corn was cultivated for the last time July 6, with a six-shovel cultivator, which left the surface fine and mellow to the depth of three or four inches. Soil samples, taken July 29 gave the following results:

Moisture in soil. Samples taken July 29, 1903.

	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.
Listed corn..........	14.71%	22.31%	23.11%	21.28%	20.80%	20.34%
Level-planted corn...	12.63	20.10	20.81	18.35	18.84	19.07
Differences.......	2.08	2.21	2.30	2.93	1.96	1.27

Average difference 2.12 per cent., in favor of the listed-corn plot.

It appears from the results given above, that more moisture was conserved in the listed plot than in the level-planted plot, after the corn was laid by. The early part of the season of 1903 was too wet and cold for listed corn; hence the level-planted corn thrived best, and produced the larger crop by about eight bushels per acre, the comparative yields being 52.3 and 44.4. bushels per acre, respectively. The larger crop would require more soil moisture, which may account partly for the lower per cent. in the level-planted plot. No moisture determinations were made at the close of the season,

DEEP OR SHALLOW CULTIVATION. Since the roots of corn spread out near the surface of the ground, it is evident that too deep cultivation (or too close cultivation of level-planted corn) will cut the roots and is apt to injure the corn. In many experiments reported from other states, the results have often favored shallow cultivation of corn as opposed to deep cultivation. As a rule, however, the deep cultivation in such experiments was extremely deep, usually five to six inches. Medium deep cultivation, three or four inches, and not too close to the corn, should not injure the roots, and in some soils and climates the deeper cultivation may often give better results than shallow cultivation. In 1893-'97 a series of experiments in corn cultivation were carried on at this Station. In summing up the results of these experiments, in Bulletin No. 64 of this Station, Professor Georgeson says: "Our experience also seems to indicate that it is not best to pin one's faith strictly to the shallow culture. . . . A judicious mixture of shallow and deep cultivation gives better results than to continue either one through the entire season."

Too deep cultivation not only injures the corn by destroying the roots, but, during the period of cultivation, it prevents the roots from feeding in the most fertile part of the soil. On the other hand, the practice of shallow cultivation may be carried too far. A relatively thick mulch of mellow soil will conserve more moisture than a thin mulch, as shown by King in his experiments in Wisconsin.* As regards the conservation of soil moisture, the early cultivation of corn may be shallow. A deep soil mulch is not required at this season of the year, since the weather is moist, and cool and evaporation is not great. But later in the season, when the hot, dry days of July and August come, a deeper mulch is necessary in order to keep the soil from drying out. Shallow cultivation early in the season also clears the ground of weeds better than deep cultivation, and a thin mulch may favor the quicker warming of the soil in spring. Loose soil is not so good a heat conductor as firm soil, and more heat can reach the firm soil through a thin mulch than through a thick mulch. On the other hand in the hot part of the season the thick mulch may act as a regulator of the soil temperature and prevent the soil from becoming too hot as well as too dry.

Cultivation experiments with corn at the North Dakota Experiment Station, and also at the Illinois station, gave yields favoring the shallow cultivation early, followed by deep cultivation, as opposed to deep cultivation early, followed by shallow cultivation.†

In the cultivation experiments made with corn at this Station last season, the yields did not vary sufficiently to be worthy of note. Samples of soil were taken from the several plots early in the season before cultivation was begun, and again at the close of cultivation. At the early date the moisture was found to be about the same in all plots. In the following tables the moisture content of the several plots, about two weeks after the corn was laid by, is compared.

The deeper cultivation as the corn was laid by seems to have conserved more moisture than the shallow cultivation. No moisture determination were made at the close of the season.

Moisture in the soil. Samples taken July 16, 1903.

Kind of cultivation.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.
Shallow	22.15%	26.55%	25.05%	22.99%	22.54%	22.63%
Deep	21.52	25.21	27.59	23.99	22.41	22.08
Differences	0.63%	1.34	—2.54	—1.00	.13	.55

Average difference 0.13 per cent., in favor of deep cultivation.

*King's Agricultural Physics, page 186.

†North Dakota Bulletin No. 51, and 13th Biennial Report Kansas State Board of Agriculture, page 798.

Moisture in the soil. Samples taken July 16, 1904.

Kind of cultivation.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.
Deep early, shallow late	21.12%	20.38%	23.02%	21.24%	21.05%	21.64%
Shallow early, deep late	22.03	28.72	26.17	21.44	21.28	20.77
Differences	—0.91	—8.34	—3.15	—0.20	—0.23	0.87

Average difference of 1.99 per cent., in favor of shallow early and deep late cultivation.

KAFIR-CORN ROOTS.

In plate 5 is shown a sample of Kafir-corn roots taken July 28, seventy days after planting. The Kafir-corn was planted adjacent to the corn, in hills three and one-half feet apart, and received similar cultivation to that given the corn. In this sample, which is the Black-hulled White variety, the stalks stood about four feet high and were well covered with leaves. The plants appeared to be thrifty and in good growing condition.

The roots of Kafir-corn are finer and more fibrous than the corn roots. At this stage, a few of the roots had reached a depth of nearly three feet, but the greater part had not penetrated below eighteen inches. The root system is similar to that of corn, but the vertical growth seems to be much less strongly developed in the Kafir-corn. The root-crowns are large and fibrous and the lateral roots are well developed. The depth of the main lateral roots averaged about the same as in the corn, but above the main lateral growth the soil was filled with great numbers of very fine, surface-feeding roots, more noticeable in this sample than in the corn. Compared with corn, Kafir-corn is evidently much more of a surface-feeding crop.

The root development of the matured Kafir-corn is shown in plate 6. This sample was taken October 10, 144 days after planting. The seed had been ripe some time, but the stalks and leaves were green and growing when the sample was taken. The roots in this sample do not extend so deep as do those of mature corn. Some roots were found growing at a depth of three and one-half feet, but the greater portion stop at three feet, and these are much less in number than the roots of corn at the same depth. However, the upper eighteen inches of the soil, as shown by the sample, was very completely filled with a fine, wiry, fibrous network of roots. Some of the main lateral roots lie within four inches of the surface midway between the rows, and from these numerous fine, fibrous branches spread out in all directions, feeding to the very surface of the ground. From the top of the root-crown radiate several large, rather short roots, apparently similar to the brace roots of corn. It was observed that all the roots were tough and wiry; in fact, the whole plant gives an impression of hardiness and vigor.

The drought-resisting qualities of Kafir-corn are well established. That this character is not due to the deep feeding of the roots is evident, since the plant is even more of a surface-feeder than corn. It is the experience of many farmers that Kafir-corn is a "hard crop on the land." Crops following Kafir-corn are often less thrifty and less productive than the same crops following corn or other crops, and sometimes the injurious effect is observed for several seasons. No exact experiment has been recorded at this Station to prove this report, but there is little question but that the facts are as stated, and the study of the root system of the plant, together with other characteristics of the crop, offer a reasonable explanation of the facts observed. Kafir-corn is a great producer, yielding in an eleven years' trial at this Station more fodder and grain per acre than corn. The crop draws the plant-food and water required to produce this large growth mainly from the surface eighteen inches of the soil, and, growing late into the fall, it gives the land little chance to accumulate water or develop available plant-food in preparation for next season's crop. Thus the soil is apt to be left with insufficient moisture and soluble plant-food, hard in texture, and altogether unfavorable for starting the crop planted on the field the same fall the Kafir-corn is harvested, or the following spring ; and without proper tillage and favorable weather, the unfavorable condition of the soil may continue for more than one season, resulting in poor crops.

MOISTURE CONDITION OF KAFIR-CORN *versus* CORN LAND IN 1903. In a comparative soil-moisture study made at this Station last season little difference was observed in the moisture content of the soil of the Kafir-corn and corn plots up to September 7, but between September 7 and 28 the Kafir-corn ground lost a much larger amount of moisture than the corn ground. The following table shows the moisture condition of the soil in the two plots when the crops were removed:

Moisture in the soil. Samples taken September 28, 1904.

	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.
Corn plots...........	20.28%	22.07%	20.75%	21.21%	20.53%	19.79%
Kafir-corn plots......	16.16	19.09	18.50	19.42	17.59	16.57
Differences......	4.12	2.98	2.25	1.79	2.94	3.22

Average difference 2.88 per cent., in favor of corn plots.

The results indicate that Kafir-corn rapidly exhausts the soil moisture in the latter part of the season, leaving the ground drier than does corn. This condition is especially noticeable in the surface soil. The season of 1903 was exceptionally wet. In a season of of less rainfall the drying effect of Kafir-corn on the soil would doubt. less be more marked than was observed in the above trial.

If the rainfall is not sufficient to supply the normal amount of moisture before winter sets in, Kafir-corn ground will be deprived of a portion of the loosening benefits of winter weathering which result from the expansion and contraction of the soil by means of the freezing and thawing of the soil moisture. Thus the soil may be left in a physical condition unfavorable to the absorption of the spring rains and the development of the roots of the succeeding crops. This study suggests that Kafir-corn should be followed the succeeding year by late-planted crops, in order to allow the soil to regain, previous to planting, its normal amount of moisture and fertility. It was observed late in the fall that the soil of the Kafir-corn ground was apparently firmer and more compact than that of other plots, which observation was supported by the fact that the determination of the weight per cubic foot of the soil in the several plots showed that the dry weight of the first foot of soil in the Kafir-corn ground was greater than the weight of the soil to a like depth in other plots tested. The results of the moisture trial this spring, given below, also indicate that the rains have not percolated so readily into the soil of the Kafir-corn plot as into the soil of the corn plot.

Moisture in the soil. Samples taken March 15, 1904.

	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.
Corn plot............	25.69%	30.33%	26.86%	24.44%	24.05%	24.26%
Kafir-corn plot.......	25.91	28.13	23.78	20.73	20.08	15.84
Differences.......	.22	2.20	3.08	3.71	3.97	8.42

Average difference 3.53 per cent., in favor of corn plots.

Compared with the samples taken last fall, it will be seen that the Kafir-corn ground has not gained so much water as the corn ground, which indicates a less absorption of the rains, also that in the Kafir-corn ground a large proportion of the water has been collected in the first two feet of soil and the moisture percentage decreases rapidly as the depth increases, while in the corn ground the percentage of moisture is about the same in the lower four feet of soil.

SORGHUM ROOTS.

In plate 7 is illustrated a sample of sorghum, showing the root development at seventy-six days from planting. The sorghum (variety, Folger) was planted adjacent to and on the same date as the Kafir-corn described above, and received similar culture. In taking the sample it was found that the hill shown on the left of the cut had been planted directly over a filled trench, which was about eighteen inches wide and three feet deep. The soil which filled the trench was more mellow than that in which the roots of the other hill grew. However, there seems to be little difference in the root development of the two hills. The roots which grew in the mellower soil grew a trifle deeper, and were slightly coarser but fewer in number than the roots of the other hill. The sorghum roots are much coarser than those of the Kafir-corn, taken at about the same stage of growth, and feed deeper in the soil, a large number reaching a depth of fully three feet.

The root system resembles that of corn more than that of Kafir-corn, but the lateral, fibrous growth of roots near the surface is much less prominent in the sorghum than in either corn or Kafir-corn. The root-crown is less fibrous and deeper in the ground than that of Kafir-corn or level-planted corn. Midway between the hills the roots were six inches below the surface, and at the hill the average depth was nearly three inches, fully as deep as the seed was planted. There was much less fibrous growth in the surface soil above the main roots than was observed in Kafir-corn and corn. Sorghum is not so much of a surface feeder as Kafir-corn. At the time this sample was taken, the roots of the crop had fully occupied the soil to the depth of nearly three feet, and the great bulk of the roots was growing between six and twenty-four inches from the surface.

Plate 8 shows the sorghum at maturity, 117 days after planting. This sample was taken from a plot of sorghum planted June 15, twenty-seven days after the first planting, the soil being the same as that described for the first sample. Thus, the two samples are not exactly comparable, since their periods of early growth were under different conditions of soil, temperature, and weather. It seems probable that if the sample shown in plate 7 could have completed its growth, a greater development of roots would have resulted than is shown in plate 8.

In this sample some of the roots reached a depth of three and one-half feet, but the bulk of the roots was within two and one-half feet of the surface. The roots have increased in number and are relatively finer and more fibrous than in the sample taken earlier in the season. The main lateral roots interlace within four inches of the surface midway between the rows, and the upper soil above the large roots was filled with numerous fine branches and fibers which fed to the very surface of the ground. In the matured sample, the root-crowns are more fibrous and appear nearer the surface, and all together the root system resembles that of the Kafir-corn much more than did that of the sorghum sample taken earlier in the season. However, compared with Kafir-corn, the roots of sorghum penetrate deeper and occupy a larger feeding space in the soil; hence sorghum is not so great a surface feeder as Kafir-corn.

The study of the moisture condition of the soil as affected by growing sowed sorghum which was made at this Station last season, gave much the same results as stated above for Kafir-corn, but the sorghum plots, as compared with the corn plots, were left even drier at the close of the season than the Kafir-corn plots. Sorghum planted in rows and cultivated should not exhaust the soil moisture to such a degree as the sowed crop, but the general experience is that its effect is much the same as that of the cultivated Kafir-corn.

WHEAT ROOTS.

A sample of wheat roots, variety, Red Winter, was taken July 7, at maturity. The wheat was planted October 11, 1902, with a disk-drill. The grain was a little overripe when the sample was taken, and the roots seemed brittle and were broken off easily in washing them oat; also, the subsoil was a stiff, heavy clay, very compact, and resisted washing, so that a poor sample was secured. No photograph was made, but the sample, together with the field-notes, afforded opportunity for a careful study of the root system. The first foot of soil, which was fairly mellow and fertile, was filled with a fine network of roots, the main roots being caught on the wire rods two and one-half inches from the surface. It was observed that the fine, fibrous roots extended to the very surface of the ground, so that some were caught in the plaster of Paris cast, but, being very tender, they were broken by the force of the water. Below the fibrous growth in the first foot of soil, slender roots extended directily downward, many reaching the depth of fully four feet, in the hard subsoil. These roots did not seem to branch much, and it was estimated that the absorbing surface of the roots was greater in the first foot of soil than in all the lower soil.

