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THE EFFECT OF SOIL TEXTURE, WATER SUPPLY, AND NUTRIENT
SUPPLY UPON THE ROOT DEVELOPMENT OF MAIZE

by

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*Approved
W. H. Miller*

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THE EFFECT OF SOIL TEXTURE, WATER SUPPLY, AND NUTRIENT SUPPLY UPON THE ROOT DEVELOPMENT OF MAIZE.

Plant growth is dependent on the supply of mineral nutrients which the plant can obtain from the soil solution by absorption through the roots. These mineral nutrients are found in the soil solution only in very small quantities. According to Brezeale and Le Clere¹ the film of moisture surrounding the soil particles is in equilibrium with the soil particles. If the plant root removes some of the potassium from the soil solution some more of the potassium compounds in the soil will go into solution until the concentration of the potassium is the same as before. The same is true of the other nutrients. The plant is constantly removing mineral nutrients from the soil solution, thus disturbing the equilibrium between the soil and solution. This causes more of the minerals in the soil to go into solution in order to reestablish the condition of equilibrium. But the minerals in the soil dissolve very slowly so it is necessary for the plant to have a wide feeding range in order to obtain the nutrients as rapidly as needed from the dilute soil solution.

Most soils contain some colloids. These soil colloids are important because of their ability to fix the soluble bases which would otherwise be lost in the drainage water. Hans Niklas² says the colloids retain the bases by a process of selective absorption. The root colloids also have the power of selective absorption of bases and, as Nicklas² says, "the root colloids strive with the soil colloids for the possession of

the bases".

A large root system then is a great advantage to the plant and the factors which influence the development of roots is of interest to the agriculturist.

Among the early investigators of root development was Muller Thurgau³. He found a large mass of roots in dry soil and attributed this to the plant's efforts to overcome the deficiency of moisture by a wider feeding range. In a soil with adequate moisture the plant can obtain sufficient water with a small root system but in a dry soil a large root system is necessary to obtain a sufficient quantity of water for the needs of the plant.

Gain⁴ found that the root mass in the dry soil was much greater in proportion to the aerial part than in the moist soil. An increase in moisture "decreased the terminal growth of the principal roots and increased the growth of the secondary and tertiary ramifications". The top increased with an increase in moisture.

The great difference in the character of roots grown in soils containing a large amount of water and in normal soils is attributed by Wagner⁵ to absence of atmospheric air in the wet soils and its presence in the normal soils. He observed that the exclusion of atmospheric air caused the formation of long slender roots, less branched and less woody than roots found in normal soils. The character of the roots were the same whether grown in solutions or in soil filled with water. The cause of this peculiarity seemed to be due to the absence of air. In well aired soils normal roots formed, in soils filled

in
with water and solutions the roots were abnormal.

Collier⁶ found that rice blight is due to a lack of aeration. When the rice fields were kept flooded throughout the growing period, the roots were injured and the grain failed to develop. This condition is known as rice blight. When the water was allowed to drain away so the air could penetrate the soil and then flooded again the percent of blight was materially decreased and in some cases entirely prevented. These results led Collier⁶ to advise the farmers to allow the soil to drain and aerate for two or three weeks at the time the head is forming and then flood again, instead of constant flooding as is usually done.

Tucker and von Seelhorst⁷ grew oats in pots with low, medium, and high water content. They found the lowest absolute weight of roots in the pots with medium water content except in two cases. The highest ratio of tops to roots was found in the pots with high water content and the lowest in the pots with low water content. The growth of tops varied directly with the water content of soil. The large mass of roots in the dry soil is attributed to the plant's inability to obtain sufficient nutrients with a small root system. It is necessary therefore to increase its feeding range by developing a larger root system.

Wilms and von Seelhorst⁸ found that the moisture content of soil influenced the composition of the plant in nitrogen and ash. The ash content of grain increased with increase of water from low to medium. The effect of higher water content is doubtful.

Widdsoe⁹ and his co-workers found that an increase of irrigation increased the production of dry matter but the production of dry matter per acre inch of irrigation water decreased steadily with increased amounts of irrigation water. Increased water decreased the percent of protein in wheat. The development of roots was not considered by these investigators.

Bouyoucos¹⁰ grew wheat in a clay loam and in a sandy loam and applied nutrient solutions of various concentrations. The clay loam gave the highest weight of dry matter except where solutions with a lower concentration than 100 parts per million were used. Wheat grown in coarse and fine sand gave the heaviest growth in the fine sand.

Morgan¹¹ found the greatest root development in the soil with least moisture. The water content varied from 17.6 percent to 42.8 percent. The variation in root development was inversely proportional to the water content.

Polle¹² grew barley and wheat in a loam and in a sandy soil. The soil was packed in some of the pots and loose in others. Some were fertilized and others unfertilized. With barley he obtained the greatest length of main roots in the moist packed unfertilized loam. The greatest length of branch roots was in the unfertilized loose, moist loam. In the loam the moist soil always gave a greater length of main roots and branch roots than the dry soil. In the unfertilized sandy soil the results were similar, but in the fertilized sandy soil, the dry soil gave longer main roots when the soil was loose, the moist soil when it was

packed. In both cases the greatest length of branch roots was in the moist soil. With wheat both soils, whether loose or packed, gave the greatest length of both main roots and branch roots when the soil was moist.

The total weight of barley roots in both soils, when unfertilized, was greater in the moist soil than in the dry. In the fertilized pots the results were the reverse except in the packed sand. In all cases the weight of branch roots was greater in the moist than in the dry soil. There were more irregularities in the weights of main roots than in their lengths. In both soils wheat gave greater total root weights in the dry soil when packed, in the moist soil when loose. In the packed soils the greater weight of branch roots were in the dry soils. In the loose soils the inverse was true except in the loose, fertilized loam. Both unfertilized soils gave greater weight of main roots in dry soil where packed, in moist soil when loose. The same was true of the fertilized except in the loose sand.

Bunger¹³ found that "with constant dryness the poorer soil produced the stronger root system, with higher moisture the richer soil".

Lemmerman¹⁴ grew maize and barley in pots of different size and found the larger growth in the larger vessels. He attributed the difference to the lack of sufficient nutrients in the small vessel rather than to the small volume.

The investigations of von Seelhorst¹⁵ showed that fertilizing increased not only the mass but also the number and depth of penetration of the roots.

The influence of nitrogen on the development of the

the roots was investigated by von Seelhorst and Bunker¹⁶. They used a heavy and a light application of nitrogen. In the early period of growth the light application produced the greater root system. This was reversed in later periods of the growth. At first the ratio of top to root was greater with the heavy application of nitrogen, in later stages the light application produced the higher ratio.

Karl Meyer¹⁷ found that the absolute root weight was higher in soil with high water content than with low water content. This was the case in both the fertilized and unfertilized soil. Burnester¹⁸ found that the quantitative formation of both the root and aerial part of the plant were depressed by deficient nutrient supply but that the root was diminished to a less extent than the aerial part.

