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THE EFFECT OF A VARYING MOISTURE SUPPLY UPON THE DEVELOPMENT AND COMPOSITION OF THE MAIZE PLANT AT DIFFERENT PERIODS OF GROWTH

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Abstract.—Corn was grown in fertile soil in large potometers, with varying amounts of moisture during three different periods of growth. Optimum (28 per cent) and minimum (13 per cent) moisture treatments were supplied to the crop in all possible combinations with the three periods of growth. The moisture supply during the second period, or from the time the plants set their ninth leaves until about tasseling time, had by far the greatest effect upon the total dry weights of the plants. Plants stunted by minimum moisture during the first period were able to recover and produce good plants if conditions were favorable during the last two periods, but the time for maturing was somewhat prolonged. Minimum moisture during the third period gave a greater weight of root growth than optimum moisture. In all periods minimum moisture gave a greater root growth in proportion to tops than did optimum even though the actual weight was less during early growth. Optimum moisture during the third period gave considerably greater production of grain than did the low soil moisture content. The amount of water transpired per unit of dry matter produced, varied greatly during the different years due to variation in the climatic conditions. The variation in the transpiration ratio between different treatments was not great, but was slightly less with low soil moisture. Chemical analyses showed that in practically all cases the maize plants contained a higher per cent of nitrogen and mineral elements where the moisture content of the soil was low.

The amount of water transpired in the production of a given amount of dry matter in different crops has been the subject of much study during the past twenty years. Most of this investigation has been carried on in the arid and semi-arid regions of the West, where irrigation is commonly practiced. In only a few cases, however, has the water used during different periods in the life of the plant been determined. The investigation here reported was devised to study under humid conditions, the effect both of a copious and of a meager supply of water upon the growth and water transpired by the maize plant at different periods in its growth, as well as to find what effect early and late drought would have upon the final yields of grain and stover. On two crops, 1916 and 1919, chemical analyses were made in order to determine the effect of the supply of water upon the composition of the crop.

From a practical standpoint this work may have a direct bearing upon the date of planting corn, the selection of varieties maturing in the proper length of time, and the probable composition of the crop after it is produced.

These experiments were first undertaken in 1913, but this first year and the year 1914 were largely used in improving the technique of management so that the results are not included in this report.* During 1917 and 1918 the work was discontinued because of the war, but it was taken up again during the season of 1919.

The analytical work was done by the Department of Agricultural Chemistry under the direction of Dr. C. R. Moulton and Dr. L. D. Haigh, to whom credit for this phase of the work is largely due.

REVIEW OF LITERATURE

No attempt has been made to review all the literature on this subject, since this has been done very thoroughly by Briggs and Shantz in Bureau of Plant Industry Bulletin 285 (1913). In this review will be included only such material as shows the factors affecting the transpiration from the maize plant or its relation to other crops.

Widstoe[15] made determinations of the water requirements of several crops at the Utah Station in 1901. In some of the plots corn was grown. The length of growing season was 147 days. The amount of water required to produce 1 pound of dry matter in corn varied from 276 to 1,087 pounds.

King[7] grew barley, oats and corn in 50 gallon barrels. The plants received the rainfall and in addition enough water to keep the barrels at nearly constant weight. Surface evaporation was not checked, but the loss was assumed to be slight. The water transpired per pound of dry matter were as follows:

	1891	1892
	pounds	*pounds*
Barley	401.74	375.21
Oats	501.47	525.59
Corn	301.49	238.22
Clover	------	564.43
Peas	------	477.37

Montgomery and Kiesselbach[12] at Nebraska reviewed some previous work carried on at that station in which it was found that the water loss from the plant was closely correlated with the loss from a free water surface, being increased or decreased by the same climatic factors.