The main roots spring from the lower part of the root stem in whorls, consisting usually of not more than four roots. The roots of the upper whorls were coarser than the others, resembling somewhat the brace roots of corn, and, perhaps, serving a similar purpose.

Plate 9 shows the root system of a sample of spring wheat which the author prepared when connected with the North Dakota Experiment Station. Although this wheat grew in a different soil and climate, the root system is quite similar to that described above, and will serve to illustrate the root growth of this crop.

OATS ROOTS.

In plate 11 is shown a sample of oats roots taken July 11, when nearly mature, 103 days after planting. The variety is Minnesota No. 202, a medium late maturing sort, which did not prove to be a good producer in 1903, being damaged by hot weather. This sample made a good growth of straw, but the heads were light. The oats were planted with the single-disk grain-drill, in drills eight inches apart. A cross-section of two drill rows is shown in the figure.

The root system is similar to that of wheat, but the roots are slightly coarser and more numerous and the fibrous growth extends deeper than described for wheat. Several of the main roots were washed out to the depth of four and one-half feet, and a few extended even deeper, but were broken off at the depth named. The larger side roots interlace between the drill rows within two inches of the surface, and the soil above the main roots was filled with a fibrous growth, as observed in the description of wheat roots.

The roots start out from the root-stem in whorls, as described for wheat, and the crowns lie very near the surface. Extending down from the center of the root-crown of eaoh plant in this sample was observed a short rudimentary root-stem which ended abruptly with a slight enlargement from which radiated a few short, fine, wire-like roots. Often the old seed coat was found clinging to the enlarged terminus. The depth at which the seed was planted determined the length of the lower root-stem. The explanation of this rudimentary growth is that the seed was planted too deep, or below the point at which the soil conditions were most favorable for starting the young roots; hence, the root-crown formed considerably above the seed, the lower root-stem remaining rudimentary and the little rootlets which started from it ceasing to grow early in the season. The fact that the root-crowns will form at a certain depth, depending upon the soil and season, no matter how deep the seed is planted, provided it is not planted so deep but that the young shoot may reach the surface, has been shown by previous experiments. When seed is planted in furrows, however, as observed in the listed corn, it is possible to cause the root-crown to develop deeper in the soil, since the furrowed condition lowers the apparent soil surface, allowing the roots to develop under fairly normal conditions; then as the soil becomes warmer and the furrow is gradually filled, the normal conditions remain and the plant thrives on its original root system, whereas, with surface planting, as the season advances and the hot weather comes, the roots may lie too near the surface to have the best conditions and environment, and the crop is more apt to be injured by heat and drought than the lister-planted crop,

BARLEY ROOTS.

The sample of barley (variety, Common Six-rowed) shown in plate 11 was taken at maturity, July 8, ninety-seven days after planting. This sample was not taken from the same field as the oats, but was from land which had previously been in alfalfa for three years and was spring-plowed. The soil appeared to be more mellow than the average Station soil, and at the depth of four and one-half feet rested upon a bed of loose, broken rock, which was underlaid with solid limestone. The grain was planted with the disk-drill in drill rows eight inches apart, and the sample is a cross-section of two drill rows.

The roots reach about the same depth as noted for oats, and were slightly coarser but not quite so fibrous in the first twelve to eighteen inches as the oats roots. The lower part of the block of soil cracked and crumbled badly during the washing, and some of the deeper roots were broken off. All of the roots seemed tender and were easily broken. The root system is very similar to that of oats. Both of these crops leave the soil loose and mellow, as is readily observed in the plowing of oats or barley stubble. The dense, matted growth of fibrous roots near the surface explains this characteristic. Barley and oats are closer feeders and stronger growers than wheat, and will often thrive better than wheat in "tough" soils and poor land.

FLAX ROOTS.

No sample of flax roots was taken at this Station last season. In plate 10 is shown the illustration of flax roots as secured by the author in his studies at the North Dakota Experiment Station.* Flax has a different root system from that of wheat or corn. With the latter many roots radiate from a center or crown spreading outward and downward into the soil. With flax, each plant sends down a single tap-root, which gives off many side roots or branches, and these in turn give off many fibrous roots or feeders. The upper branches or side roots soon curve downward along with the tap-root, which becomes rapidly slender and thread-like, until it can scarcely be distinguished from the branches. The roots do not go so deep as do those of wheat or oats, but make a thick fibrous growth in the upper two feet of the soil and fully occupy that portion of the soil.

Flax is more of a surface feeder than any of the grain crops studied. It is also doubtless a closer feeder, and, drawing its water and plant-

*See North Dakota Experiment Station Bulletin No. 43.

food largely from the upper part of the soil, it is apt to leave the soil in a dry, unfavorable physical condition, and lacking in available plant-food, which may sometimes work injury to succeeding crops. Flax has the name of being a "hard crop on the land," not because it exhausts the fertility of the soil sooner than other crops, but because it has been observed that other crops do not always thrive well after flax. This bad effect of flax is more noticeable when the crop has been grown on sod. The flax, being a strong surface feeder, draws the water out of the sod and prevents it from decaying, and when such land is backset (especially if the season has been dry), the sod turns over in dry, hard, unrotted chunks which will not "work up." The sod has in a measure become embalmed, so that it will not decay readily; it is difficult to put such a field into a good physical condition for growing any crop, and it may require several seasons for the injurious effects to entirely disappear. On the other hand, because of its strong surface-feeding habit, flax has a subduing effect upon new land, and in a wet or favorable moist season it makes a good crop to kill out the grass and subdue the sod.

On old land no bad effects from growing flax are likely to occur, with proper tillage and rotation of crops. Flax land should be plowed soon after harvest, and deeper, as a rule, than is the ordinary practice. If the ground is hard and cloddy it should be thoroughly pulverized, It is best to follow flax with some deeper-rooting crop, preferably a cultivated crop such as corn or potatoes. It may not always be best to fall-plow flax land for spring crops, but the ground should at least be disked soon after harvest in order to give the most favorable conditions for regaining and conserving soil moisture and developing a new supply of available plant-food.

ORCHARD-GRASS ROOTS,

The sample of orchard-grass roots shown in plate 12 was washed out of the soil June 27, 1903, being the first sample prepared in this way at this Station. The soil washed well, the deeper subsoil being quite sandy and inclined to cave. The roots were not easily broken and were preserved in good condition. This was a fine sample of grass, measuring nearly three and one-half feet in height, with a thick, leafy undergrowth. The heads were turning brown and beginning to ripen when the sample was taken. The age of the grass is not definitely known, but this is either the second or third year since seeding,

In this sample the extreme depth of the roots is practically the same as the extreme height of the grass. The first six inches of soil was filled with a thick, fibrous mass of roots, so dense that it was hardly possible to wash out all the soil. Below ten inches in depth the roots rapidly became thinner. The largest part of the root growth lies within twelve inches of the surface. The root system resembles that of the annual grasses, wheat, oats, and barley, but with a greater fibrous growth in the upper soil. The roots are tough and woody, and nearly white in color. Orchard-grass grows in tufts or bunches, and does not form a perfect sod. The sample shows the root development from one large bunch or stool, and could hardly be taken as representing the sod of an orchard-grass meadow.

BROMUS INERMIS ROOTS.

The *Bromus inermis* roots shown in plate 12 were taken from a three-year-old meadow. The texture of the soil in this field is similar to that described for orchard-grass, but at the depth of four feet and three inches the fine earth rested on solid limestone rock, and the lower subsoil contained some gravel and small pieces of rock. The grass roots penetrated fully to the rocky floor and made some fibrous growth upon it. This is not shown in the figure, because the sample was injured and some of the roots were broken off before the photograph was taken. The larger portion of the roots reached the rock surface, and when the sample was first taken the whole cage was filled with a thick growth of roots. Brome-grass makes a very thick sod. In this sample the roots form a dense growth to the depth of ten or twelve inches, where they thin out a little and take nearly parallel courses downward, but are still so numerous in the sample as to form a thick veil through which the light can scarcely penetrate. The roots are rather coarser than those of the orchard-grass and have a dark brown color. Some lighter colored roots were observed. Apparently these were younger roots, and the color becomes darker as the roots grow older.

From this study and the investigations at other experiment stations, it appears that the roots of perennial grasses do not die and decay, but year after year the plants keep sending down new roots, while the old roots continue to live and grow. Soon the soil becomes filled with the grass roots. Most of the nitrogen and some of the mineral elements of plant-food are stored up in these roots. The growth of foliage becomes less each year and the meadow or pasture becomes unproductive; hence the application of manures and fertilizers to old meadows is very beneficial, quickly causing an increased growth of grass. However, with such a grass as the *Bromus inermis,* the meadow becomes "sod-bound," and in order to renew the growth of the grass, it is necessary to kill out part of it by disking or plowing, thus allowing a part of the roots to decay, supplying plant-food for a renewed growth of grass and giving room in the soil for a new growth of roots.

Bromus inermis is a deeper rooting grass and a much more extengive feeder than orchard-grass. In a deeper soil the roots would have extended to a greater depth than found in this sample. At the North Dakota Experiment Station the roots of brome-grass were secured to the depth of five and one-half feet. This grass spreads by underground rootstocks and forms a perfect sod, growing thicker as it grows older. Because of its deep-rooting character, it resists drought well and is adapted for growing in light soils and dry climate, and is proving to be one of the best grasses to reseed the lands of the Western plains.

BIG BLUESTEM ROOTS.

In plate 14 is shown a sample of the Big bluestem grass *(Andropogon furcatus)* one of the most common native Kansas grasses. The sample was taken from an upland prairie pasture on the Station farm, and represents the full growth of the grass to August 7, at which date the sample was secured. This is an excellent specimen of grass roots and is indeed a wonder when we consider the large number of roots and their great length. The roots were broken at four and one-half feet from the surface, but from the size and the number of roots at this depth, they must have penetrated at least two feet deeper through a compact, clayey subsoil. This grass apparently makes a deeper root growth than the *Bromus inermis,* but the roots are less numerous, though somewhat coarser and present a more irregular and tangled growth. It forms a dense, tough sod, six to eight inches thick and the subsoil is filled with a great mass of roots. When the sod is broken up and the grass killed, these roots gradually decay and form humus, making the fertile soil for which Kansas is famous.

BUFFALO-GRASS ROOTS.

No grass of the Western plains is better known for its valuable characteristics as a pasture grass than the famous buffalo-grass *(Buchloe dactyloides),* a sample of which is shown in plate 13. Withstanding drought, hot winds and the persistent tramping of cattle, this grass thrives on the dry uplands of central and western Kansas, filling the soil with roots and covering the earth with its thick mantle of stems and leaves. Favored by the spring rains, it makes a quick, early growth, and as summer advances and dry weather begins, it ceases growth but does not die. The crop cures on the ground, furnishing grazing of the best quality. When the rain comes in the fall, the grass starts again, producing a second crop, which continues to furnish grazing, when not pastured too closely, throughout the winter. This grass spreads by runners or prostrate stems, which creep along the ground, rooting at intervals. The leaves are short and curly and the plants form a mellow sod, covered with two or three inches of soft, cushion-like foliage.

The roots are numerous, but they do not penetrate deeply into the soil. A few roots in the sample reached a depth of two and one-half feet, but the larger part are less than two feet in length. The roots seem to grow straight downward and do not form the woven network characteristic of Big bluestem and other grasses. The first four inches of the soil, however, were very completely filled with roots which formed a fairly firm sod. The roots are small and thread-like and almost white in color. On the whole the feeding capacity of this grass is much less than that of *Bromus inermis* or Big bluestem; hence it is less productive than either of these grasses, and although it is uninjured by drought, it ceases growth sooner when a drought approaches than do the deeper-rooting grasses mentioned. The sample was taken October 20 from an upland prairie pasture near the College farm. The surface foot of soil was a mellow, dark loam, underlaid with a rather compact, clayey subsoil.

KENTUCKY BLUE-GRASS ROOTS.

The sample of Kentucky blue-grass roots shown in plate 15 was taken from the College campus September 4. The soil in which the grass grew was similar to that described under orchard-grass and *Bromus inermus,* being a rather yellow loam. The age of the grass is not known, but it may be described as an old blue-grass sod. The grass spreads by creeping rootstocks, and makes a very dense and web-like growth of roots in the first six inches of soil, forming a firm, tough sod. Below six inches the roots gradually become thinner. A few roots in this sample reach a depth of nearly four feet, but at two feet the number is small, and comparatively few roots extend below the depth of eighteen inches. As will be observed, the roots are very dark in color, and also very fine and fibrous. Although some of the roots go deeper, yet the total root growth of the blue-grass scarcely equals that of the buffalo-grass.

These grasses are quite similar in the place which each holds in the regions where they abound. Both are valuable pasture grasses, The blue-grass, "having no rival within the limit of its growth," is a ranker grower and more productive than the buffalo-grass. It requires a moist climate for its successful propagation, yet it is not easily destroyed by drought, but, like the buffalo-grass, it ceases growth, and may even become brown and apparently dead during a protracted dry period, but it starts quickly again after the rains. The study of the root systems of these grasses gives a better understanding of the characteristics of their growth.

GRASS AS A ROTATION CROP.