The above mentioned investigators confined their attention mainly to the small grains. Very little had been done with maize until recently when the Missouri Agricultural Experiment Station began work on the factors which influence the growth^{of} Maize. Miller¹⁹ grew Boone County White and Reid's Yellow Dent on two types of soil, upland silt loam and sandy bottom land. Both the Boone County White and Reid's Yellow Dent produced a larger root mass in the upland silt loam than in the sandy bottom land.

Evans²⁰ grew maize in silt loam with high and low water content. The growing period of the plant was divided into a first, second, and third period and the water content of the soil varied from one period to another. It was found that the

best root development was in the pots with high water content during the first period followed by low water content during the other two periods.. Low water content the first period followed by high water content during the other two periods gave the next higher root development. The next highest root development was in the pots with high water content during the first two periods followed by low water content during the last period. This was only slightly higher than the pots with high water content during all three periods. Low water content the first two periods gave slightly less root mass than constant highwater content. The lowest results were from the pots with high moisture first period, low second period, and high third period. Constant low water content gave slightly higher root mass.

Hackleman²¹ grew maize in sand and applied full nutrient solutions of two degrees of concentration. The periods of growth were the same as in the work of Evans²⁰ and in some of the pots the concentration of the solutions was varied at different periods. The best growth of roots was in the pots that received an application of weak nutrient solution during the first two periods followed by a strong nutrient solution during the third period. The next highest root weight was from the pot receiving the strong nutrient solution during all three periods. Application of weak nutrient solution during the first period followed by the strong nutrient solution during the next two periods gave the lowest root weight. A weak nutrient solution during the first period followed by

strong nutrient solution the second period and weak solution again the third period gave a slightly higher root weight.

Kirby²² grew Maize in sand, silt loam, and clay with optimum water content and in sandy loam with minimum and optimum water content. With optimum water content he found the greatest mass of tops with the silt loam and the least with the sand. The greatest weight of roots however was in the clay and the least in the sand. The compactness of the soil seemed to favor the production of a large root mass as Polle¹² found in his work with barley and wheat.

With varying water contents in sandy loam Kirby²² found the greatest mass of both tops and roots with the optimum water. Minimum water gave the least mass of tops and maximum water the least mass of roots. The ratio of top to root was greatest with the maximum water content.

Rotmistrov²³ has investigated the role of the root system of plants in the water regime of the soil and finds that the root growth of cereals ceases after flowering. "Spring cereals reach a depth of 110 c.m. and spread out to almost the same extent. Maize is an exception for its root system is greater in width (up to 150 c.m.) than in length. The root system of winter cereals is longer than that of spring cereals and reaches 130 c.m. (rye)".

This investigator found that cereals have a much denser root system than dicotyledons. He finds that the thickness of the root system is almost equal throughout the soil layer which they occupy. This dense network of roots makes it possible for them to obtain sufficient water from a soil too dry for plants with a weak root system.

EFFECT OF SOIL TEXTURE AND WATER SUPPLY ON ROOT DEVELOPMENT.

Plan of the Experiment.

The experiments on soil texture and water supply were carried out in four gallon stone jars. Three different soils were used, a sandy loam(loess), and upland silt loam, and what was virtually a clay subsoil. This clay was taken from the side of a hill where erosion had removed the surface soil and left the clay subsoil exposed. It was deficient in organic matter and nitrogen.

Three different degrees of water content were maintained. The growing period of maize was divided into three periods as in the work of Evans²⁰ and Hackleman²¹. It was the purpose of these experiments to show the effect of a difference in water supply during the first period and the effect of a change in water supply as well as the effect of a constant difference in water supply. Pots containing loess and receiving the different degrees of water supply were washed out at the end of the first period. In others, the water supply was changed during the second period and washed out at the end of the second period. Others received constant water supply during both periods. All the pots containing loam and clay received constant water through the first and second period. The treatments were as follows:-

Pots washed out at the end of the First Period.

Kind of Soil.	Water content of Soil.	
Loess	Minimum	1st Period.
"	Optimum	" "
"	Maximum	" "

Pots washed out at the end of Second Period.

Kind of Soil.	First.	Second.
Loess	minimum	minimum.
"	"	optimum
"	"	maximum
"	optimum	minimum.
"	"	optimum.
"	"	maximum.
"	maximum	minimum.
"	"	optimum.
"	"	maximum.
Silt Loam	minimum	minimum.
" "	optimum	optimum.
" "	maximum	maximum.
Clay	minimum	minimum.
"	optimum	optimum.
"	maximum	maximum.

Method of Procedure.

The loess and silt loam were sieved but the clay had to be ground in order to get it thoroughly pulverised. Uniform compactness was obtained by adding a shovelful at a time. After the additions of each shovelful the pots were raised six inches and allowed to drop to the ground. This was done five times after the addition of each shovelful of soil. The amount of soil used per pot was 16½ kilograms of loess, 17 kilograms of upland silt loam, and 20 kilograms of clay.

The three degrees of water content used were the maximum at which the plant can grow and function properly, the content that will produce the optimum growth of the plant, and the minimum at which the plant can grow. The optimum water content was taken as that degree of moisture which produces the best physical condition in the soil. This was determined by the feel of the soil. This method gave 20 percent for loess, 22 percent for upland silt loam, and 25 percent for the clay. These water contents were changed for reasons that will appear later. The minimum water content was taken as 8 percent for the loess, 10 percent for the silt loam, and 13 percent for the clay. The maximum water content was taken tentatively as 24 percent for the loess, 25 percent for the silt loam, and 27 percent for the clay. These figures were found too low so the water content was increased.

The loess and upland silt loam were not air dry when placed in the pots. The amount of water present was determined and enough added to bring the water content up to 20 percent of air dry weight in all the pots. The clay was air dry when placed in the pots. 4000 C.C. of water was added to each pot containing clay. This made the water content 20 percent of the air dry weight. The object in bringing all the pots up to the same water content before planting the maize was to settle the soil and insure a more uniform compactness.

The water content was made up to 20 percent in all the pots on December 2, 1913, the maize was planted Dec. 12, 1913.

Eight kernels of Reid's Yellow Dent were planted in each pot. One kilogram of sand was spread over the surface of the soil in each pot to retard evaporation and prevent checking. The plants came up Dec. 22 giving a uniform stand. They were thinned down to four stocks per pot.

The pots were watered by pouring the water over the surface and allowing it to soak in. The pots were weighed weekly and water added to bring them to the proper water content. All the pots had the same water content when the maize was planted. No water was added to the minimums until they reached the water content taken as minimum. All the other pots were made up to 20 percent on Dec. 16th. On Dec. 23, the loess was made up to 20 percent for the optimum and 24 percent for the maximum, the silt loam to 22 percent for the optimum and 25 percent for the maximum, and the clay to 25 percent for the optimum and 27 percent for the maximum. On Dec. 30 it was observed that the pots receiving maximum water had the best growth of tops. This indicated that the optimums and maximums were too low. So the water content of the loess was raised to 25 percent for the optimum and 27 percent for the maximum, of the silt loam to 25 percent and 30 percent respectively, and of the clay to $27\frac{1}{2}$ percent and 30 percent respectively. Jan. 6, 1914, the maximum for the loess was made 29 percent and the silt loam was raised to 28 percent for the optimum and 32 percent for the maximum. Jan 13 the loess was raised to 28 percent for the optimum and $32\frac{1}{2}$ for the maximum and the silt loam to 30 and 35 percent respectively. Jan 30th

the loess was raised to 30 percent for the optimum and 35 for the maximum and the silt loam to 40 percent for the maximum, the optimum remaining at 30 percent. These water contents were maintained for the loess and silt loam until Feb. 17. During this time the plants in the loess and silt loam made as good a growth with maximum water content as with optimum.