Plants grown in a dry greenhouse showed a ratio of water used to dry weight of 340, while plants grown in a humid house showed a similar ratio of only 191. The effect of season was illustrated by the data for 1910 and 1911, the water transpired per pound of dry matter produced for corn being 250 the first year and 345 the second. The effect of fertility in lowering the water transpired by corn was shown by results

*A. R. Evans and J. C. Hackleman who were then members of the Department of Agronomy had charge of the details of this work during 1913 and 1914.

obtained in 1911. A summary of the data secured from 23 large pots containing soils of 6 degrees of fertility was as follows:

Kind of Soil	Grams of water used per gram of dry wt. of plant
Infertile soil	549.5
Infertile soil and manure	350.3
Intermediate soil	478.9
Intermediate soil and manure	341.3
Fertile soil	391.8
Fertile soil and manure	346.6

Briggs and Shantz[2] determined the water transpired by a large number of crops at Akron, Colo., in the central part of the Great Plains. The plants were grown in large galvanized iron pots holding about 115 kg. of soil. Rich surface soil which was also fertilized was used in growing the plants. The pots were weighed two or three times a week and watered so as to maintain them at approximately normal weight. They were placed inside a screened enclosure which was found to reduce the water transpired about 20 per cent. The average transpiration ratio of all the varieties of Zea Mays was 368. There was a range, however, from 315 for Esperanza, a Mexican variety, to 413 for China White. Bloody Butcher and Iowa Silvermine were also above 400.

The water transpired was found to be about 30 per cent higher in the similar seasons of 1911 and 1913 than in 1912. The season of 1912 was cooler and the evaporation and light intensity were much lower.

Kiesselbach[8] found that no more water was transpired by corn plants of the same parentage growing in wet soil than by those growing in much drier soil, provided it was not so dry that the plants wilted. With the soil containing the smaller amount of water somewhat less water was used in producing a given dry weight, but the decrease in yield was proportionately greater.

The root development was proportionately much greater in dry than in wet soil. Plants which make their early growth in dry soil may then be expected to better withstand a later period of drought because of an increased absorbing surface.

Kiesselbach and Montgomery[9] grew corn plants in large potometers with soil at different moisture contents. Optimum soil saturation for growth was from 60 to 80 per cent. The percentage of ear increased as the soil moisture content decreased down to 45 per cent of saturation.

The largest weight of ear was produced at 60 per cent and the greatest amount of dry matter at 80 per cent of saturation.

When the hourly fluctuation in evaporation of free water was compared with the transpiration of a corn plant, they were found to fluctuate in almost perfect accord. Evaporation exceeded transpiration toward the end of the season after the plants began to ripen. Transpiration for the 12 hours of the day was about thirteen times greater than for the 12 hours of night.

Leather[11] found that the exposure of jars to the sun had no appreciable effect upon the transpiration ratio. Small jars holding about 15 kilos of soil showed a higher ratio than larger jars containing 40 kilos of soil. Manure or fertilizer tended to decrease the transpiration ratio, or cause the plant to make a more economic use of the soil water. In fact anything that caused a greater development of the plants seemed to lower the ratio. The relative humidity had a marked effect on the transpiration. The transpiration from maize in July was shown to be about four times as great during 10 hours in the day as in 14 hours at night.

The amount of water used by the plants was found to rise rapidly when they began to make a larger growth and to remain high, excepting during wet weather, until near the time of maturity, when it fell rapidly.

The transpiration ratio for maize varied in 1918 from an average of 315 in the case of Akola soil treated with nitrogen and phosphorous to 678 in the soil without treatment.

Leather also conducted tests to determine the effect of the percentage of water in the soil upon the transpiration ratio. The results were not conclusive, partly because of imperfectly developed plants in the unmanured series. There were no very consistent differences in the ratio in soils having 10, 15 and 20 per cent water.

Kiesselbach[10] found the size of the potometer used to be a source of great error. Potometers 16 by 36 inches were thought to be of sufficient size for reliable data, even though larger pots gave a somewhat larger growth and lower the amount of water transpired.

The water transpired was only slightly affected by the exposure of the pots to the sun, and it was therefore decided that comparable results could be obtained from exposed pots.

The transpiration was found to vary with several climatic factors in much the same way as evaporation takes place. The average hourly transpiration during the night was only 7.5 per cent of the hourly day loss. The variation in loss from day to day was very great and several times varied 300 to 400 per cent in successive days, with a maximum of 600 per cent observed in two successive days.