The following is quoted from a paper by the writer on "Grasses," published in the report of the Kansas State Board of Agriculture for the quarter ending March, 1904:

"Grass is a soil-protector, a soil-renewer, and a soil-builder. Covering the land with grass is nature's way of restoring to old, worn-out soils the fertility and good tilth characteristic of virgin soil. The true grasses do not add nitrogen to the soil, as do clover and alfalfa, yet they are in a sense nitrogen-gatherers, in that the nitrogen of the soil is collected and stored up in the roots of the grass in the form of humus. Thus grasses prevent the waste of nitrogen and olher plant-food elements and serve to protect the soil and to maintain its fertility. By extensive and deep-penetrating root systems many grasses also tend to break up and deepen the soil, gathering and storing plant-food in their roots, and thus actually increasing the available plant-food of the soil. . . .

"When the wild prairie is first broken, the soil is mellow, moist, and rich, producing abumdant crops. After a few years of continuous cropping and cultivation, the physical condition of the soil changes; the soil grains become finer; the soil becomes more compact and heavier to handle; it dries out quicker than it used to, bakes worse, and often turns over in hard clods and lumps when plowed. The compact texture and bad mechanical condition of the soil make it difficult for the young roots of plants to develop properly, causing at the same time an insufficient supply of air in the soil, which is almost, if not equally, as detrimental to the crop as an insufficient supply of water. After a clayey soil has been cropped and cultivated a long time it tends to run together, and is very sticky when wet, but when dry the adhesive characteristic disappears almost entirely. The grass roots which formerly held it together are decayed and gone, and now, when loosened by the plow, it is easily drifted and blown away.

"The perfect tilth and freedom from clods, so characteristic of virgin soils, is always more or less completely restored whenever land has been laid down to grass for a sufficient length of time. After the ground is covered with sod, the puddling action of rain is prevented. As the roots grow, the soil particles are wedged apart in some places and crowded together in others, and, by means of lime and other salts, the small soil grains become cemented into larger ones, and thus the open and mellow texture characteristic of virgin soil is restored; and not only this, but, by the accumulation of plant-food in the roots, the soil is made more fertile for succeeding crops. . .

"Grasses and legumes maintain the supply of soil nitrogen and restore the proper soil texture; besides they are profitable crops, and in fact absolutely necessary on every farm upon which stock is kept. Pasture must be had upon every farm, and it is quite essential that it be made a part of the regular crop rotation. Many soils become too light and mellow by continuous cropping, and need the tramping of stock to firm them. Then, so much more grass can be produced when the pastures are kept fresh and new, and the increase of fertility and improvement of soil texture result in larger crops of corn and grain when the pasture is broken up and planted to these crops. A convenient and desirable time to manure land is when it is being used as meadow or pasture. If the manure is applied a year or two before breaking it will stimulate the growth of grass, and cause a greater production of pasture, giving more and better grazing; meanwhile the soil is enriched by an increased root growth and the formation of humus. Besides these beneficial results, some plant-food will be supplied by the manuring to the first crop which is grown on the breaking, at a time when it is much needed, because the larger part of the fertility in the new breaking is in an unavailable state, and cannot readily be used by the new crop."

CLOVER ROOTS.

Clover thrives well in this locality, and a large acreage was seeded on the Station farm in the spring of 1903, resulting in an excellent catch, but it happened that there were no old fields on the farm or in the vicinity last season. The figures shown in plate 16 is the cut of a single plant of common Red clover, which was taken September 7, from a corner of the College campus, where the grass was thin. The exact age of the plant is not known, but it was probably a year old, a fall seedling. The sample is therefore hardly a fair representative, and the root development is perhaps somewhat irregular, as other studies have indicated. In the experiments at the Wisconsin station in 1892, it was found that clover produced large, long tap-roots (something after the manner of alfalfa; see plate 16), which reached a depth of more than four feet. In the present sample, the main root (not readily observed in the cut) reached a depth of two and one-half feet, when it divided into several small branches. From the upper part of the main root, and near the crown, several large, irregular branches are given off, which form quite a fibrous growth in the upper fifteen inches of the soil. A few of the branch roots penetrate to the depth of three feet and nine inches, but most of the root growth lies within eighteen inches of the surface. Numerous small tubercles were observed upon the fibrous roots in the surface soil.

ALFALFA ROOTS.

The root development of alfalfa has received considerable study at this Station and in other states. In Bulletin No, 114 of this Station, Prof. H. M. Cottrell has published the interesting results of his investigations. From upland soil he secured the roots of an alfalfa plant nine years old, which measured nine feet and nine inches in length. Dr. W. P. Headden, in Colorado,* traced the roots of alfalfa to the depth of twelve and one-half feet in mellow, dry soil (not irrigated), and secured two samples of plants with roots measuring, respectively, eleven and one-half and eleven and three-fourths feet in length. From the studies of these gentlemen, it is evident that the young alfalfa quickly sends its roots deep into the soil. Doctor Headden found the roots of plants only nine months of age at a depth of over nine feet, while Professor Cottrell shows a cut in his bulletin of a young plant, taken in April, 1902, from seeding made the previous fall, whose roots had penetrated to a depth of over seven feet.

The sample of alfalfa roots shown in plate 16 was taken from an upland meadow on the Station farm. The soil was the average upland loam described in this bulletin, with a rather compact, clayey subsoil. The meadow was seeded in the spring of 1900. The sample, taken September 1, 1903, was the third crop of that season, and the alfalfa was just beginning to bloom. This field has received little or no cultivation since seeding. In fact, it had, previous to 1902, been subjected to considerable tramping of cattle passing over it and feeding upon it more or less, as they were being driven to pasture. The stand was poor on most of the field, but at the spot where the sample was selected the alfalfa was a good stand, and had a dark green, healthy color.

The root system of alfalfa is simple and easily observed. Usually the plant sends a single, large tap-root almost straight downward into the deep subsoil. This main root gives off some branches in its downward growth, but these are comparatively few, the singular fact in regard to the roots of alfalfa being the lack of branches and fibrous roots. When the sample was taken, the tap-roots averaged about one-half inch in diameter near the crown. In some plants the tap-root is not so much in evidence, but at the depth of a few inches to several feet from the surface it appears to divide into a number of smaller secondary roots which take on the characteristics of a tap-root, and, spreading very little, pursue an almost vertical course downward. Usually, however, these divided roots do not reach so great a depth as do the single tap-roots. In this sample several roots were traced to a depth of eight and one-half feet.

*Bulletin No. 35, Colorado Experiment Station.

There is considerable growth of fibrous roots in the surface foot of soil. This growth seems to proceed largely, however, from plants which have no tap-root. Apparently in some plants the tap-root had been destroyed, and the plant was making a new growth of roots. Usually the larger proportion of fibrous root growth lay below the depth of four feet. The fibrous roots in the surface soil held quite a number of small tubercles. Several clusters of tubercles were observed in the deeper soil, one large cluster being found at the depth of three feet.

This study, as well as those of other investigators, leads to the conclusion that alfalfa is a deep feeder. The only surprise is, considering the vigorous growth and productivity of the plant, that the roots are not more numerous and fibrous in their development. However, the method by which the plant feeds (taking its nitrogen from the air by means of the bacteria which grow on its roots), and the great depth of the roots, compensate for the fewer roots and the lack of fibrous growth.

From a study of this root system, one cannot fail to appreciate the beneficial effects which such a crop should have in disintegrating and loosening the hard, compact subsoil, characteristic of some lands. Drawing its water and mineral plant-food from the deeper subsoil, alfalfa is a drought-resisting crop, and receiving its nitrogen from the air, it actually increases the supply of this valuable plant-food, in the soil by the dropping of its leaves and by the decay of its tubercles and roots. Meanwhile several large and profitable crops of the most nutritious hay are harvested each year. It is evident, however, from the nature of this crop and its great productiveness that it must in time tend to exhaust the mineral plant-food of the soil, if the land is kept continually in alfalfa. By a proper rotation of alfalfa with other crops, however, there may result an actual increase of the available plant-food in the surface soil, since the alfalfa, by its deep feeding, may draw the mineral plant-food from the lower subsoil, where it is beyond the reach of common crops, and store some of it in the large, fleshy roots in the upper soil, which, by their decay, leave it in an available condition for the use of surface-feeding crops.

It was observed in digging and washing out this sample that the soil below the depth of three or four feet, and continuing to the depth of eight or nine feet, was thickly perforated with small holes which had apparently been left by decaying roots. Other investigators have assigned other causes for this condition, but it is evident that the roots of the alfalfa plants are constantly decaying. Doctor Headden estimated that in a field of alfalfa, five years after seeding, two-thirds of the plants had died and the casts of the dead roots still remained in the soil. (The yield of alfalfa from this field had not materially decreased.) In the illustration of the sample, one dead root (and plant) is shown near the middle of the cage, but the plants do not always die when the roots are injured. From the illustration, it is evident that the lower roots of some plants had died, either from injury or other causes, and that a new growth of small roots had resulted, taking the place of the original tap-root system. Thus, by the death of some plants, and the dying of roots, which are replaced, and by the dropping of leaves, alfalfa tends, for a time at least, to increase the supply of both the organic and mineral plant-food in the surface soil.

SOY-BEAN ROOTS.

The sample of soy-bean roots shown in plate 17 was taken August 14, fifty-five days after planting, just as the pods were beginning to form. This is the Early Yellow variety, an early-maturing sort and not a very rank grower. The beans were planted with the lister, in furrows about four inches deep. Thus it will be seen that the root. crown has developed at about the depth at which the seed was planted, although there is usually some slight growth of fibrous roots higher up on the root-stem. The tendency of the plant is to form a taproot, which starts out with about the same diameter as the root-stem, but grows rapidly smaller, so that it can scarcely be distinguished from the branch roots. From the upper part of the tap-root, or lower extremity of the root-stem, several large side roots spread outward and downward into the soil, making some fibrous growth near the plant. In the first sample taken, the root development was very meager. Some roots reached a depth of about two and one-half feet, but there was a very small and short lateral growth at this time. The plants shown are about three feet apart and were growing in the same row, so that no injury could have come to the roots by cultivation. The roots were very tender and only the coarser ones were saved, which accounts somewhat for the sparcity of roots in the sample. The root growth, however, was indeed small, considering the age of the plants.

The mature sample of beans shown in plate 19 was taken September 15, from the same field as the sample just described. These plants were on opposite rows, three feet apart. Compared with the sample taken earlier, the lateral root development has greatly increased, the roots now interlacing between the hills, but the vertical roots have not penetrated much deeper. The root system is not extensive, the bulk of the roots being between four and twelve inches from the surface. No tubercles were found on the roots of these plants.

The small root growth of soy beans indicates that the crop should be planted thicker than is the usual practice, in order to get the largest production from the land; also since this is a legume crop, which, with the required bacteria present, takes its nitrogen from the air, a thicker growth of plants would leave more roots in the soil, and hence a greater supply of humus and nitrogen for the use of succeeding crops. Such tests as have been made at this Station indicate that the soy bean is not a great exhauster of soil moisture.

COWPEA ROOTS.

A field of Whip poor will cowpeas was planted June 16 with the grain-drill, in drill rows forty inches apart. The land was average upland soil, spring-plowed, and in a good condition of tilth. The crop received ordinary, shallow cultivation. A sample of cowpea roots taken from this field August 20 is shown in plate 18. At this date the plants stood about thirty inches high and were just coming into bloom.

The cowpea develops a system of roots similar to that of the soy bean, but the former makes a more extensive root growth than the latter. There is a well-developed tap-root, from the upper part of which large branches spread outward almost horizontally from one to two feet, when they turn downward, some reaching a depth nearly equal to that of the tap-root. Other branches strike off at different angles. Some of the longest roots measure nearly three feet in length, but the bulk of the root growth lies within fifteen inches of the surface in this sample. At this stage the roots easily meet and interlace between the rows, which at this point were three and one-half feet apart. Midway between the plants the roots lie four inches below the surface, while near the hill they rise to within two inches of the surface. The fact that this crop was level-planted, while the soy beans were planted in lister furrows, would favor a shallower growth of roots for the cowpeas.

The roots of these two plants differ also in color, those of the soy bean being quite dark, while the cowpea roots are nearly white. Quite a nurmber of tubercles were found on the cowpea roots. These tubercles had a tendency to follow along certain roots in disconnected chains. The root system was really more extensive than appears in the sample, since the long, slender branch roots which threaded the soil in every direction were washed away by the first touch of the water, and only the main roots were saved.

The sample of cowpea roots shown in plate 20 was taken October 5, 111 days after planting, from the same field as the sample just described. At this date the crop was nearly mature — about one-half the pods were turning yellow. Since the early sample was taken the plants had made a large increase in their root development, feeding now to the depth of four feet, or through twice the soil space occupied by the younger plants. The cowpeas develop a much stronger and more extensive root system than the soy beans, and will not bear so close planting. On the other hand, this crop would seem better adapted for use as a rotation crop and soil-renewer, not only because of its greater root development, but because the bacteria which thrive on the roots of the cowpea appear to be more or less present in all soils, and tubercles are more readily developed. So far as known, cowpeas had never been grown in this field before, yet a fair number of large tubercles were found on the roots. As in the first sample, the long, slender, secondary branch roots mere broken off in washing, and the roots remaining are merely the coarser skeleton of the root system. This is true, more or less, of all the root systems illustrated.

POTATO ROOTS.

No study of potato roots has been made at this Station. The cut shown in plate 23 was made from a photograph taken by the writer at the North Dakota Experiment Station in 1899. These potatoes were a late variety known as Rural New Yorker No. 2, and the sample shows the root growth which had been made in ninety days from planting. The tubers were of fair size but not nearly mature, the vines of this variety being perfectly green when killed by frost September 20, a month after the sample was taken.