From Dec. 30, 1913, to Feb. 10, 1914 the optimum and maximum water contents in the clay ^{were} maintained at $27\frac{1}{2}$ and 30 percent respectively. Early in February the plants receiving optimum water as well as those receiving maximum water showed the effects of too much water. Previous to this the growth had been practically the same in all the pots. All the plants were lacking in color and none made as good a growth as the plants in the loess with maximum water content. It was evident that the optimum and maximum water content were too high so they were changed to 25 percent and $27\frac{1}{2}$ percent respectively.

On washing out the pots which only continued through the first period, it was observed that the character of the roots in the pots with optimum water as well as those in the pots with maximum water, had the character of water roots as mentioned by Wagner.⁵ This indicated that the optimum was too high so the optimum for both loess and silt was lowered to 25 percent. The maximums were kept at 35 percent, and 40 percent as before.

There was so much cloudy weather during the latter part of December and the first part of January that the

corn made a poor growth. On this account the time of harvesting the plants which were to run only through the first period was delayed until the early part of February. Photographs were taken on Feb. 4 and the corn cut on Feb. 7. The plants running through both periods were photographed on Mar. 11 and the corn cut on March 11th and 12th. This made the second period shorter than the first but the corn was beginning to tassel so it was decided that the second period of growth was completed. The tops were air dried and weighed.

Method of Separating the Soil from the Roots.

The roots were washed out by laying the pot on its side and directing a fine stream of water from a hose against the surface of the soil. This loosened the soil and washed it away gradually. In this way the soil was prevented from breaking off in large pieces and carrying some of the roots with it. The soil and water was passed through a fine screen which retained the small roots that had broken off with the soil. Considerable inert organic matter was intimately mixed with the roots and it was difficult to separate from them. The greater part was removed by picking it out by hand. Considerable soil remained in the root web especially where there was a large amount of fine roots. This was corrected by burning the roots and deducting the weight of the residue. The amount of root ash was so small it was not considered.

Before determining the weight of roots they were separated into two groups. The brace roots and other large roots were placed in one class called main roots and the fine fibrous branch roots in another called branch roots. ^{each} ~~was~~ weighed

separately, then burned, and the weight of the residue deducted. The separation was difficult as it was hard to decide which class some of the roots should go in. But the mass of roots which were doubtful was so small that the method was fairly accurate.

Experimental Results.

Effect of a Variation in Water Content During the First Period.

The weights of the roots and tops of the plants grown in loess soil with varying water during the first period are shown in table I.

TABLE I.

Water Content.	Main Roots.	Branch Roots.	Total Roots.	Tops.
Minimum	0.79g	2.85g	3.64g	5.20g
"	0.58	2.53	3.11	5.88
"	0.55	2.13	2.68	4.07
Optimum	0.75	2.38	3.15	9.24
"	0.38	2.30	2.68	8.95
"	0.32	1.27	1.59	5.15
Maximum	0.70	2.46	3.16	8.44
"	1.17	2.39	3.56	9.05
"	1.15	2.57	3.72	9.85

In all of these pots the roots had penetrated to all parts of the soil. The pots with maximum water had the largest mass of roots but the roots were mainly of the long slender variety mentioned by Wagner⁵. The branch roots near the

PLATE I.

Growth of Maize in Loess Soil with Varying Water Content, at
the End of First Period.

Water Content.

First Period.

1. Minimum
2. Optimum.
3. Maximum

PLATE II.

Root Development of Maize in Loess Soil with Varying Water Content, at the End of First Period.

Water Content.
First Period.

1. Minimum
2. Optimum
3. Maximum

surface were short. In the pots with optimum water there were more fibrous branch roots near the surface but the roots in the lower part of the pot were similar to those in pots with maximum water but there were fewer them. In the pots with minimum water there was a fine network of fibrous branch roots near the surface but there were comparatively few roots in the lower part of the pot.

A glance at Table I shows that there is considerable variation in the pots receiving the same treatment. This is probably due to some factors not under control. The low weight of main roots from one of the pots with maximum water is due to damage by a mouse. One of the pots with optimum water gave extremely low results. The reason for this is unknown. The top growth was retarded in about the same ratio as will be seen by referring to Table II.

TABLE II.

Water content of soil.	Ratio of main roots to branch roots	Ratio of total roots to tops
Minimum	1:3.60	1:1.43
"	1:4.36	1:1.89
"	1:3.87	1:1.52
Optimum	1:3.17	1:2.93
"	1:6.05	1:3.34
"	1:3.97	1:3.24
Maximum	1:3.51	1:2.67
"	1:2.04	1:2.54
"	1:2.24	1:2.65

The variation in pots receiving the same treatment is so great that it is difficult to see the effect of the difference in water content. This becomes more clear if we take the averages of the different treatments. Table III gives the average weights for the different treatments. In the pots with optimum water content the average is of the two pots in which the plants were normal. The plants in the other pot were so abnormal that it could hardly be considered. The roots from one of the pots with maximum water was damaged by a mouse. This was also discarded and the average of the other two taken.

TABLE III.

Water content.	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	0.64g	2.50g	3.14g	5.05g
Optimum	0.57	2.34	2.91	9.12
Maximum	1.16	2.48	3.64	9.45

The optimum water content gave the lowest total weight of roots, the lowest weight of branch roots and the lowest weight of main roots. This agrees with the work of Tucker and von Seelhorst⁷ who found that "the oats in the pots with medium water content gave in general the least mass". The pots with maximum water gave the greatest total weight of roots and the greatest weight of main roots but the weight of branch roots was slightly less than in the pots with minimum water.

The tops increased with increase of water but the difference between the pots with optimum and those with maximum water was less than the difference between those with minimum

and those with optimum water. With the exception of the pot with abnormal plants already referred to, all the pots with optimum water gave a much better growth of tops than the best yield from the pots with minimum water. The average of the maximums was only slightly better than that of the optimums and the best growth with optimum water was better than the poorest with maximum water. The ratios between main roots and branch roots and between total roots and tops is given in Table IV.

TABLE IV.

Water content of soil.	Ratio of main roots to branch roots.	Ratio of total roots to tops.
Minimum	1:3.91	1:1.62
Optimum	1:4.11	1:3.13
Maximum	1:2.13	1:2.32

The least amount of branch roots in proportion to the main roots was found in the pots with maximum water content. This was not due to a decrease in branch roots for Table III shows us that the average for the pots with maximum water was greater than the average for the pots with optimum water and but slightly less than that for the pots with least water. The cause was due rather to the increase of main roots in the pots with maximum water. The greatest amount of branch roots to a unit weight of main roots was in the pots with optimum water. The average weight of the main roots and branch roots in these pots were less than in the pots with minimum water but the weight of main roots was relatively lower than that of the

branch roots.