The amount of water used by plants increased until the plants had developed their maximum leaf area. The four or five weeks following this are usually the hottest and driest of the season and about one-half the total water used was transpired during this period.

The transpiration ratio, varied greatly from year to year and there seemed to be no definite requirement for any one kind of crop.

A reduction in soil moisture below the optimum reduced the water transpired per pound total dry matter 7.9 per cent. This reduction, however, was accompanied by a 30.7 per cent lower yield of dry matter. With the soil moisture content above optimum there was an increase in water transpired of 8.2 per cent and a reduction in the yield of dry matter of 16.7 per cent.

Montgomery[13] found that the water transpired per square inch of leaf area increased with increase in soil moisture content, while the water used per gram of dry weight seemed to have an optimum percentage at a point where it is used most economically. The transpiration ratio was therefore increased when the soil water content was increased or decreased from this point. The following table shows the results bearing on this matter.

Percentage of saturation maintained	Water used per gm. dry wt.	Water used per sq. inch of leaf area
	grams	*grams*
100	290	97
80	262	97
60	239	88
45	229	56
35	252	33

Il'enkov[6] (reviewed by Briggs and Shantz[2]) did some of the first work in testing the effect of soil moisture upon the water requirement. Although his work was not very carefully controlled he secured about the same general results as later workers on this subject; that is, when the soil was very wet the water requirement was exceptionally high, while in very dry soil it was also higher than in the soils with a medium amount of water.

Harris[4] showed that corn, wheat, and peas growing a number of weeks in sand containing different amounts of moisture showed a proportionately greater root growth in the drier sand. In fact different roots of the same corn plant grown in very wet and in moist sand showed a greater root growth with the lower amount of water.

Wheat harvested at different stages showed relatively more roots during early stages of plant growth than later. Wheat grown to maturity showed a greater relative root growth with low than with high soil moisture, and the moisture during the early stages of growth had the greatest influence on that ratio. Fertilizers added to soil reduced the relative root growth of wheat.

Harris[5] used two moisture contents at different stages of growth in much the same manner as was used in the investigation reported in this bulletin. He worked with wheat and found the moisture at different periods to affect the plant very materially.

These data show that raising the soil moisture content during any period increased the yield of both grain and straw. The ratio of tops to roots was wider where the supply of moisture was abundant.

It was also found in this work that the percentage of nitrogen was highest in the plants grown on the driest soil. Nitrogen fertilizer increased the protein content of the plants. The percentage of nitrogen in the crop decreased from the boot stage to maturity, the decrease being greater in the tops than in the roots, and greater in the crops on the wet soil than in those on the dry.

The percentages of crude ash, calcium, magnesium, potassium, and phosphoric acid were lower in wheat straw grown with high moisture than in that grown with low moisture.

PLAN OF EXPERIMENT

In this experiment corn plants were grown in potometers 24 inches in diameter and 30 inches deep. These were filled with about 480 pounds of fairly fertile silt loam soil taken from alluvial bottom land on the University Farm. When made up to the proper moisture content the total weight of can and soil was approximately 675 pounds.

The galvanized iron potometers were coated inside with paraffin to prevent any possible effect of the zinc upon the roots. A coiled block tin watering tube with small holes at 6 inch intervals on the under side was placed in the potometer and the soil packed around it. On the upper end of the coil and on the outside of the potometer was placed a one-gallon can through which the watering was done. (See Fig. 4.) This was similar to one used by Montgomery[12].

The preliminary tests which were carried on during 1913 and 1914 determined the technique of handling the experiment. The first year the growing period was taken as 120 days, but this was found to be too long for Reid's yellow dent corn, the variety selected, and 90 days was used thereafter. The plan finally worked out was to divide the growing season into three 30-day periods. The first began at the time of planting. The second 30-day period usually began about the time the larger plants were setting their ninth leaves. The third period began at about the time the more advanced plants began to tassel, and ended 90 days after planting. At this time those having low amounts of water were drying up, but the other plants, and particularly those having high moisture during the last period, were relatively green.