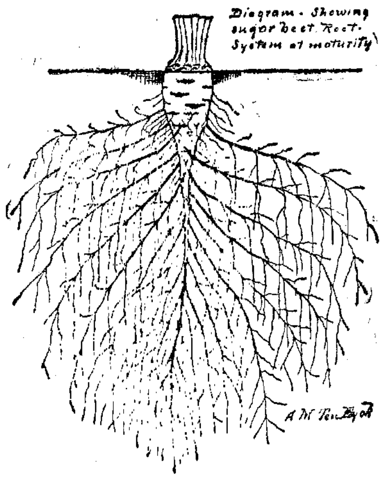
In this sample the roots reached a depth of fully three feet. The lateral roots interlaced between the rows, the hills being three feet apart. Midway between the rows the roots were only three inches from the surface. The sample is a fair illustration of the main root system, but the roots were found to be very tender and the branches were broken off badly by the washing. Like the cowpea, the potato sends out from the main roots, in all directions, many long, hair-like branches. These slender branch roots give rise to numerous small feeders and root-hairs, so that the soil to the depth named was well occupied with feeding roots. From this and other studies it was shown that late potatoes root more freely and more deeply than early potatoes. The late-maturing varieties thus require more root room and will not allow so close planting as the early sorts.

The new tubers form above the old seed tubers and the roots also start from the root-stem above the seed, as may be seen by a careful examination of the figure. Thus the depth of planting (if not too deep) determines largely the depth of the root-crown and the depth at which the new potatoes are produced, and to some extent the depth of the lateral roots between the hills. For its best development the potato requires a light soil and a deep, mellow seed-bed.

SUGAR-BEET ROOTS.

In plates 1, 21 and 22 are shown the roots of mature sugar beets. These samples were taken at the North Dakota Experiment Station and constitute part of a study of the effect of subsoiling on the root growth and development of the sugar beet. Quoting from the North Dakota Bulletin No, 43: "The root system of the sugar beet differs from that of any of the other plants studied. The vegetable itself is really the enlarged upper part of the tap-root, which extends almost perpendicularly downward into the ground, the lower part of the root being quite small and thread-like, and reaching, in several samples, a depth of over three and one-half feet. From the central root, branches spread outward and downward into the soil on all sides. The upper main branches are the largest and extend outward almost horizontally for more than two feet. The deeper ones incline more and more, until the last branches run nearly parallel to the tap-root."

The samples illustrated do not fairly exhibit the actual root system. Only the larger roots were secured, and these were often broken. Sugar-beet roots are so tender and brittle that the writer has been unable, in six trials at different stages of their growth, to secure a good sample. The diagram given below was made from a study of a sample taken in 1898,and is perhaps a little overdrawn, but gives a better idea of the development of the roots than can be obtained from the sample illustrations :



The field in which the long, well-shaped beets grew was subsoiled eight inches below the bottom of a six-inch furrow; thus the ground was loosened to the depth of fourteen inches. The other sample came from ground which was simply plowed six inches deep. Each sample is a cross-section, showing beets on adjacent rows.

The sugar beet is a deep feeder, making very little root development in the surface six or eight inches of soil. It will stand deep cultivation without injury to the roots, and requires a deep, well-loosened soil, not only that it may have room to expand and grow, but also that the roots may properly develop and secure the necessary plant-food. On compact, shallow-tilled land the beets grow up out of the ground; hence there is more waste in trimming, and the ill-formed beets are not so profitable for sugar production as the long, tapering beets.

THE ROOTS OF TREES.

It was not planned to make any study of the root growth of trees, and no particular study has been made. But in making the examination of the "flood-damaged lands," in preparing Bulletin No. 121, recently published, several interesting specimens of tree roots were discovered and protographed. Plate 24 is the photo-engraving of the roots of a bur-oak, as washed out by the water. The tree had been cut a year or two and a new growth of sprouts had started from the stump, as shown in the illustration. The roots of this tree strike at once into the soil, seldom making an angle of more than forty-five degrees with a vertical line. The tree grew on the roadside near a cultivated field. The soil was a deep, sandy loam.

The other cuts are illustrations of the roots of the Soft maple. These trees were thirty-five to forty years old and had been cut about two years. The maple roots were found in the same field as-those of the bur-oak, at a place where the water had made a deep wash through a cultivated field and across the public road, cutting through the tree row bordering the field. In plate 23 is shown the root development on the side toward the road, while plate 26 shows a small section of the washed area exhibiting the tree roots which grew in the soil of the cultivated field. The roots at the left of the picture are over thirty feet from the nearest stump. Some of the larger roots shown in the cut are only eight inches below the surface of the ground, and this great mass of roots lay largely within two feet of the surface. The roots of these trees were traced to the distance of eighty feet from the stumps. At fifty feet from the stumps, roots an inch in diameter were found only eight inches beneath the surface of the soil. This explains the unproductiveness of land bordering a row of large trees of this character. Such trees exhaust the moisture and fertility of the soil for several rods each side of the tree row. The Soft maple is a strong surface feeder and is not a desirable tree to plant on the borders of cultivated fields.

On the other hand, judging from the sample, the bur-oak does not send out surface roots, but feeds deep in the soil, and would apparently do little harm to crops growing near it, except as its shade might injure the growth of some plants. In another locality in similar soil, the roots from an Osage-orange hedge (trees six to eight inches in diameter) were found forty-five feet from the hedge. These roots extended out almost horizontally at a depth of twelve to eighteen inches. This growth was in a cultivated field. On the side next the road, the roots grew deeper but did not extend so far.

The roots of a honey-locust tree growing in the Osage-orange hedge row were observed forty feet from the tree. The roots of a large box-elder tree were found in light, sandy loam fifty-five feet from the tree trunk. This growth extended across the road, the roots lying four to five feet beneath the surface at their extremities. In a near-by orchard, the roots of an old apple tree, from which the earth had been washed away, were discovered at a distance of sixty feet from the base of the tree. At this point the roots were three to five feet under ground. The roots seemed to run out nearly horizontally after attaining their depth near the tree. There were some roots nearer the surface, extending out twenty feet or more, but these were not so numerous as the deeper roots. There was much less growth near the surface by the apple tree than by the maple. This root development was in cultivated ground.

THE MOISTURE OF THE SOIL AS AFFECTED BY DIFFERENT CROPS.

Some of the results of the soil-moisture studies carried on at this Station in 1903 have been referred to in the preceding pages of this bulletin. It is evident that the character of the root system, as well as the nature and productiveness of the crop, is related to the amount of moisture taken from the soil; also, that some plants are shallow feeders and others are deep feeders, according to the development of their roots. The moisture condition of the soil at the close of the season, as left by several crops, is given in the following table:

Moisture in the soil. Sample taken September 28, 1903.

Crop grown on plot.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Average difference compared with corn plot.
Corn	20.28%	22.07%	20.75%	21.21%	19.78%	19.78%	....
Kafir-corn	16.16	19.09	18.50	19.42	17.59	16.57	—2.88%
Sorghum (sowed)	18 24	20.05	17.85	16.71	15.24	15.24	—3.51
Soy beans	22.07	24.61	21.37	24.01	21.95	21.12	1.75

The spring moisture condition of the soil of various plots which grew different crops in 1903 is given in the following study. These plots lay adjacent to each other, on fairly uniform land, which had been cropped in 1903 with the crops named in the table. The land was unplowed at the time the soil samples were taken and had received no treatment after the harvesting of the crop in 1903, except that the weeds were cut on the grain plots after harvest.

In the following table are given the average percentages of moisture found in each foot of soil, to the depth of six feet, in duplicate plots (except potatoes). The plots are arranged in the order of their total moisture content, and all the plots are compared with the corn plot as regards the percentages of moisture found in the soil.

Moisture in the soil. Samples taken March 14, 1904.

Crop in 1903.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Average difference compared with corn plot.
Corn	25.69%	30.33%	26.86%	24.44%	24.05%	24.26%	....
Potatoes	26.01	33.11	24.55	24.58	21.39	18.19	—1.30%
Millet	26.07	28.81	26.71	23.17	21.58	20.88	—1.40
Soy beans	25.20	28.13	24.56	23.20	21.54	20.26	—2.11
Sorghum (sowed)....	25.67	28.47	24.45	22.46	19.82	19.08	—2.61
Oats	25.09	25.45	20.25	18.61	18.96	28.78	—2.91
Wheat	25.16	27.14	22.54	21.97	20.56	20.52	—2.97
Barley	25.69	27.11	23.29	18.93	20.81	20.43	—3.23
Emmer	26.56	28.23	22.53	21.00	17.94	19.22	—3.36
Flax	26.15	27.12	22.37	20.69	20.30	18.39	—3.43
Kafir-corn	25.91	28.13	23.78	20.73	20.08	15.84	—3.53

With the exception of Kafir-corn, the ground which grew cultivated crops last season showed the largest amount of moisture in the soil, and the millet ground also ranked high. The grain plots contained 2.91 to 3.34 per cent. less moisture than the corn ground, the flax plot ranking lowest. The Kafir-corn ground contained less moisture than any other plot, averaging 3.63 per cent, less than the percentage found in the corn ground. The sorghum ground seems to have regained more moisture during the winter than the Kafir-corn ground, due, perhaps, to the thick growth of stubble which held the snow and served to prevent loss by evaporation. The grain plots showed a more even distribution of moisture throughout the several feet than the sorghum or Kafir-corn plots, the Kafir-corn ground being especially low in moisture in the deeper soil. The corn plot not only contained a higher total average per cent. of moisture than any other plot, but contained a uniformly high percentage of moisture in each foot of soil. The potato plot contained a higher percentage of moisture in the first two feet of soil than any other plot.

SUMMARY.

1. The root samples show the natural growth of the plant roots under ordinary field conditions, no artificial preparation of the soil being required previous to the taking of the samples.

2. Corn roots deeper and feeds through a greater volume of soil than Kafir-corn or sorghum.

3. Cultivation should not be so deep as to break the large lateral roots of corn, which usually lie at a depth of about four inches midway between the rows.

4. The root system of corn planted in lister furrows develops at a uniform depth, and the surface roots lie uniformly deeper in the soil than do the roots of the level-planted corn.

5. Listed corn may be cultivated close to the hill and three to four inches deep at the last cultivation without injuring the roots.

6. Level-planted corn may not be cultivated so close to the hill at the last cultivation as listed corn, because with the level-planted corn the roots rise nearly to the surface several inches from the hill and are readily destroyed by close cultivation.

7. In a hot, dry climate, rather deep cultivation of corn is desirable, especially as the season advances. A thin soil mulch will not conserve so much moisture as a relatively thick mulch.

8. The practice of laying corn by early in the season requires the forming of a deep soil mulch at the last cultivation in order to conserve the soil moisture and keep the ground from drying out.

9. Kafir-corn, is evidently a strong surface feeder. The thick growth of surface roots and the fact that the Kafir crop grows late into the fall result in the exhaustion of the soil moisture and available plant-food to a greater degree than observed for corn. Thus the crop is "hard on the land."

10. The root system of sorghum resembles that of corn more than that of Kafir-corn.

11. The roots of wheat, oats and barley do not spread out so far horizontally as do the roots of corn and other cultivated crops, but they penetrate deeper into the soil. This may be the result of different methods of culture, or rather the different methods of culture are more likely the result of the different systems of rooting which is characteristic of the several plants.

12. Grain crops, especially oats and barley, produce a large fibrous growth of roots in the surface soil, which has the effect to give the soil a loose, mellow texture at the surface when it is plowed.

13. Flax is a strong surface feeder and in some respects its effect on the soil is similar to that of Kafir-corn, as described above.

14. Grass is a soil-maker, a soil-improver, and a soil-protector. If we had no other evidence of these facts, the root samples would stand as ample proof. No other crop equals the perennial grasses in producing such an immense fibrous growth of roots in the upper soil,

and the roots of certain grasses also penetrate deep into the soil, being exceeded only by one other class of crops, the perennial legumes.

15. Alfalfa is the deepest-rooting crop studied. It makes only a small fibrous growth of roots in the upper 'soil, and is clearly a deep. feeding crop. As a soil-maker and a soil-improver no other crop equals alfalfa, when it is grown with the presence of the nitrogen-assimilating bacteria which live upon the roots of the plants.

16. The annual legumes, cowpeas and soy beans, appear to be light-rooting crops, and the apparent improvement which soil shows when these crops are grown is evidently due to the rest and change which the land receives from continuous grain cropping and also to the acquisition, perhaps, of a small amount. of nitrogen when the roots and tubercles decay.

17. The study of sugar-beet and potato roots suggests the necessity of a deep loosening of the soil in preparing a seed-bed for planting these crops. The root system of the potato requires that the crop be given shallow culture, while that of the sugar beet will permit of deep cultivation without injury to the roots.

18. Such observations as were made on the roots of trees indicate that the root systems are very different, and the study suggests that certain trees may be much better suited than others for planting along roadsides and cultivated fields. Tree roots might properly be given much profitable study by those who are interested in that particular line of work.

19. The study of the growth and development of the roots of plants offers a wide and profitable field for investigation, which has barely been touched upon by the limited work in this line which has already been done. Plant study in the past has been mainly above ground. We have practiced certain systems of planting and cultivation because experience has taught us that they are best, often not knowing the reason why. The study of the soil and of the roots of crops has explained some of the difficult problems of crop production and has helped us to farm more intelligently and more profitably.

ACKNOWLEDGMENTS.

Mr. H. C. Kyle, B. S., a graduate of this College in 1903, has had direct charge of the root work as a special assistant, and was recently elected a regular assistant in the Farm Department. During the summer of 1903, he was assisted by Mr. J. M. Scott, a student of this College, now assistant in agriculture at the New Mexico Agricultural College. The photographic work was in the care of Dr. S. C. Orr, of Manhattan.