The pots with optimum water gave more weight of top to a unit weight of total roots than either of the other treatments. The least weight of tops per unit of total root was in the pots with minimum water. This indicates that the lack of water retards the development of top much more than the root.

THE EFFECT OF A VARIATION IN WATER SUPPLY DURING THE SECOND PERIOD FOLLOWING A CONSTANT MINIMUM WATER SUPPLY DURING THE FIRST PERIOD ON LOESS SOIL.

The water content of the loess soil was maintained at a minimum during the first period but varied during the second period. On Feb. 3 the growth of tops was uniform in all the pots. The change in water content was changed on Feb. 3 and, in the pots receiving optimum and maximum water the plants began to grow more rapidly than those in the pots receiving minimum water. The growth of all the plants in the loess soil was checked near the end of the second period, probably due to a lack of plant food. The leaves began to turn yellow regardless of the treatment received. This indicated a lack of nitrogen as the plants in the silt loam, which received the same treatment, had a dark green color. This indicates that the ability of loess to produce good crops is due to the physical conditions in the soil rather than to the plant food present. The structure and texture of the loess favors the movement of soil water so the plant is more certain of a plentiful supply of water and of the nutrients dissolved therein than is the case in a soil with finer texture.

The weight of the roots and tops from the pots containing loess with varying water contents during the second period following constant minimum water content during the first period are reported in Table V.

(See next page for table)

TABLE V.

Water content of soil	Main roots.	Branch roots.	Total roots	Tops.
Minimum	2.15g	5.67g	7.82g	23.20g
"	3.00	5.22	8.22	23.90
"	2.60	6.98	9.58	26.20
Optimum	2.60	5.00	7.60	36.05
"	2.65	6.11	8.76	32.15
"	2.68	7.95	10.63	31.65
Maximum	1.98	3.52	5.50	37.70
"	2.58	5.78	8.36	34.30
"	2.85	6.49	9.34	36.25

The lowest weight of main roots was in one of the pots with maximum water. The same pot also had the lowest weight of branch roots but the highest weight of tops. In the pots with optimum water there was little variation in the mass of main roots. The branch roots showed greater variation but the pot with the greatest amount of main roots also had the greatest amount of branch roots and the pot with the least amount of main roots had the least amount of branch roots. On the other hand the greatest mass of tops was found with the least mass of roots and the least mass of tops with the greatest mass of roots. The variations in the pots with minimum water were less regular.

A glance at Table VI will show the relation between the main roots and branch roots and between the total roots and the tops in the individual pots.

Plate III.

Growth of Maize in Loess Soil with Varying Water Contents,
at the End of Second Period.

No. of pot.	Water 1st Per.	Content. 2d Per.
4.	Minimum	Minimum
5.	"	Optimum
6.	"	Maximum
7.	Optimum	Minimum
8.	"	Optimum.
9.	"	Maximum
10.	Maximum	Minimum
11.	"	Optimum
12.	"	Maximum

TABLE VI.

Water content of soil 2d period.	Ratio of main roots to branch roots.	Ratio of total roots to tops.
Minimum	1:2.64	1:2.97
"	1:1.74	1:2.91
"	1:2.68	1:2.73
Optimum	1:1.92	1:4.74
"	1:2.51	1:3.67
"	1:2.91	1:2.88
Maximum	1:1.78	1:6.85
"	1:2.24	1:4.10
"	1:2.28	1:3.86

The average weights of the main roots and branch roots and of the tops, and the ratios between the average weights of main and branch roots and of the total roots and tops will give a better idea of the effect of varying water content during the second period following a constant minimum water supply during the first period. The average weights of main and branch roots and of tops are reported in Table VII. Table VIII gives the ratios between the average weights of main and branch roots and between the average weights of total roots and tops.

TABLE VII.

Water content of soil	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	2.58g	5.96g.	8.54g	24.43
Optimum	2.64	6.35	9.00	33.28
Maximum	2.47	5.26	7.73	36.08

PLATE IV.

Root Development of Maize in Loess Soil with Varying Water Contents, at the End of Second Period.

No.	Water Content of Soil.	
	1st Period.	2d Period.
4.	Minimum	Minimum
5.	Minimum	Optimum
6.	Minimum	Maximum

TABLE VIII.

Water Content of soil	Ratio of main roots to branch roots.	Ratio of total roots to tops.
Minimum	1:2.31	1:2.74
Optimum	1:2.41	1:3.70
Maximum	1:2.13	1:4.67

A change to optimum water during the second period increased the development of both main and branch roots but the branch roots increased much more than the main roots as will be seen by referring to Table VIII. A change to maximum water decreased the formation of both main roots and branch roots but the decrease was greater in the case of the branch roots. The greatest weight of main roots and also of branch roots was in the pots with optimum water and the least weights of both main and branch roots were in the pots with maximum water. This is the reverse of what was found during the first period. It would seem then that a high amount of water is favorable to the development of roots, especially main roots, during the first period, but that a moderate amount is more favorable during the second period.

The weight of tops varied directly with the amount of water applied during the second period. The maximum water produced the greatest mass of tops per unit of total root and the minimum water the least.

EFFECT OF VARYING WATER CONTENTS DURING THE SECOND PERIOD
FOLLOWING CONSTANT OPTIMUM WATER CONTENT DURING THE FIRST PERIOD
ON LOESS SOIL.

The change from optimum water content to minimum water

PLATE V.

Root Development of Maize in Loess Soil with Varying Water Contents at the End of the Second Period.

Number	Water Content.	
	1st period	2d period
7	Optimum	Minimum
8	Optimum	Optimum
9	Optimum	Maximum

content decreased the formation of main roots but increased the formation of branch roots. The change from optimum to maximum retarded the development of both main roots and secondary roots. The development of tops was retarded by the change to maximum as well as the change to minimum. This is shown clearly in Table IX which gives the weights of main and branch roots and tops from the pots receiving varying amounts of water during the second period following constant optimum water during the first period.

TABLE IX.

Water content of soil	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	2.17g	5.46g	7.63g	35.25g
"	2.59	5.81	8.40	34.30
"	2.73	6.25	8.98	37.20
Optimum	2.40	4.70	7.10	51.15
"	3.28	5.15	8.43	51.85
"	3.20	6.07	9.27	39.15
Maximum	2.45	3.67	6.12	46.75
"	2.58	4.80	7.38	42.45
"	2.95	7.16	10.11	44.15

The pot giving the lowest weight of main roots received minimum water, the highest was from one of those receiving optimum water. Both the highest and lowest weights of branch roots were from pots receiving maximum water. The highest weight of branch roots was associated with a high weight of main roots but the branch roots were relatively much higher as will be seen by referring to Table X which gives the ratio of main to branch roots and of total roots to tops in the individual pots.

TABLE X.