METHOD OF TREATMENT

The plan of the experiment included 14 different treatments. The first eight treatments were run in duplicate, but the last six which included plants grown for only one or two periods, were not duplicated.

With two moisture contents and the growing season divided into three periods, all possible combinations of moisture content and period of growth were used.

The treatments are shown in the following table in which O (optimum) represents 28 per cent moisture and M (minimum) represents 13 per cent moisture, calculated on the dry weight of soil.

No. of Potometer	Treatment			
	1st 30-day period	2nd 30-day period	3rd 30-day period	
A 1 & B 1	O	O	O	Harvested at end of 90 days
A 2 & B 2	O	O	M	Harvested at end of 90 days
A 3 & B 3	O	M	O	Harvested at end of 90 days
A 4 & B 4	O	M	M	Harvested at end of 90 days
A 5 & B 5	M	M	M	Harvested at end of 90 days
A 6 & B 6	M	M	O	Harvested at end of 90 days
A 7 & B 7	M	O	M	Harvested at end of 90 days
A 8 & B 8	M	O	O	Harvested at end of 90 days
A 9	O	O	—	Harvested at end of 60 days
A 10	O	M	—	Harvested at end of 60 days
A 11	O	—	—	Harvested at end of 30 days
A 12	M	—	—	Harvested at end of 30 days
A 13	M	O	—	Harvested at end of 60 days
A 14	M	M	—	Harvested at end of 60 days

It was determined by preliminary tests that 28 per cent was optimum for the growth of corn on this soil and that 13 per cent was about as low as the moisture could be allowed to go and still keep the plants in reasonably healthy condition. The soil had a calculated wilting coefficient of 7.6.

In changing from one period to another it was of course easy to change from a low to high moisture content by adding water. The change from high to low moisture was much more difficult, since it was necessary to stop the addition of water and allow the plants to remove the excess down to 13 per cent. After the plants were well advanced it took only a few days to reduce this moisture to the proper percentage, but at the end of the first period it often took a large part of the second period. This meant that the plants did better during this time than if the moisture could have been removed at once. This of course corresponds to the slow removal of the stored moisture in the soil under actual field conditions.

METHOD OF PREPARING SOIL

It required about eight wagon loads of soil to fill all the potometers in this experiment. The soil was run through a sieve having ¼-inch mesh and was then piled on a large platform. It was turned three or four times with shovels until thoroughly mixed. It usually contained more than 20 per cent moisture at this time. All the potometers that were to be kept at optimum moisture during the first period were filled with this moist soil. Then with the smaller bulk of soil left, it was possible to spread this out and reduce the moisture content to approximately 13 per cent before filling the potometers that were to be kept at minimum moisture. In filling the potometers the soil was added a bucketful at a time, spread out and pressed down by hand. The same man did the filling in all cases and, after a little practice, it was possible to get a very uniform job of compacting. After the potometers were filled, the soil was brought up to the proper moisture content by the addition of water. Water from the University plant was used in this work. It contains considerable amounts of calcium and magnesium salts. Six to eight kernels of corn were planted in each potometer but early in the first period this number was reduced to three.

It was necessary to leave a 6-inch hole in the lids of the potometers, through which the plants could grow, and in order to lessen evaporation loss, a piece of oilcloth was placed immediately over the surface of the soil. This was left on and the hole in the lid remained open until during the second period when the plants extended well through it. At this time a piece of oilcloth was cut in such a way that it fit very well around the stalks and was then tied tightly over the opening in the lid. This oilcloth was then covered with modeling clay which was fitted tightly against each cornstalk. This practically eliminated evaporation from the soil and prevented water from flowing in during rains. During heavy winds it was difficult to keep the clay in close contact with the stalks, but this was reworked when necessary. During about the first fifty days the plants were covered with a large canvas during rains which prevented the water from entering the openings in the tops of the potometers.