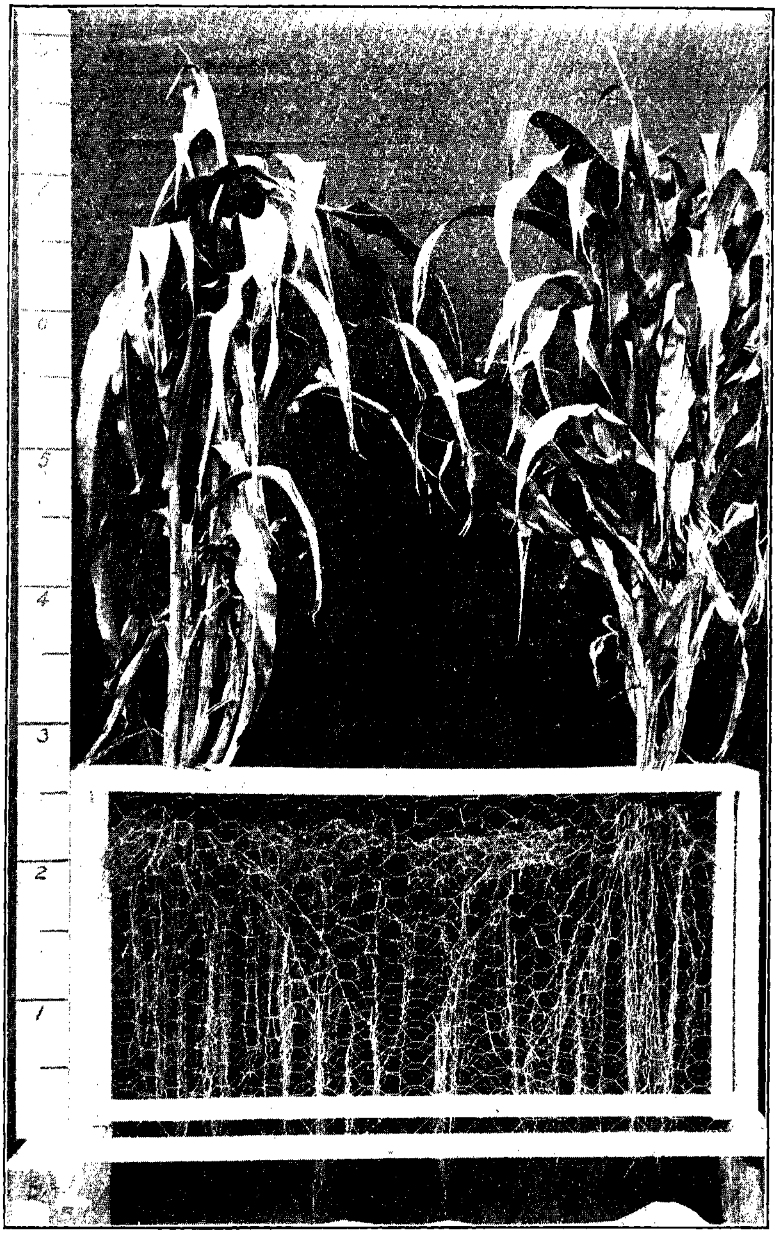


Plate 1. Showing distribution of roots between two hills of level-planted corn, sixty days after planting.

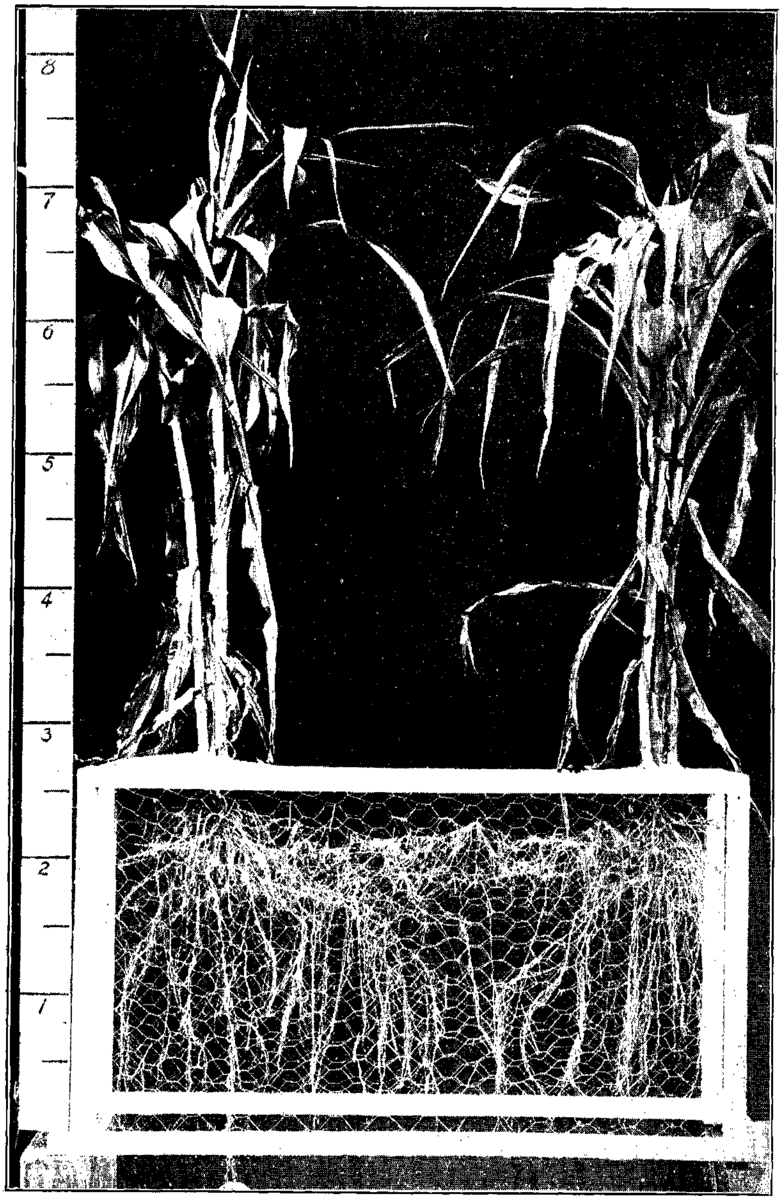


Plate 2. Showing distribution of roots between two hills of corn planted in lister furrows, sixty-five days after planting.

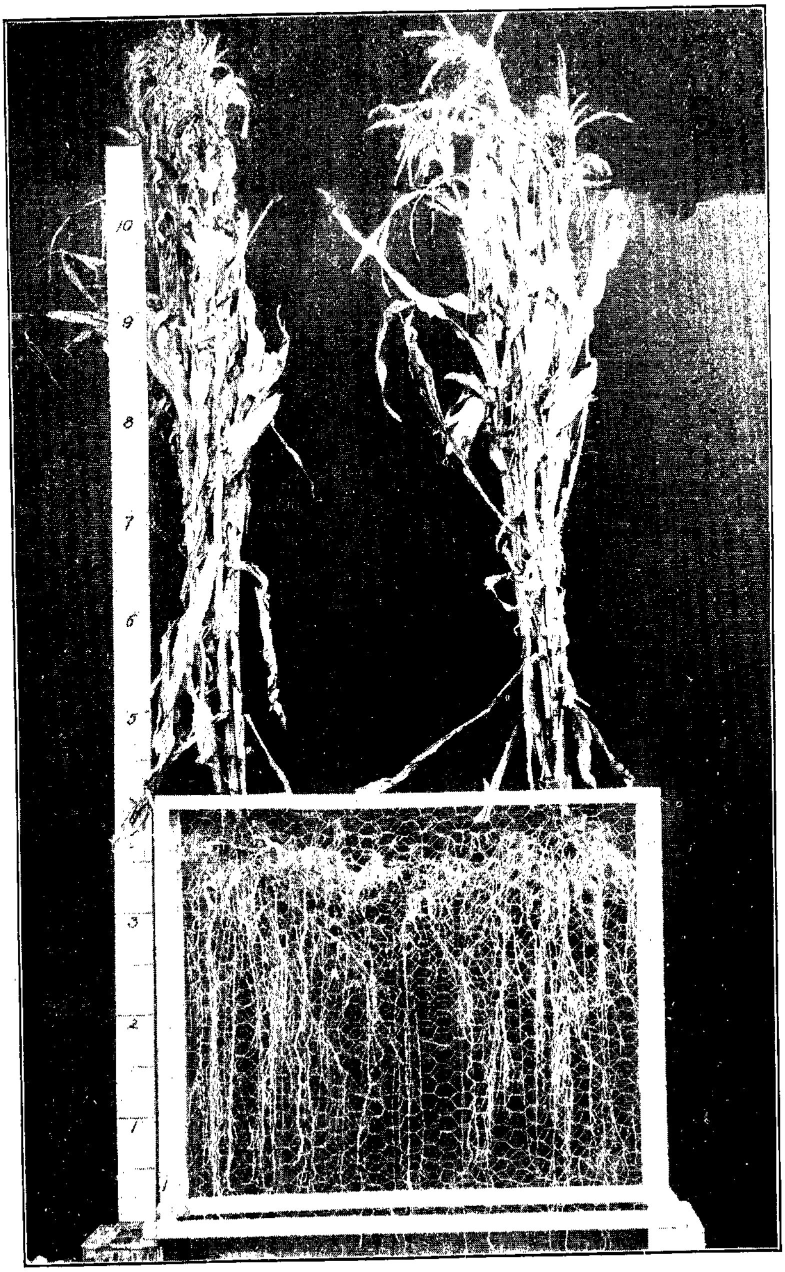


Plate 3. Roots of corn at maturity, planted in lister furrows.

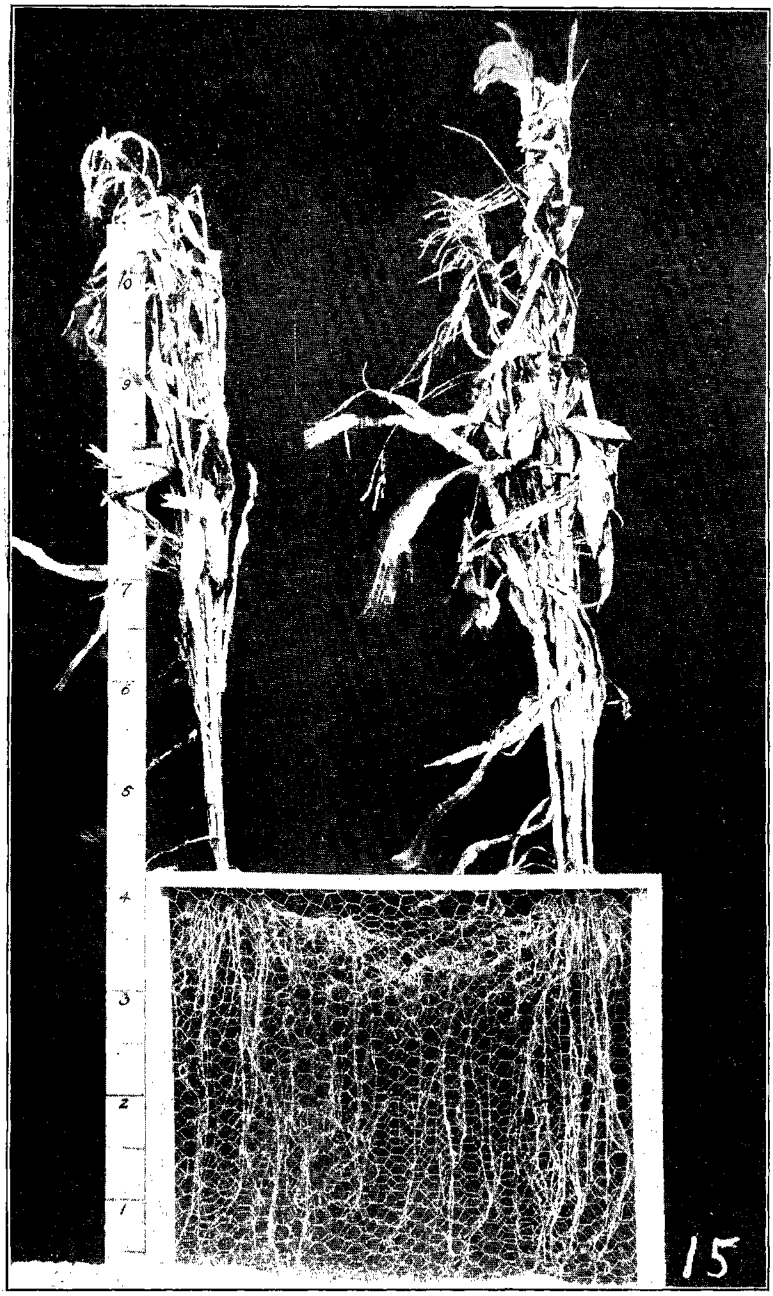


Plate 4. Roots of corn at maturity, planted with check-row, level planter.

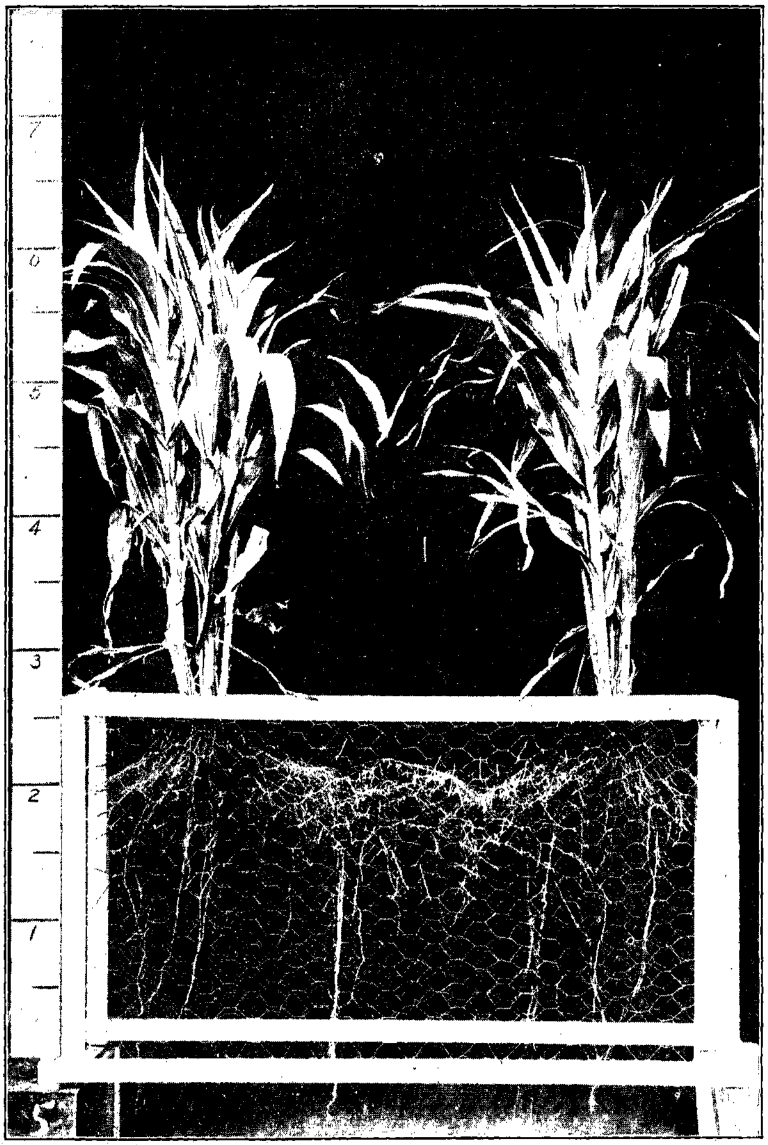


Plate 5. Showing the growth of the roots of Kafir-corn, seventy days after planting.