Water content of soil	Ratio of main roots to branch roots	Ratio of total roots to tops.
Minimum	1:2.41	1:4.62
"	1:2.24	1:4.08
"	1:2.29	1:4.14
Optimum	1:1.96	1:7.20
"	1:1.57	1:6.14
"	1:1.90	1:4.22
Maximum	1:1.50	1:7.64
"	1:1.86	1:5.75
"	1:2.46	1:4.37

The individual pots with minimum water show considerable variation in the mass of both main roots and branch roots but the variations are in the same proportion so the amounts of branch roots to one unit of main roots do not differ greatly. The variation is greater in the pots with optimum water and still greater in the pots with maximum water. This is due to the exceedingly large mass of branch roots previously mentioned. The pots with maximum water also show considerable variation in the ratios of total roots to tops. The same is true of the pots receiving optimum water.

The average weights of roots and tops produced by varying water contents during the second period following constant optimum water during the first period are shown in Table XI and the ratios of the averages in Table XII.

TABLE XI.

Water content of soil.	Main roots.	Branch roots.	Total Roots	Tops
Minimum	2.50g	5.87g	8.34g	35.58g
Optimum	2.96	5.31	8.27	47.72
Maximum	2.66	5.21	7.87	44.75

TABLE XII.

Water content of soil	Ratio of main roots to branch roots	Ratio of total roots to tops
Minimum	1:2.34	1:4.27
Optimum	1:1.79	1:5.77
Maximum	1:1.96	1:5.69

The total weight of fine roots and of total roots are inversely as the amount of water applied, but the weight of main roots is greatest with optimum and least with minimum water. This indicates that a change from optimum to maximum, as well as a change from optimum to minimum, retards the development of main roots. This retardation is relatively less for maximum than for minimum water content.

The average weight of tops is greatest with optimum water. The change to maximum water seems to have a harmful influence on top growth.

THE EFFECT OF VARYING WATER CONTENTS DURING THE SECOND PERIOD FOLLOWING MAXIMUM WATER DURING FIRST PERIOD.

The best growth of tops was with the maximum water content as in the case where minimum water was followed by varying water content. This would seem to show that a constant high water content is not ^{so} injurious as a change from a lower to a very high water content, as was the result with maximum water

PLATE VI.

Root Development of Maize in Loess Soil with Varying Water
Contents at the End of the Second Period.

Number	Water Content.	
	1st period	2d period.
10	Maximum	Minimum
11	Maximum	Optimum
12	Maximum	Maximum

following optimum water.

We see by referring to Table XIII, that there is wide variation in the weight of main roots in pots with the same water content. The highest weight of main roots was in one of the pots with maximum water both periods. the next highest in one of the pots with minimum water the second period. The two lowest weights of main roots were in pots with minimum water the second period. There were also wide variations in the weight of branch roots.

Table XIII gives the weights of roots and tops in all the pots with varying water content during the second period following maximum water during first period.

TABLE XIII

Water content of soil	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	1.71g	5.02g	6.73g	32.95g
"	1.90	6.07	7.97	33.60
"	3.13	5.47	8.60	36.85
Optimum	1.98	3.76	5.74	50.45
"	2.40	4.24	6.64	46.90
"	3.05	6.88	9.93	46.00
Maximum	2.77	3.56	6.33	54.70
"	2.52	4.60	7.12	44.00
"	3.61	6.49	10.10	47.50

The relations between the main roots and branch roots and between the total roots and tops are brought out more clearly in Table XIV. There is considerable variation in the ratio of main roots to branch roots, as well as in the ratio of total roots to tops, in pots receiving the same treatment.

TABLE XIV.

Water content.	Ratio of main roots to branch roots	Ratio of total roots to tops
Minimum	1:2.94	1:4.90
"	1:3.19	1:4.34
"	1:1.75	1:4.28
Optimum	1:1.90	1:8.79
"	1:1.77	1:7.06
"	1:2.22	1:4.62
Maximum	1:1.29	1:8.64
"	1:1.83	1:6.16
"	1:1.80	1:4.73

A better idea can be obtained of the effect of varying water during the second period if the averages are compared. The average weights of roots and tops as given in Table XV and the ratios of the averages in Table XVI.

TABLE XV.

Water content.	Main roots.	Branch roots.	Total Roots.	Tops.
Minimum	2.25g.	5.52g	7.77g	34.47g
Optimum	2.48	4.96	7.44	47.78
Maximum	2.97	4.88	7.85	48.73

TABLE XVI.

Water content.	Ratio of main roots to branch roots	Ration of total roots to tops.
Minimum	1:2.45	1:4.56
Optimum	1:2.00	1:6.42
Maximum	1:1.64	1:6.20

The mass of main roots vary directly, the mass of branch roots inversely, with the water content of soil during the second period. A change from maximum to a lower water content retards the development of main roots but accelerates the formation of branch roots. But the change to optimum water seems to retard the formation of main roots much more than it accelerates the formation of branch roots. This probably accounts for the lowest total weight of roots with optimum water. Maximum water during both periods gave practically the same weight of main roots as optimum water during both periods. This indicates that constant optimum water is just as favorable to the development of main roots as constant maximum water but the constant optimum water is more favorable to the development of branch roots. The weight of top is only slightly greater with the constant maximum water.

EFFECT OF VARYING WATER CONTENT DURING FIRST PERIOD WHEN FOLLOWED BY MINIMUM WATER IN LOESS SOIL.

It was observed that, at the end of the first period maximum water gave the greatest amount of main roots and minimum water the greatest amount of branch roots and that the least weight of both main and branch roots was produced with optimum water. When pots which had received minimum, optimum, and maximum water during the first period were all given minimum water during the second period, some interesting results were observed. Table XVII gives the average weights of roots and tops from pots which receive minimum water the second period following varying water content during the first period.

TABLE XVII.

Water content 1st per.	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	2.58g	5.96g	8.54g	24.43
Optimum	2.50	5.84	8.34	35.58
Maximum	2.25	5.52	7.77	34.47

The growth of the main roots is checked by a change from optimum or maximum to minimum water and the greater the change the more growth is retarded. The mass of branch roots is inversely proportional to the water content during the first period. The ratio of branch roots to main roots is greatest with maximum water during the first period and least with minimum water during the first period. This shows that the change from maximum to minimum caused a relatively greater development than the change from optimum to minimum water. These ratios are shown in Table XVIII.

TABLE XVIII.

Water content. 1st per.	Ration of main roots to branch roots	Ration of total roots to tops.
Minimum	1:2.31	1:2.74
Optimum	1:2.34	1:4.27
Maximum	1:2.45	1:4.56

The greatest amount of tops per unit of total root was with maximum water. The weight of top was slightly greater with optimum water first period but the total root weight was so much greater with optimum than with maximum water the first period that the ratio of top to root was greater with the maximum.

EFFECT OF VARYING WATER CONTENT DURING THE FIRST PERIOD
WHEN FOLLOWED BY OPTIMUM WATER CONTENT IN LOESS SOIL.

It is seen, by referring to Table XIX, that optimum water during both periods gave more weight of main roots than either minimum or maximum followed by optimum water but the weight of branch roots was inversely proportional to the water content during the first period. The weights of roots and tops with varying water content first period followed by optimum water second period are given in Table XIX.