The weighing of the potometers was done with a large steel-yard of 2,000 pounds capacity. This instrument was graduated to one-half pounds and when kept in good condition would break very readily with half-pounds or less. The potometers were weighed once each week, and brought up to the proper moisture content. When transpiration was very high, water was added two or three times between weighings, in order to keep the moisture content of the soil approximately uniform from day to day and prevent it from falling far below the proper amount.

RESULTS OF EXPERIMENTS

The plan of this experiment provided for harvesting the plants from certain potometers at the end of each period, all possible combinations of treatment being included. The plants were then divided into four parts (1) roots, (2) stalks, tassels, and shanks, (3) leaves, (4) ears. The average dry weights of the different parts of the plants for the 1915, 1916, and 1919 crops are shown in Table 1.

PLANTS GROWN FOR THREE PERIODS (90 Days)

It will be seen from a study of Table 1 and figures 1 and 6 that the supply of water during the second period of growth had a much greater effect upon the total production of dry matter than the moisture content at any other time. If No. 2 (O-O-M) which had optimum moisture for 60 days and minimum for 30 days is compared with No. 3 (0-M-0) it is evident that the low moisture content during the middle period in No. 3 lowered the yield much more than did the low moisture during the third period in No. 2. Again No. 7 (M-O-M) shows a much higher yield than either No. 4 (O-M-M) or No. 6 (M-M-O) which had only one period of

TABLE 1.—AVERAGE DRY WEIGHT OF DIFFERENT PARTS OT CORN PLANTS During 1915, 1916, and 1919. (Wt. in grams)

Potometer No.	Treatment	Roots	Stalks	Leaves	Ears	Total top	Total plant
A and B 1	O-O-O	98.09	216.80	227.68	329.40	773.90	871.99
A and B 2	O-O-M	118.52	214.48	205.77	186.54	606.83	725.33
A and B 3	O-M-O	62.74	136.85	199.20	212.81	553.87	616.61
A and B 4	O-M-M	72.25*	139.66	172.18	107.66	419.51	488.77
A and B 5	M-M-M	52.98	112.10	143.11	53.37	308.59	361.57
A and B 6	M-M-O	56.52	119.87	170.22	138.05	428.15	484.67
A and B 7	M-O-M	98.19	206.90	206.80	111.57	525.30	623.50
A and B 8	M-O-O	95.29	202.06	219.57	248.09	669.73	765.03
A 9	O-O	98.02	157.69	192.30	14.13*	364.13	462.16
A 10	O-M	66.25	105.41	148.77	------	254.15	320.40
A 11	O	12.81	2.29*	30.92	------	33.21	46.03
A 12	M	4.62	2.14*	7.52	------	9.66	14.28
A 13	M-O	70.75	138.57	153.82	------	292.39	363.14
A 14	M-M	43.16	58.94	93.29	------	152.24	195.39

*One year results.