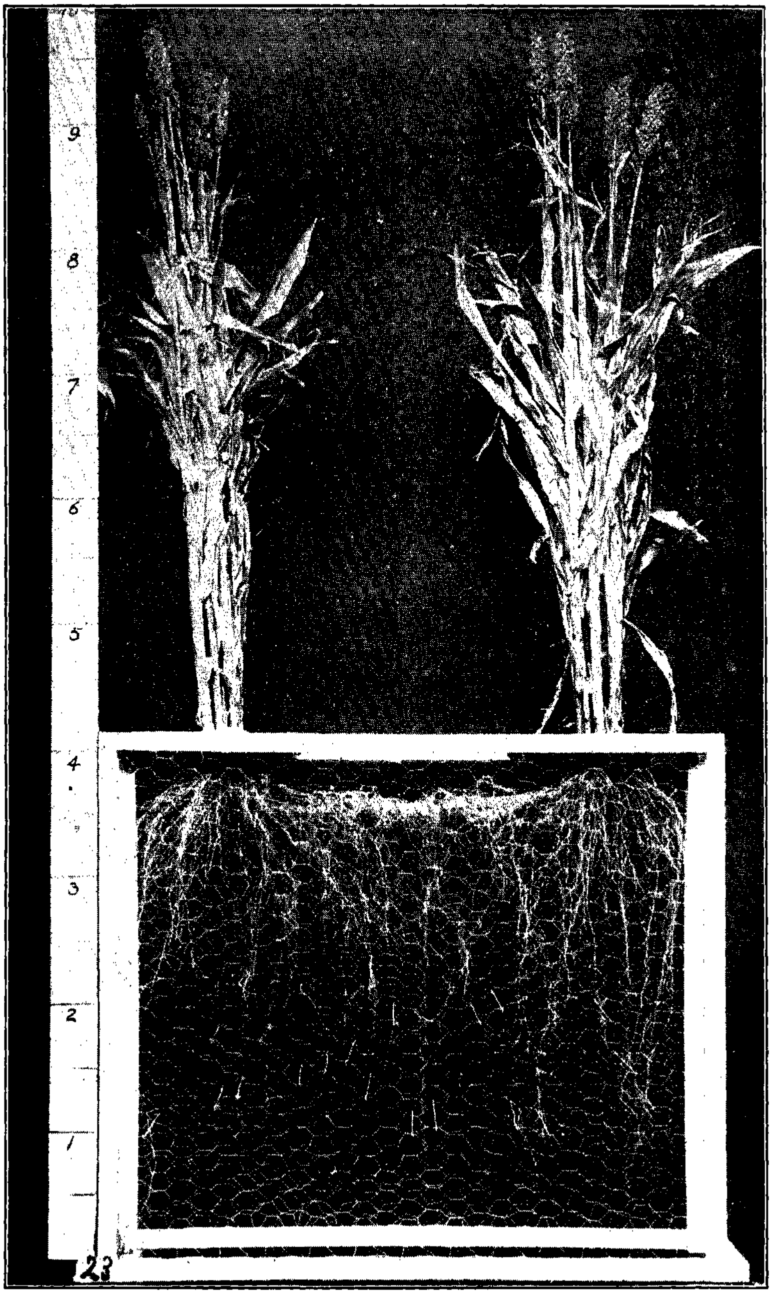


Plate 6. Kafir-corn root system at maturity.

Plate 7. A sample of sorghum roots, taken seventy-six days after planting.

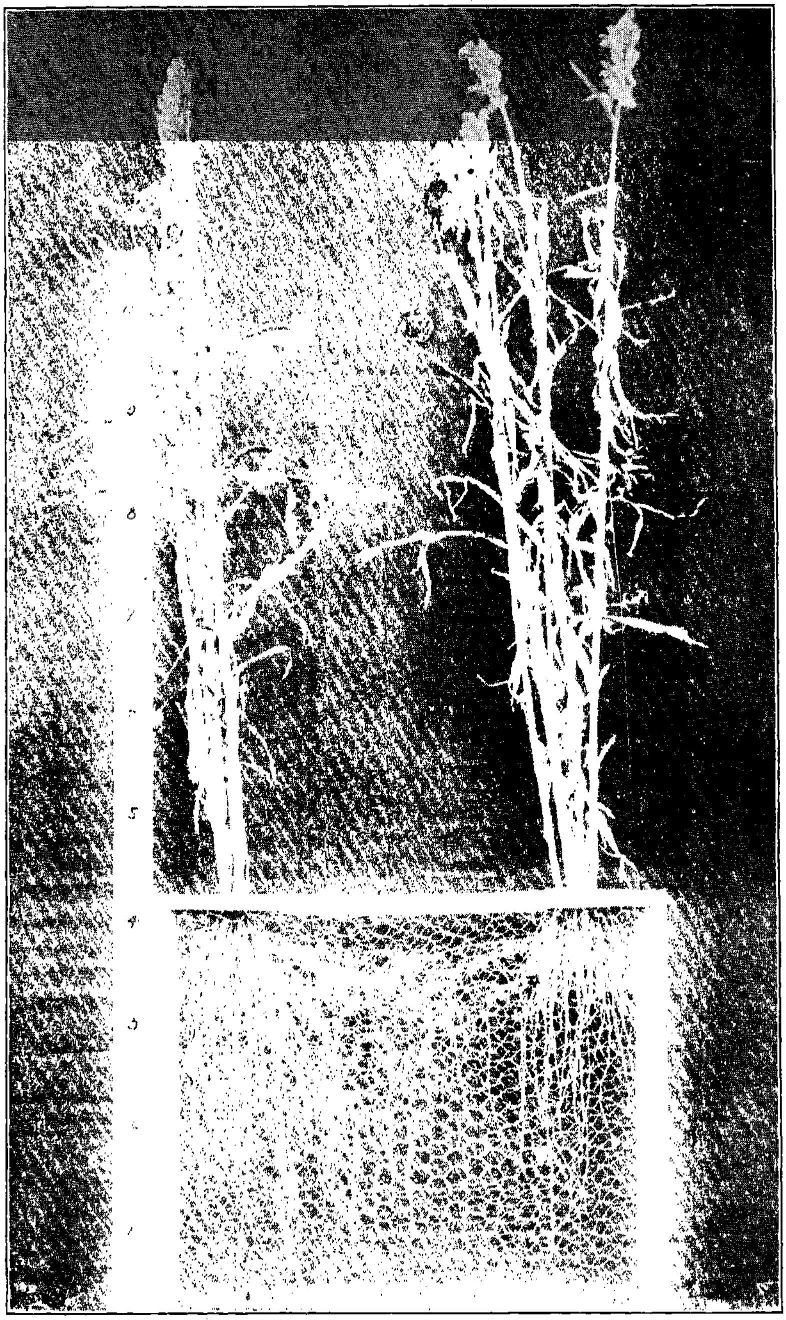


Plate 8. Sorghum roots at maturity.

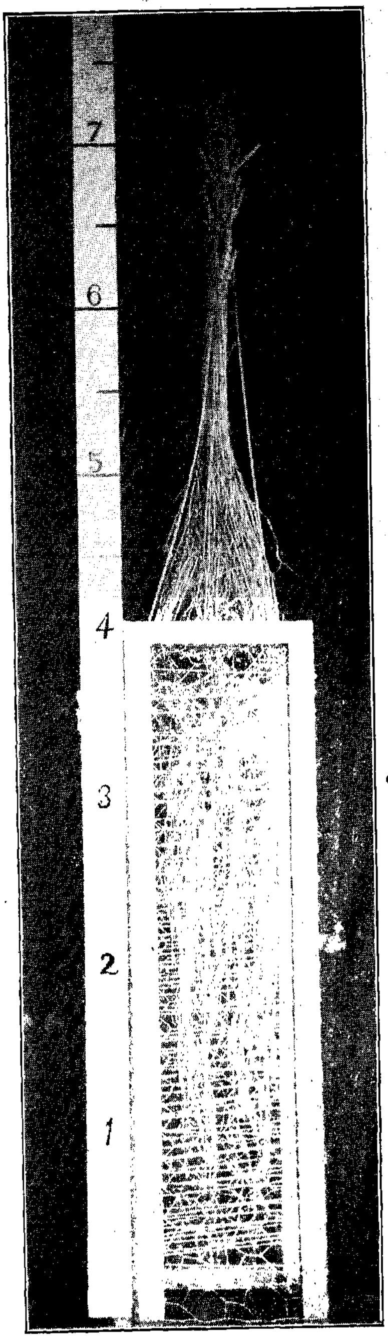


Plate 9. Wheat roots.

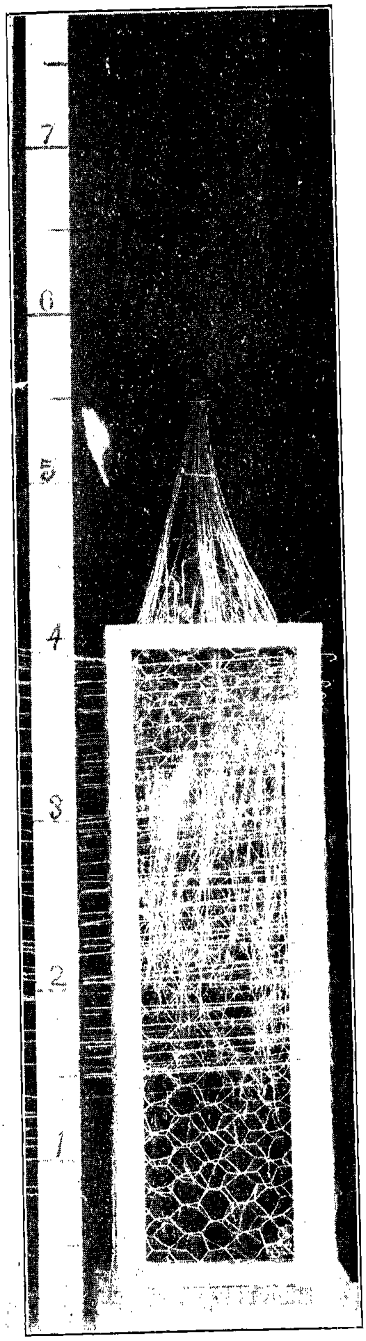


Plate 10. Flax roots.

By permission of North Dakota Experiment Station

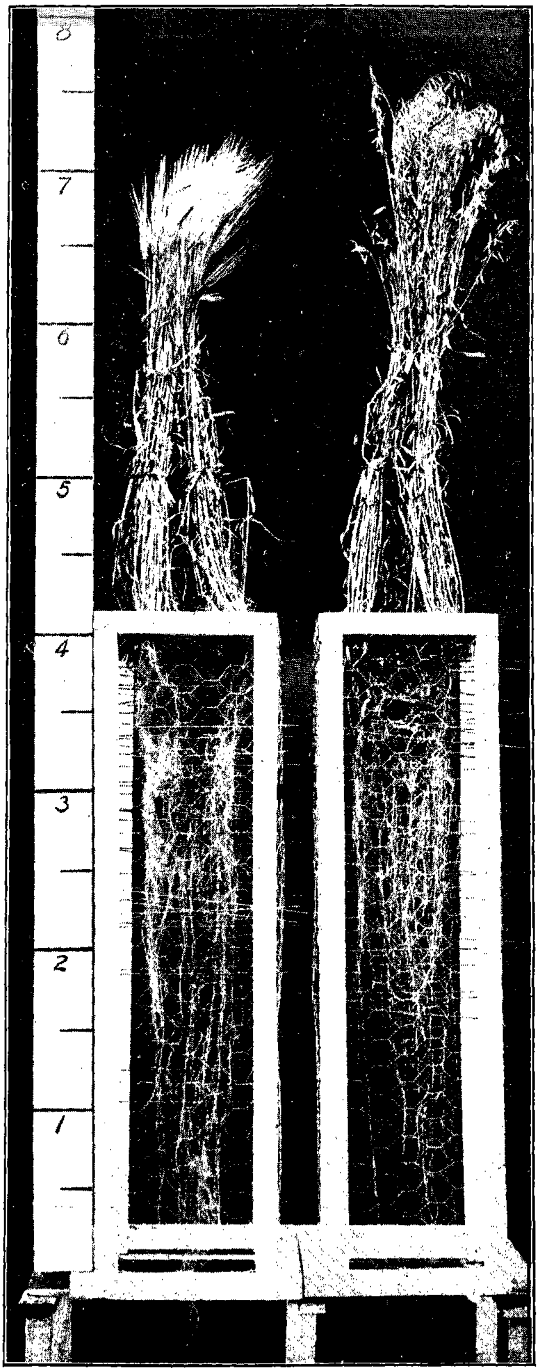


Plate 11. Barley roots. Oats roots.