TABLE XIX.

Water content 1st per.	Main roots.	Branch Roots.	Total Roots.	Tops.
Minimum	2.64g	6.55g	9.00g	33.28g
Optimum	2.96	5.31	8.27	47.72
Maximum	2.48	4.96	7.44	47.78

The ratios are reported in Table XX.

Water content 1st per.	Ratio of main roots to branch roots	Ratio of total roots to tops.
Minimum	1:2.41	1:3.70
Optimum	1:1.79	1:5.77
Maximum	1:2.00	1:6.42

Maximum followed by optimum water gave slightly larger tops than optimum both periods but the small development of roots in the former made the ratio of tops to roots much larger.

EFFECT OF VARYING WATER CONTENT DURING THE FIRST PERIOD
FOLLOWED BY MAXIMUM WATER CONTENT DURING THE SECOND PERIOD IN
LOESS SOIL.

Table XXI shows the average weights of roots and tops obtained when varying water content during the first period was followed by Maximum water during the second period. Table XXII

gives the ratios of those averages.

TABLE XXI.

Water content. 1st per.	Main roots.	Branch roots.	Total roots	Tops.
Minimum	2.47g	5.26g	7.73g	36.08g
Optimum	2.66	5.21	7.87	44.75
Maximum	2.97	4.88	7.85	48.73

TABLE XXII.

Water content 1st per.	Ratio of main roots to branch roots	Ratio of total roots to tops.
Minimum	1:2.13	1:4.67
Optimum	1:1.96	1:5.69
Maximum	1:1.64	1:6.20

Changing the water content from maximum to optimum or minimum checked the development of main roots but accelerates the production of branch roots. The growth of tops is decreased especially with the change to minimum water.

EFFECT OF VARYING WATER CONTENT OF UPLAND SILT LOAM DURING FIRST AND SECOND PERIODS.

On the silt loam maize made as good a growth with maximum water as with optimum water until Feb. 21. At this time the growth was so rapid and transpiration was so great that the water content was made up twice a week instead of weekly as before. In two of the pots with maximum water the plants did not seem to be using water as rapidly as in the other pot. The soil did not dry out between waterings and so it was kept constantly full of water. In the other pot the water was used

rapidly, the surface of the soil dried out between watering and the growth was about as rapid as in the pots ^{with} optimum water. When the pots were washed out and the weights of roots and tops determined, it was found that this pot gave a large web of healthy roots. The weight of branch roots was less than in any of the pots with optimum water and the weight of main roots was exceeded in only one of the pots with optimum water.

The other two pots with maximum water gave a much smaller mass of main roots and a very small weight of branch roots. The roots were blackened and unhealthy looking. The weight of branch roots was so small that it seems quite probable that a large part of them rotted and were lost. The variation in top growth is in the same proportion as the variation in main roots. Table XXIII gives the weights of roots and tops from the pots containing silt loam and receiving varying amounts of water during the first and second period.

TABLE XXIII.

Water content	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	2.08g	4.92g	7.00g	43.10g
"	2.33	4.78	7.11	43.85
"	3.34	6.03	9.37	49.50
Optimum	7.38	11.85	19.23	103.00
"	6.28	11.02	17.30	87.20
"	8.20	13.31	21.51	90.55
Maximum	3.66	1.93	5.59	48.30
"	3.38	1.01	4.39	41.85
"	7.39	9.51	16.90	86.55
"				

We obtain a better idea of the relation between the main and branch roots and between total roots and tops if we compare the ratios as given in Table XXIV.

Table XXIV.

Water content	Ratio of main roots to branch roots	Ratio of total roots to tops
Minimum	1:2.32	1:6.16
"	1:2.05	1:6.17
"	1:1.81	1:5.28
Optimum	1:1.68	1:5.35
"	1:1.75	1:5.04
"	1:1.62	1:4.21
Maximum	1:0.53	1:8.64
"	1:0.30	1:9.53
"	1:1.29	1:5.12

The highest amount of branch roots is in the minimum water and, except for the pots in which the plants were injured by too much water, the highest amount of tops per unit of total root was found in the pots with minimum water. The average weights of roots, and tops and the ratios of these averages bring this out more clearly. The average weights and the ratios of the averages are reported in Tables XXV and XXVI respectively. The single pot, in which the plants grew normally, is probably a better representation of the effect of maximum water on root development than the average of the normal and the two abnormal ones. Therefore the results of the single pot are given for the maximum instead of the average.

TABLE XXV.

Water Content	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	2.58g	5.24g	7.83g	45.48g
Optimum	7.29	12.06	19.35	93.58
Maximum	7.39	9.51	16.90	86.55

TABLE XXVI.

Water Content.	Ratio of main roots to branch roots	Ratio of total roots to tops.
Minimum	1:2.03	1:5.81
Optimum	1:1.65	1:4.83
Maximum	1:1.29	1:5.12

The largest weight of main roots is with the maximum water, the largest weight of branch roots and largest weight of total roots are with the optimum. The minimum gave the lowest weight of main roots, of branch roots, of total roots, and of tops. The weight of branch roots per unit of main roots is greatest in the minimum, least in the maximum. The optimum water caused an enormous acceleration of both roots and tops but relatively more acceleration of roots than of tops so the optimum gave the least weight of top per unit of total root. The minimum gave the greatest weight of top per unit of total root. This is quite different from the results obtained with loess. In all cases with loess, minimum water gave the least top per unit of total root. This will be considered more fully later.

EFFECT OF VARYING WATER CONTENTS IN CLAY SOIL DURING THE FIRST AND SECOND PERIODS.

This part of the experiment was set up to show the effect of root development of maize in clay soil with varying water contents. But the clay used was so deficient in organic matter and nitrogen that it is difficult to determine how much of the effect was due to water content and how much due to nitrogen starvation. The water contents for optimum and maximum were made too high and the plants were injured before it was observed. The clay apparently formed such a compact mass that air and water moved very slowly through the pore spaces. There was some air in the soil before the water was applied and a small amount was probably added along with the water. In all the pots containing loess and in most of the pots containing silt loam, the water sank into the soil soon after it was applied and the top of the soil dried out before the addition of more water. When more water was added it carried some of the air down into the soil and kept the soil properly aired. In the clay soil the water sank in much slower so there was less opportunity for the air to penetrate the soil than was possible in the silt loam which was maintained at a higher water content. That the exclusion of air caused the injury seems probable for in the three pots with silt loam which were kept at a maximum water content the two in which the plants were injured failed to dry out on the surface between waterings while the other, although maintained at the same water content, had a dry surface each time it was watered. The first two were too wet for the air to penetrate and the roots were abnormal. The

other dried out sufficiently to let in some air and the plants developed normally. This saturated condition in the silt loam was not observed until the middle of February. Up to this time they presented ^eas good growth of maize as the pot in which the growth was normal until harvested.

When the tops of the maize in the clay with optimum and maximum water showed signs of injury the water content was lowered but the injury had already been done and the plants failed to recover. This accounts for the greatest development in tops and roots being found in the pots with minimum water. The experimental results are given in Table XXVII.