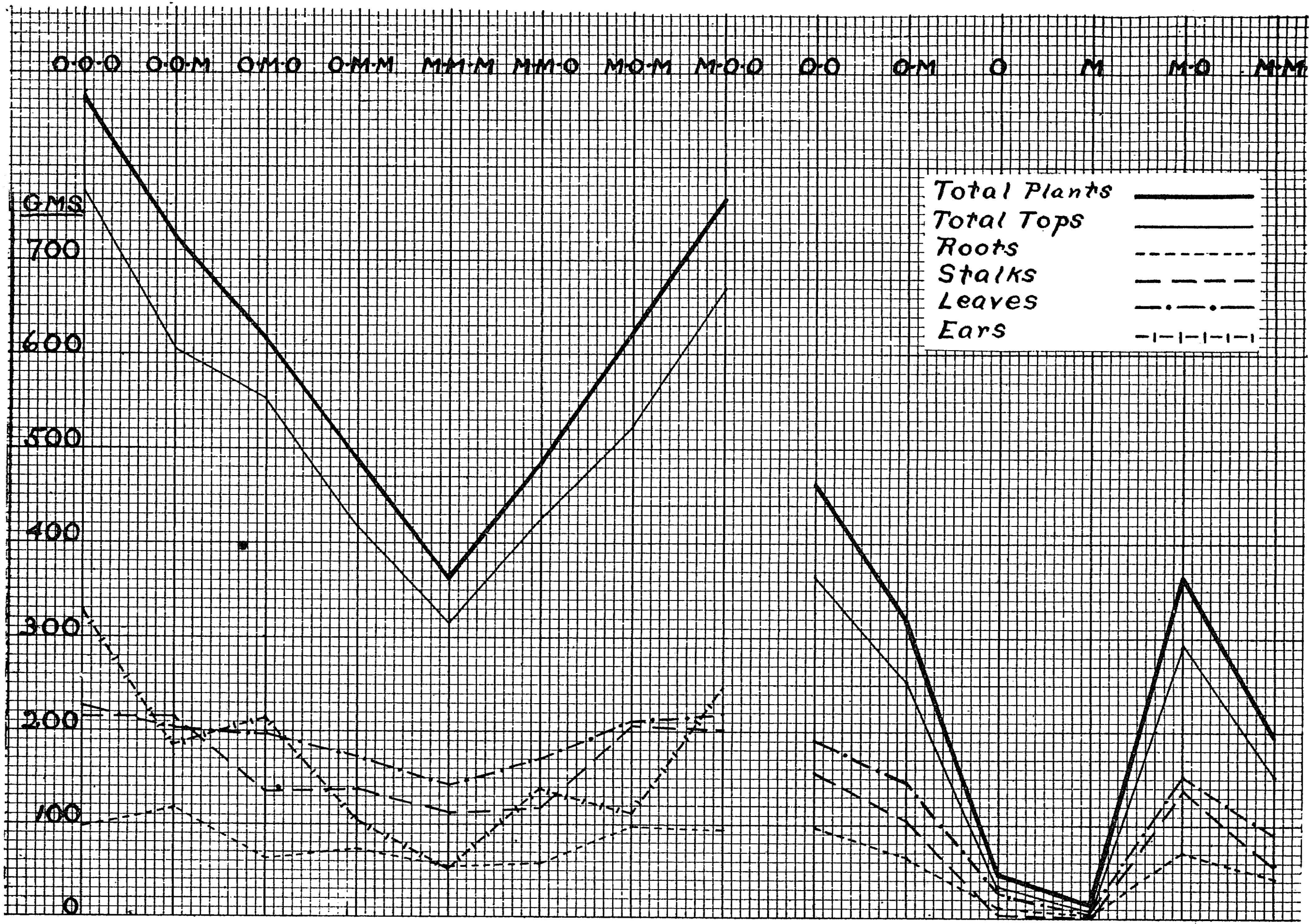

Fig. 1.—Curves showing dry weight of plants having different treatments and at different stages of growth.

optimum water, but in these cases the high moisture was either the first or last rather than the middle 30-day period. In a previous publication by the authors[3] the enormous importance of this middle period in the nutrition of the corn plant was emphasized. The effect of low moisture at this time showed a very similar effect to that of a low supply of nutrients.

Also the effect of a low supply of moisture on the total weight during the first period is similar to the effect during the third period. This is shown by the fact that the total weight of No. 4 (O-M-M), which had optimum the first 30 days and then minimum during the remainder of the time, was 488.7 grams and the weight of No. 6 (M-M-O), which had optimum during the last 30 days, was 484.6 grams. The weight of No. 2 (O-O-M) was 725.3 grams and No. 8 (M-O-O) was 765.0 grams which might indicate that the last period is equally as important as the first or perhaps slightly more so. At least it shows rather clearly, along with the other facts brought out, that corn may recover from a bad start and produce a good yield in the end provided conditions are favorable. That is, the corn plant may be severely stunted during its early growth, due to lack of water or nutrients, but this may be almost entirely overcome if conditions become favorable during the latter two-thirds of the growing period. It might be said, however that while the effect of the first and third periods have a similar effect upon the weight of plants there is a marked difference in the character of growth.