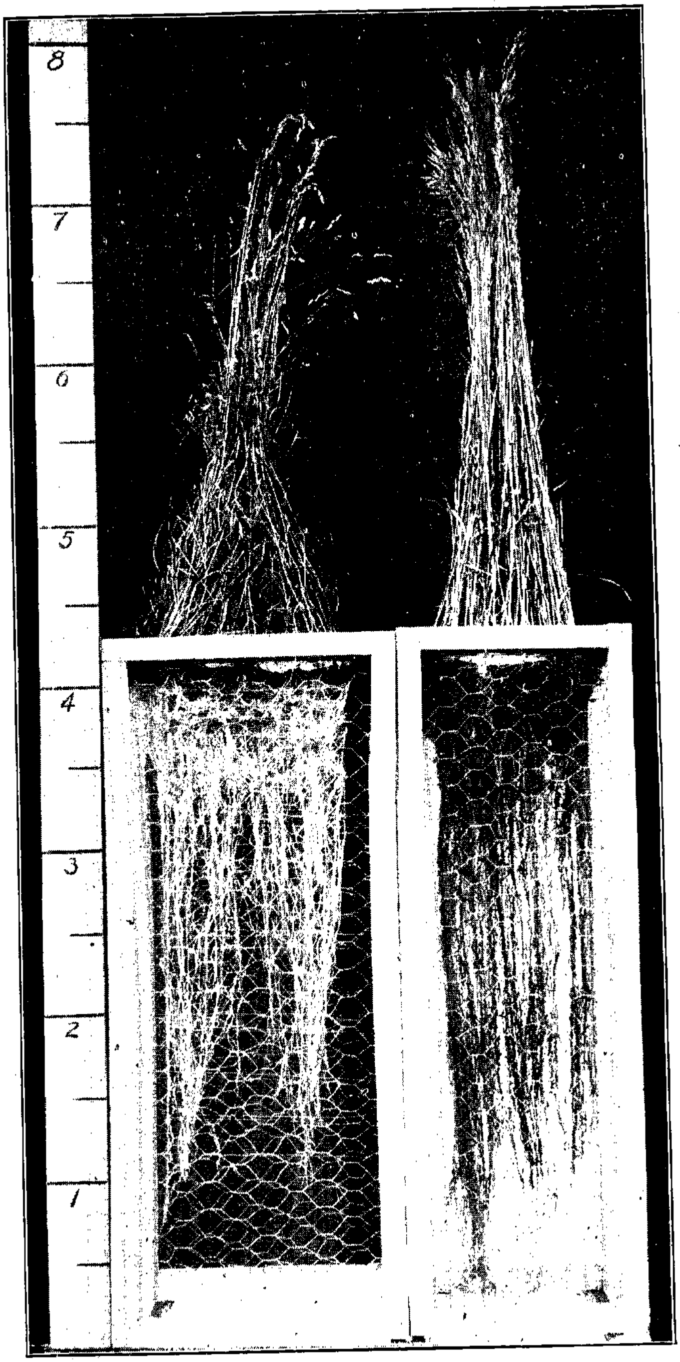


Plate 12. Orchard-grass roots. *Bromus inermis* roots.

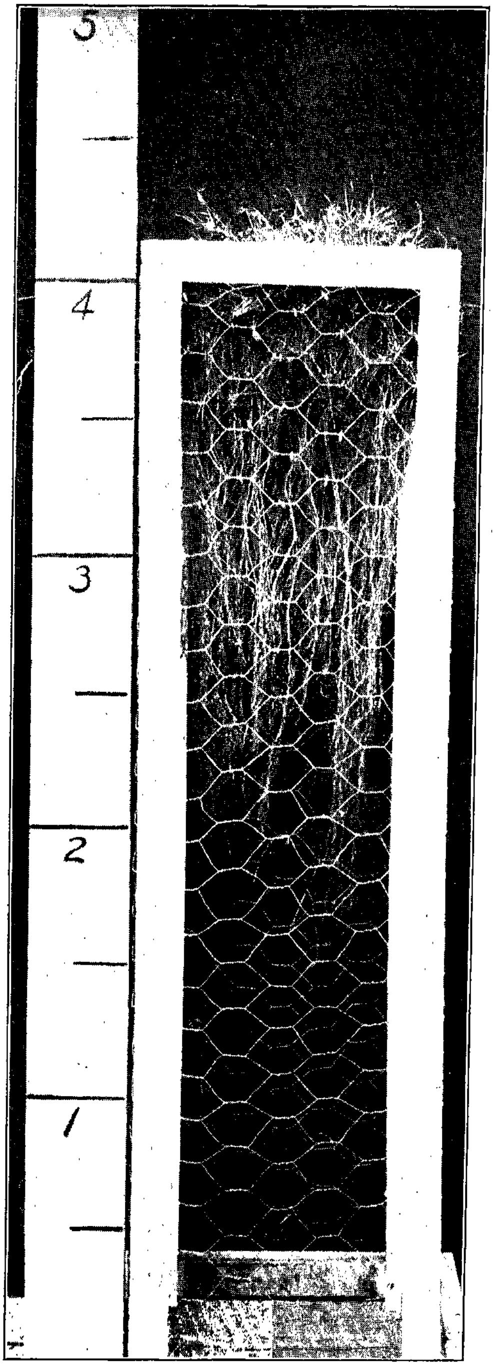


Plate 13. Buffalo-grass roots.

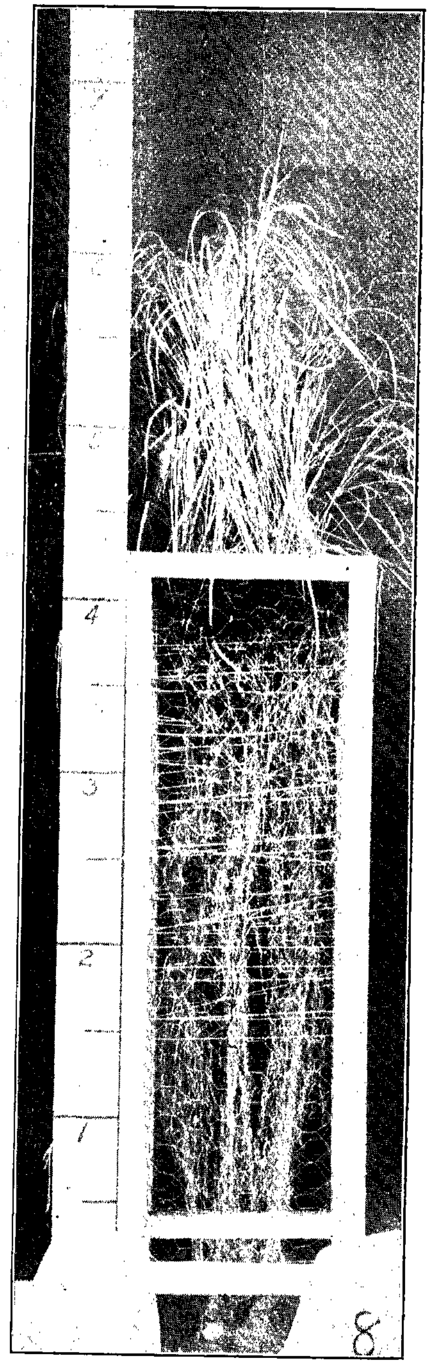


Plate 14. Big bluestem roots.

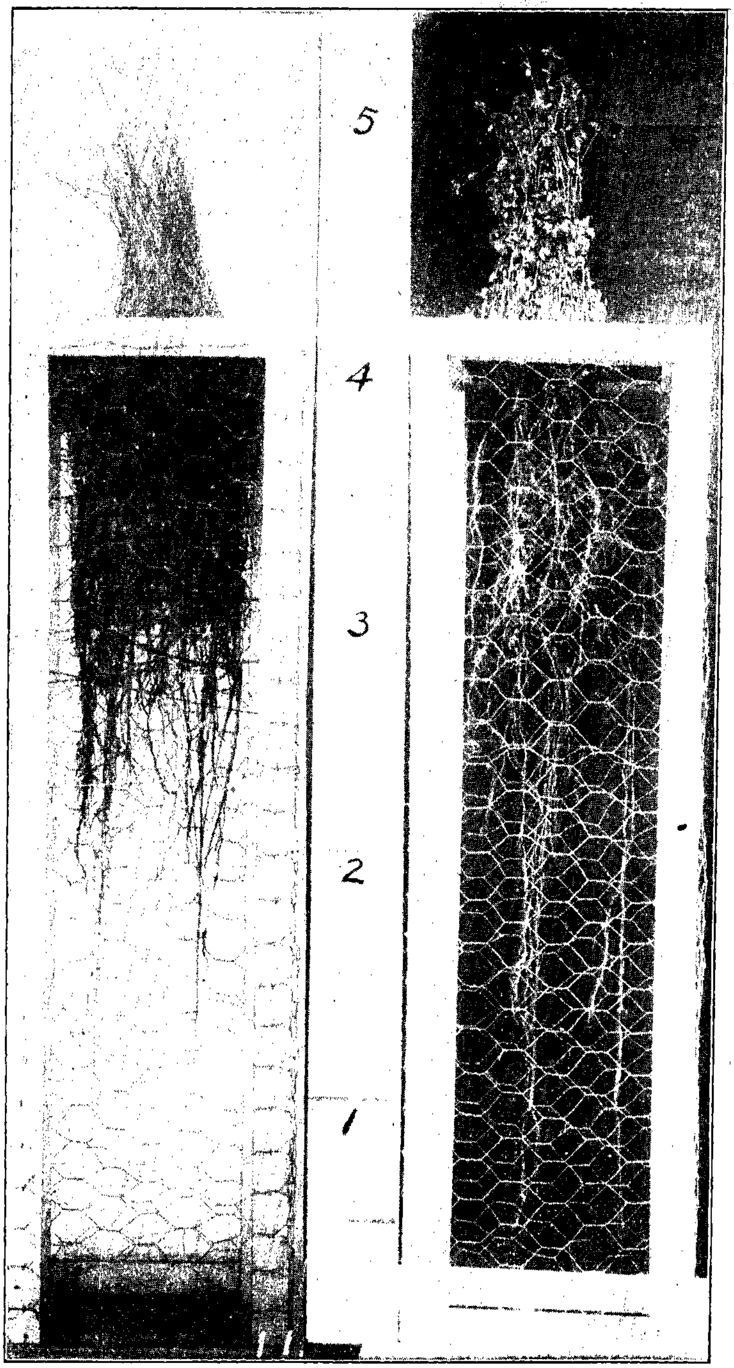


Plate 15. Kentucky blue-grass roots. Common Red clover roots.

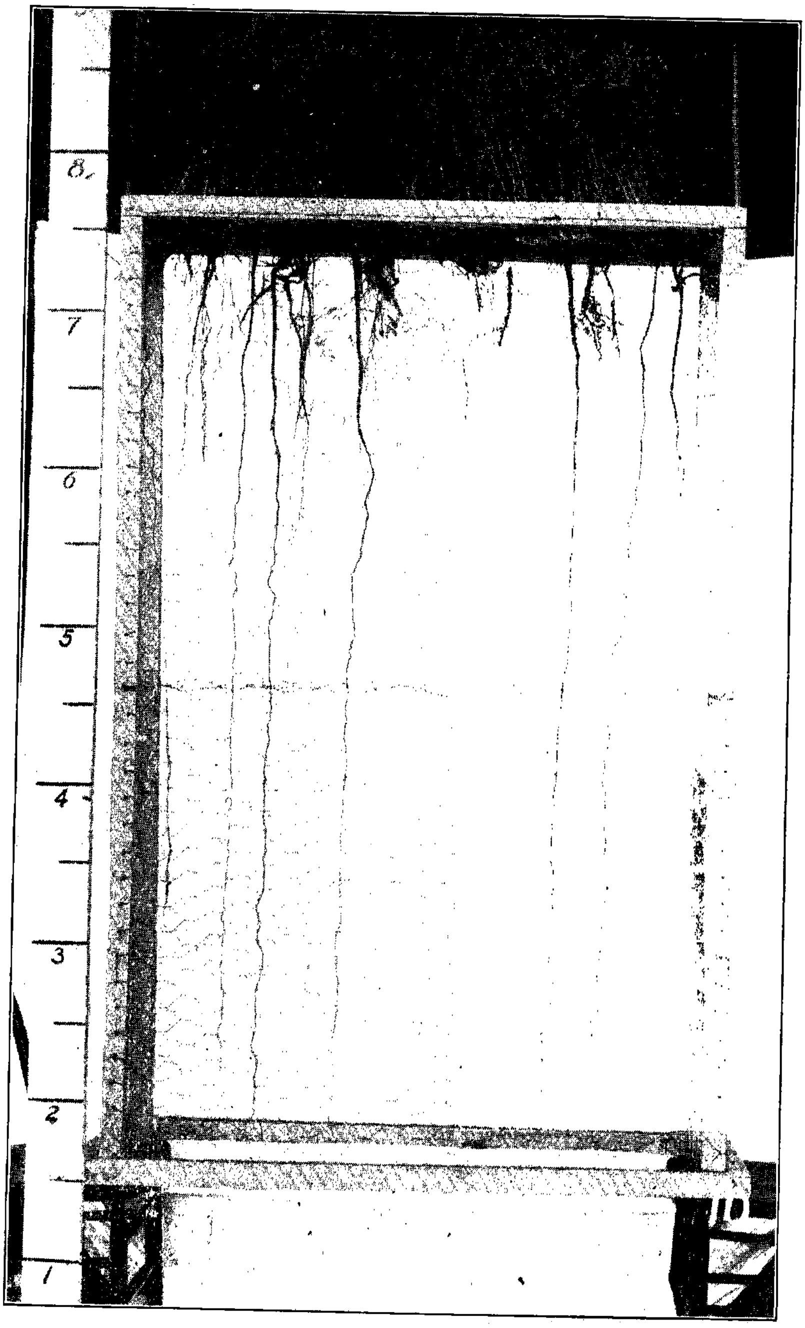


Plate 16. Alfalfa roots, three years after seeding.