TABLE XXVII.

Water content.	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	2.25g	3.40g	5.62g	28.85g
"	2.60	3.96	6.56	27.65
"	2.42	4.28	6.70	22.65
Optimum	0.79	0.45	1.24	14.25
"	1.05	2.12	3.17	15.70
"	0.80	1.12	1.92	8.60
Maximum	0.65	0.23	0.88	5.60
"	0.48	0.05	0.53	5.10
"	0.45	0.29	0.74	4.95

We see a relatively low development of branch roots. In some cases the weight of branch roots is less than the weight of main roots. In one instance clay with maximum water gave an almost negligible quantity of branch roots. Two of the pots, containing silt loam and receiving maximum water, also

gave a lower weight of branch roots than main roots. In both cases this was apparently due to the destruction of roots already formed as well as to the inhibition of further root development. A large part of the branch roots seemed to be so completely disintegrated that the screen would not retain them. The roots that were sound were blackened and corroded. It is interesting to compare the appearance of these roots with the roots of the blighted rice plant. Collier⁶ says: "After the sixth week, if the water has been on continuously and not moving, there is a strong indication of a suberization; that is, a thin layer of cork is formed in the outer layer of the root, that gives a yellowish color to the root in comparison to the normal root. In the strongly suberized roots, the interior structure is broken down completely after the eighth week; while if aerated about the fifth week, the roots seem to take a new hold and grow longer; in some cases the stock will put out new roots".

In Table XXVIII are shown the ratios of main roots to branch roots and total roots to tops. It will be seen that the variations are great.

TABLE XXVIII.

Water content.	Ratio of main roots to branch roots	Ratio of total roots to tops
Minimum	1:1.53	1:5.13
"	1:1.52	1:4.24
"	1:1.77	1:3.40
Optimum	1:0.57	1:11.50
"	1:2.02	1:4.95
"	1:1.40	1:4.48

TABLE XXVIII. (Continued)

Water content.	Ratio of main roots to branch roots	Ratio of total roots to tops
Maximum	1:0.35	1:6.36
"	1:0.10	1:9.64
"	1:0.64	1:6.70

The average weights of roots and tops are reported in Table XXIX and the ratios of the averages in Table XXX.

TABLE XXIX.

Water content.	Main roots.	Branch roots.	Total roots.	Tops.
Minimum	2.41g	3.88g	6.29g	26.38g
Optimum	0.88	1.23	2.11	12.85
Maximum	0.53	0.19	0.72	5.22

TABLE XXX.

Water content.	Ratio of main roots to branch roots	Ratio of total roots to tops
Minimum	1:1.61	1:4.19
Optimum	1:1.40	1:6.09
Maximum	1:0.36	1:7.25

THE EFFECT OF SOIL TEXTURE ON ROOT DEVELOPMENT WITH MINIMUM, OPTIMUM, AND MAXIMUM WATER CONTENTS DURING FIRST AND SECOND PERIODS.

The soils compared were loess, upland silt loam, and clay. The water content remained the same through both periods. The complete results for individual pots are reported in previous tables so the averages only will be given. Table XXXI gives results with minimum water content.

PLATE VII.

Root Development of Maize in Loess Soil with Varying Water Contents at the End of the Second Period.

Number	Water Content.	
	1st period	2d period
4	Minimum	Minimum
8	Optimum	Optimum
12	Maximum	Maximum

TABLE VIII.

Growth of Maize in Silt Loam and Clay with Varying Water Contents at the End of the Second Period.

Silt Loam, no.	Water Content.	
	1st period.	2d period.
13	Minimum	Minimum
14	Optimum	Optimum
15	Maximum	Maximum
Clay		
16	Minimum	Minimum
17	Optimum	Optimum
18	Maximum	Maximum

PLATE IX.

Root Development of Maize in Silt Loam with Varying Water Content at the End of the Second Period.

Number	Water Content.	
	1st period	2d period
13	Minimum	Minimum
14	Optimum	Optimum
15	Maximum	Maximum

PLATE X.

Root Development of Maize in Clay with Varying Water Contents
at the End of the Second Period.

Number.	Water Content.	
	1st period	2d period
16	Minimum	Minimum
17	Optimum	Optimum
18	Maximum	Maximum

TABLE XXXI.

Soil used.	Main roots.	Branch roots.	Total roots.	Tops.
Loess	2.58g	5.96g	8.54g	24.43g
Silt Loam	2.58	5.24	7.83	45.48
Clay	2.41	3.88	6.29	26.38

Loess and silt loam had the same weight of main roots but the loess had the most branch roots. Clay gave the best main roots and the branch roots. Silt loam gave the highest weight of tops; loess gave the lowest weight. This was rather surprising as the maize in the clay showed signs of nitrogen starvation almost from the beginning of the experiment. The relations between formation of main roots and branch roots and between total roots and tops is shown in Table XXXII. Loess gave the greatest amount of branch roots to main roots and clay the least. Silt loam gave the greatest weight of tops per unit of total roots and loess the least.

TABLE XXXII.

Soil used.	Minimum wafer content.	
	Ratio of main roots to branch roots	Ratio of total roots to tops.
Loess	1:2.31	1:2.74
Silt Loam	1:2.03	1:5.81
Clay	1:1.61	1:4.19

With optimum water control the greatest weight of main roots, branch roots, and tops was in the silt loam. The clay gave the lowest weight of both main and branch roots and of tops but the results can hardly be compared with the loess and Silt loam because of the injury caused by the clay becoming

waterlogged. Although silt loam gave the highest absolute weights of main roots, branch roots, and tops, the ratios of branch roots to main roots and of tops to total roots were higher in the loess. These are shown in Tables XXXIII and XXXIV.

TABLE XXXIII.

Soil used.	Main roots	Branch roots.	Total roots.	Tops.
Loess	2.96g	5.31g	8.27g	47.72g
Silt Loam	7.29	12.06	19.35	93.58
Clay	0.88	1.23	2.11	12.85

TABLE XXXIV.

Optimum water content.

Soil used.	Ratio of main roots to branch roots	Ratio of total roots to tops
Loess	1:1.79	1:5.77
Silt Loam	1:1.65	1:4.83
Clay	1:1.40	1:6.09

With maximum water content the silt loam gave the greatest weight of main roots, branch roots, and tops but the loess gave a greater amount of branch roots to main roots and the silt loam a greater amount of tops to total roots. These results are shown in Tables XXXV and XXXVI. In the silt loam the results are for the single pot with normal plants. The results in Clay are given but no conclusions can be drawn from them.

TABLE XXXV.

Soil used	Maximum water content.			
	Main roots.	Branch roots.	Total Roots.	Tops.
Loess	2.97g	4.88g	7.85g	48.73g
Silt loam	7.39	9.51	16.90	86.55
Clay	0.53	0.19	0.72	5.22

TABLE XXXVI.