EFFECT UPON DIFFERENT PARTS OF THE PLANTS

Root Growth.—It is shown in most cases that a low supply of moisture during the last period is conducive to increased root production as compared with high moisture at this time. The differences are not great

TABLE 2.—EFFECT OF LOW MOISTURE DURING THE THIRD PERIOD UPON THE AMOUNT OF ROOT GROWTH

No. Pot.	Treatment	Wt. Roots	Inc. due to Minimum
		Grams	*Grams*
1	O-O-O	98.09	------
2	O-O-M	118.52	20.43
3	O-M-O	62.74	------
4	O-M-M	72.25	9.51
5	M-M-M	52.98	------
6	M-M-O	56.52	−3.54
7	M-O-M	98.19	------
8	M-O-O	95.29	2.73

but due to their repeated occurrence, it seems certain that the effect is not accidental, especially since it has occurred not only with changes in moisture content, but also with variation in the amounts of soluble plant food materials as shown by the authors[3]. This fact is illustrated by the comparison of several pairs of plants shown in Table 2.

It will be noted that No. 6 gave a slight increase over No. 5. This was due entirely to the results obtained in 1915. During the other years, the weight of roots in No. 5 in each of the duplicate pots was above that of No. 6. It may be said, however, that another reason why the increase cannot be expected to be so great in this case is the fact that these plants made only a very slow growth during the first two periods. Then when a large supply of water was added on the sixtieth day to No. 6 the plants made a very rapid growth which greatly increased both tops and roots. The increase in total weight of No. 6 during the last period was 148 per cent, while the increase in No. 5 was only 85 per cent. With this great increase in total weight the root weight could hardly be expected to be actually less than in No. 5. However, the increase of roots in proportion to tops was greater in No. 5 than in No. 6.

The matter of comparative root growth is also shown in an examination of the ratios of root weight to weight of tops as is brought out in Table 3.

TABLE 3.—RELATIVE WEIGHTS OF ROOTS AND TOTAL TOPS OF PLANTS

No. Pot.	Treatment	Ratio Roots: Tops
A and B 1	O-O-O	1:7.89
A and B 2	O-O-M	1:5.12
A and B 3	O-M-O	1:8.83
A and B 4	O-M-M	1:5.81
A and B 5	M-M-M	1:5.82
A and B 6	M-M-O	1:7.57
A and B 7	M-O-M	1:5.35
A and B 8	M-O-O	1:7.03
A 9	O-O	1:3.71
A 10	O-M	1:3.84
A 11	O	1:2.59
A 12	M	1:2.09
A 13	M-O	1:4.13
A 14	M-M	1:3.29

TABLE 4.—AVERAGE HEIGHT, NUMBER OF LEAVES AND LENGTH OF INTERNODES OF ALL PLANTS FOR EACH TREATMENT AT END OF THIRD PERIOD

No. Pot.	Treatment	Average 1913, 1916, 1919		
		Height of plants	Number of leaves	Length of internodes
		inches		*inches*
1	O-O-O	107	13.8	7.75
2	O-O-M	104	13.9	7.48
3	O-M-O	81	13.5	6.00
4	O-M-M	79	13.9	5.68
5	M-M-M	76	13.4	5.67
6	M-M-O	90	13.4	6.71
7	M-O-M	97	12.9	7.52
8	M-O-O	105	12.8	8.20

It may be seen from Table 3 that the ratio of root weight to that of the tops is narrower where the period preceding the taking of weights has been minimum as compared with optimum moisture. No. 10 (O-M) is the only exception to this and here the difference is slight. In all other pairs of plants where the treatment has been identical, except the period just previous to the taking of the weights, the ones having minimum had a greater proportion of roots to tops. This may be seen by the following figures giving average results for each period where the ratio of roots to tops are averaged for all plants having similar treatment just prior to harvest.

Time plants were grown before harvesting	Treatment just before harvest and ratio of roots to tops	
	Optimum	*Minimum*
Plants grown 30 days	1:2.59	1:2.09
Plants grown 60 days	1:3.92	1:3.56
Plants grown 90 days	1:7.83	1:5.52

It, therefore, seems clear that minimum moisture is conducive to greater root development and optimum moisture to increased top growth in proportion to roots, particularly during the last period. These facts were well shown by Harris[4] for wheat plants. This condition is an important one in considering the effect of drought.