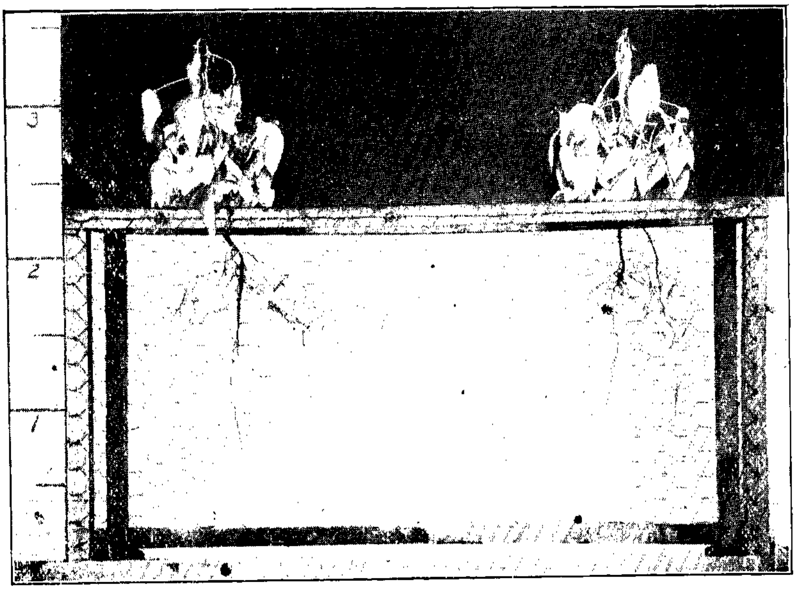


Plate 17. Soy-bean roots, fifty-five days after planting.

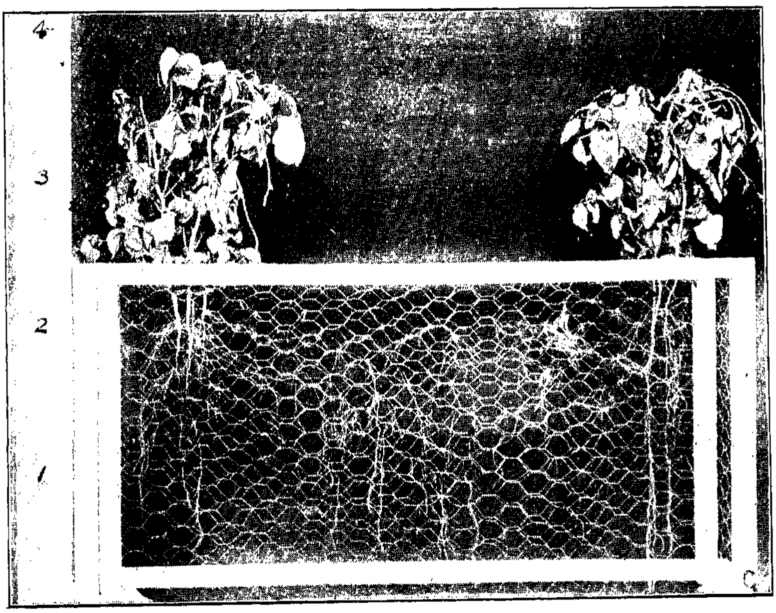


Plate 18. The roots of cowpeas, sixty-five days after planting.

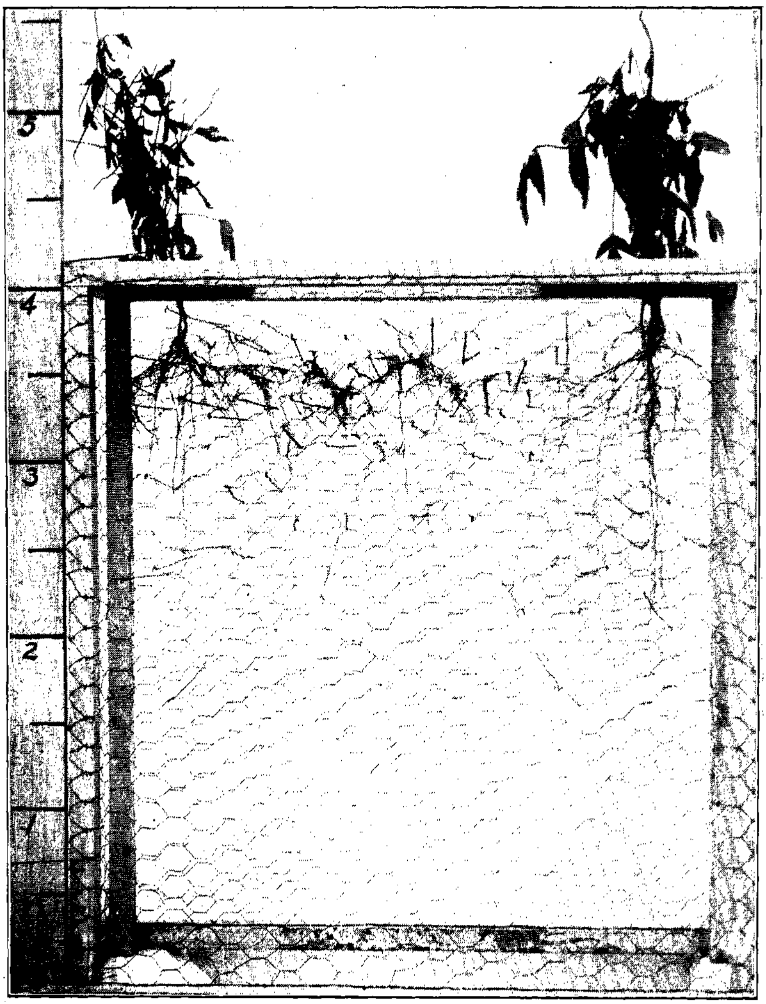


Plate 19. Showing the development of the mature soy beans.

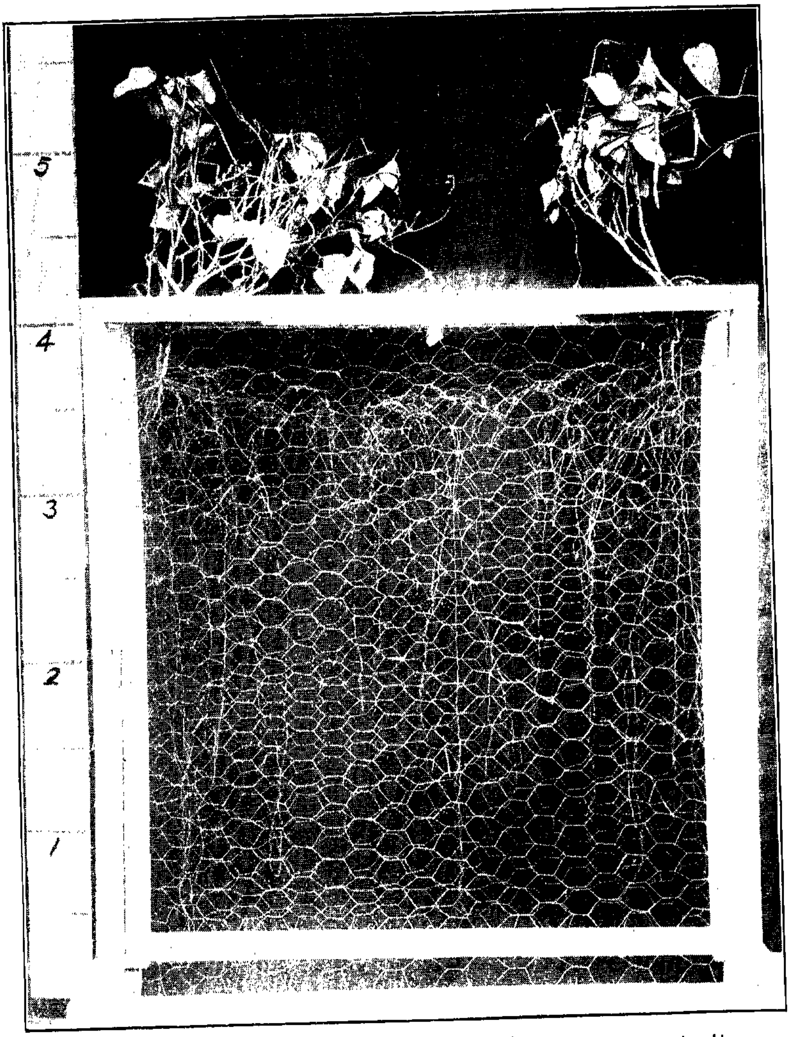


Plate 20. Showing the root system of cowpeas, near maturity, 111 days after planting.

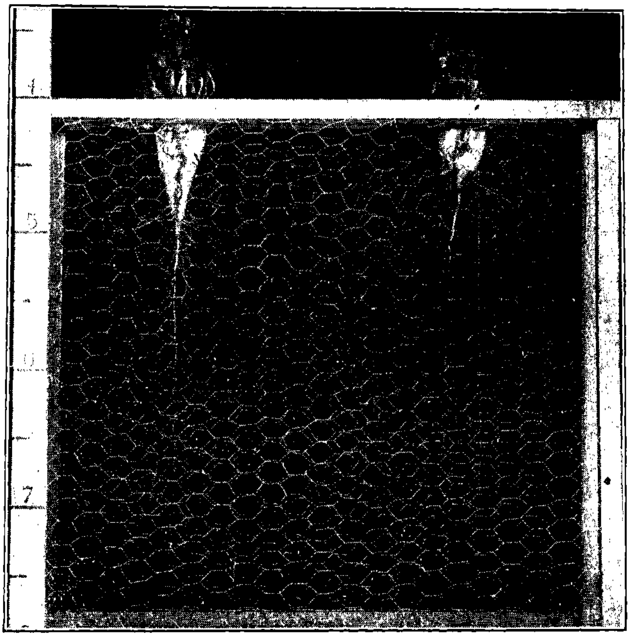


Plate 21. Mature sugar beets, grown in ground plowed six inches deep, but not subsoiled.

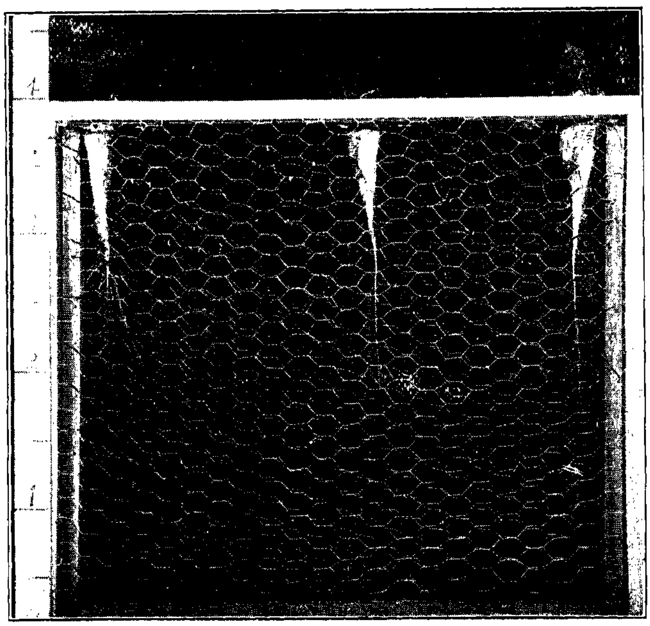


Plate 22. Mature sugar beets, grown in subsoiled ground; *i. e.*, soil loosened to the depth of fourteen inches.

By permission of North Dakota Experiment Station.

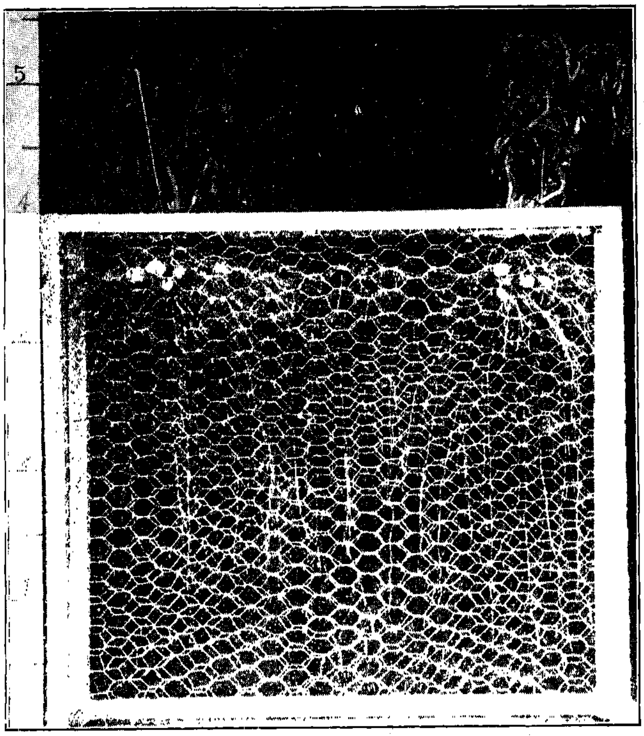


Plate 23. A sample of late potatoes, showing root system ninety days after planting.

By permission of North Dakota Experiment Station.

Plate 24. A bur-oak stump washed out by the flood, 1903.

Plate 25. Showing a stump and roots of the Soft maple.

Plate 26. Roots of the Soft maple as they grew in the soil of a tilled field.