Soil used.	Maximum water content.	
	Ratio of main roots to branch roots	Ratio of total roots to tops
Loess	1:1.64	1:6.20
Silt loam	1:1.29	1:5.12
Clay	1:0.36	1:7.25

In all degrees of water content loess gave a relatively greater formation of branch roots. The clay can not be considered except with minimum water. This gave relatively the least branch roots. Loess gave greater relative weight of top than the silt loam except with the minimum water content. It is impossible to tell how much of this is due to a difference in soil texture and how much to a difference in fertility of the two soils.

EXPERIMENT II.

EFFECT OF NUTRIENT SUPPLY ON ROOT DEVELOPMENT IN MAIZE.

Plan of the Experiment.

The experiment on the effect of nutrient supply on root development was carried out with maize grown in 4 gallon stone jars containing coarse river sand. Six pots were used, three were watered with a nutrient solution and three with distilled water. Three stock solutions were made as follows:

200gCa NO ₃	} dissolved in distilled water and made up to ^{two} 1 liters.
65 KNO ₃	
30 NaCl	

50 Mg SO₄ dissolved in distilled water and made up to two liters.

50 KH₂ PO₄ dissolved in distilled water and made up to two liters.

Equal quantities of the three stock solutions were mixed and diluted before applying.

Method of Procedure.

The pots were filled with sand on April 11 and eight kernels of maize planted in each pot. The plants came up on April 16 and were then thinned down to four plants per pot. The sand was saturated with tap water at the time the pots were filled. This was allowed to drain away through small openings in the bottoms of the pots. On April 18th three of the pots were watered with 1 litre of distilled water per pot. Each of the others received 1 litre of nutrient solution made by mixing 30 c c from each of the stock solutions and diluting to 1 litre. This treatment was repeated on April 26, the check pots receiving distilled water and the fertilized pots nutrient solutions as before.

On May 6 the tops were cut and the roots washed out. An attempt was made to divide the sand into layers and determine the weight of roots in each layer separately. The sand fell apart so easily that it was impossible to make the division at the same place each time. It was ~~discovered~~ however that practically all the roots were in the tops six inches regardless of the treatment and most of them were in the top four inches. The tops and roots were oven dried and weighed. The roots were then burned and the weight of the sand which remained deducted from the over dry weights.

Experimental Results.

The oven dry weights of tops and the corrected weights of roots are given in Table XXXVII.

(see next page)

TABLE XXXVII.

Treatment	Weight of Roots.	Weight of tops.	Ratio of roots to tops
No nutrients	0.428g	0.475g	1:1.11
" "	0.487	0.508	1:1.04
" "	0.475	0.520	1:1.09
Average	0.463	0.501	1:1.08
Full nutrients	0.580	2.290	1:6.03
" "	0.473	1.111	1:2.35
" "	0.413	2.180	1:5.28
Average	0.482	1.860	1:4.41

The individual pots without nutrients do not differ widely in either root or top growth. The pots with nutrients show greater variation. One had an unusually low weight of Roots. The same pot had the greatest weight of tops so the ratio is very high. The highest weight of roots and lowest weight of tops from the treated pots were from the same pot. This makes the ratio unusually low but it is much higher than from any of the untreated pots. The best growth of roots with nutrients was less than the growth in two of the pots without nutrients. The poorest growth of tops with nutrients was twice as great as the best growth in the pots without nutrients. The averages show the greatest top growth with nutrients and the greatest growth of roots without nutrients. This indicates that the presence of soluble nutrients stimulates top growth but retards root growth. This corresponds with the work of Polle¹² with wheat. He found that the unfertilized wheat always produced the largest mass of roots. With barley his results were more irregular. This decrease of root formation when fertilizer is applied probably holds

only in the early stages of growth for Tucker and von Seelhorst⁷ found in most cases an increase of root development for the application of fertilizer when oats were grown till the end of the growing period. The plant seems to form roots only when needed. In early stages of growth a large root system is not necessary in a soil which contains a liberal supply of soluble nutrients. In later stages of growth, when the plant's demands become greater, a large root system is necessary in order to obtain sufficient nutrients even in a rich soil.

Summary.

The best growth of plant tops was obtained in silt loam with optimum water content, the next best in silt loam with maximum water. The best growth in Loess was with maximum water both periods. Maximum followed by optimum, and optimum both periods, were but slightly less. A change from optimum to maximum decreased the growth of tops. A change from minimum to either optimum or maximum increased the growth of tops.

The clay soil could not be accurately compared with the other soils, except in the pots with minimum water, for the plants in the clay with optimum and maximum water were injured by too much water. This injury seemed to be due rather to the exclusion of the air than to any direct action of the water. Both roots and tops were injured but the roots seemed to be injured first.

Minimum water during both periods produced the greatest absolute weight of roots in loess and the greatest relative weight in silt loam. Maximum water during both periods produced the least absolute weight of roots in loess and the least relative weight in silt loam. The increase of total roots for

low water content is due to the increase of branch roots. Deficiency of water seems to stimulate the production of a fine root web reaching to all the particles that carry a film of moisture.

A change to lower water content increased the development of branch roots. This may account for the decrease in the formation of tops and main roots. The plant seems to be in a state of equilibrium and it has provided a root system for obtaining, as nearly as possible, the amount of water needed by the plant. A sudden decrease in water content disturbs this equilibrium and the plant must provide a larger root system to obtain the necessary water. Therefore it seems probable that the plant diverts all its energies to the formation of more branch roots. These branch roots penetrate to all parts of the soil, come into close contact with the soil particles, and rob them of their film of moisture. An increase in water supply makes it possible for the plant to obtain an increased supply of water without increasing its root system and the root growth is checked and more energy thrown into the development of tops.

There seems to be a slight injury from an increase of water content. This is apparent only in the change from optimum to maximum water content. The development of tops and main roots was diminished as well as the formation of branch roots.

The comparatively low weight of roots in some of the pots with minimum water may be due to the limited space for root development and the method of watering. The water was applied at the surface and the greatest mass of roots was near the surface. If the plant had had a larger volume of soil and the

moisture had been more evenly distributed, low water content might have produced a much larger root web.

The highest relative production of roots was in the loess soil. This indicates that an open structure or coarse texture favors the formation of a large root web. The lack of plant food in the loess makes the results a little doubtful as the deficiency of plant food may have had more effect than the soil texture.

The application of full nutrient solution to maize grown in sand increased the production of tops but decreased the formation of roots during the early stages of growth. The plant seems to develop roots ^{early} only as they are needed and, with a rich supply of nutrients, the plant's needs are supplied by a small root system.

It can be said in general by way of conclusion that low water content seems to divert the plant's energies from top growth to root formation.

In the field condition the water content is ^avariable, not a constant. Too much variation, especially from a low to a high water content, seems to disturb the plant's equilibrium and delay growth. It seems therefore that the best field condition is when the mean is an optimum and the variations above and below are not too great.

The production of tops and main roots appears to vary directly and the formation of fine branch roots inversely with the water content of soil. An optimum water content seems to favor a relatively high production of main roots, branch roots, and tops.

The presence of a large supply of soluble nutrients in the soil seems to stimulate the growth of tops and retard the formation of roots of maize during the early stages of growth.

DUE	RETURNED
OCT 28 1972	OCT 16 1972
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