The plants in treatment No. 8 (M-O-O) which had low moisture at the beginning of the growth period followed by abundant moisture later produced more grain than any of the other treatments except No. 1 which had optimum moisture the entire period. This would indicate that the effect of early drought is more completely overcome than at any other period, provided the remainder of the season is favorable. A low supply of moisture in the early stages favors root development and assists the plants to withstand drought occurring later in the season. This substantiates the observation of farmers that the best corn years are those in which the supply of moisture is comparatively low during the early part of the growth period and abundant during the latter part of the season.

Character of Growth.—These maize plants varied not only in the amount of growth produced, but the type of plant was materially altered by changes in the moisture content of the soil. One of the most striking effects of minimum moisture was to reduce the length of internodes. (See Table 4 and figure 12.) This was particularly true where minimum moisture was supplied during the second period. Table 4 shows that the average length of internode on No. 4 (O-M-M) was practically the same as No. 5 (M-M-M) which had minimum moisture continuously. No. 3 (O-M-O) and No. 6 (M-M-O) which had minimum during the second period, but were followed by optimum during the third period produced internodes intermediate in length between those having minimum moisture during the last 60 days and those having optimum during the second period. No. 3 (O-M-O) shows that the increase in length of internodes was much less where the plant had been severely stunted during the second period after having optimum during the first period, than was the case in No. 6 (M-M-O) where the first period was also minimum moisture. No. 3 was never able to recover from the severe shock of the minimum treatment during the second period, but No. 6 which started with minimum treatment and carried it through the second period was greatly benefited by the optimum treatment at the end. The leaves became very green and were still growing rapidly at the time the plants were harvested. The stalks increased in length until the average height was 14 inches more than in No. 5 which had minimum moisture the entire season, and 9 inches more than in No. 3 which had optimum the first period and the same treatment thereafter as No. 6.

Nos. 7 and 8 which had minimum the first period followed by optimum during the second period had a tendency to produce stalks with long internodes and with fewer leaves than the other plants. It is very noticeable that the number of leaves is practically constant for all treatments excepting No. 7 and No. 8 which are slightly lower than the others.

The height of plants varied widely as may be seen from Table 4 or Figure 8. The plants in No. 1 (O-O-O) averaged 40 per cent taller than those in No. 5 (M-M-M). This gave one of the most striking differences in the appearance of these plants.

The lower leaves on Nos. 2, 4, and 7 usually died before the end of the 90-day period, while those on No. 6 and 8 were growing rapidly and would have gone on and matured normally if the growing time had been extended. This would indicate that a drought is much more serious for the normal development of corn and particularly the production of grain if it comes at the end of the growing season than at the beginning. On the other hand, a drought during the middle part of the growing season has been far more disastrous to vegetative growth than at either the beginning or the end of this period. Harris[5] found that wheat plants were able to withstand excessive moisture better when young than when older. He also found that the plants matured 16 days earlier with 20 per cent moisture than with 11 per cent or 45 per cent. The plants in No. 5 (M-M-M) also showed the effect of continued low moisture in delaying maturity. The plants grew slowly and did not mature quickly.

Weight of Stalks.—The weight of stalks held up remarkably well with low moisture content during the third period. This is shown by the fact that the weights of stalks in each pair of treatments, which differed only in the last period, were approximately the same. Low moisture content during the second period had a very depressing effect upon weight of stalk as well as upon height as shown in the preceding paragraph. Low moisture during the first period had a depressing effect on weight of stalk if followed during the second period by a continued lack of water, but if low moisture during early growth was followed by a copious supply during the second period the effect of the previous stunting of stalk growth was almost completely overcome.

Leaf Growth.—The leaf growth responded more readily to changes in moisture content when all periods are considered than any other part of the plant. Whenever the supply of moisture was high, leaf growth was stimulated. The effect during each period is illustrated in Table 5.

TABLE 5.—EFFECT OF INCREASED MOISTURE UPON LEAF GROWTH DURING EACH OF THE THREE PERIODS

No.	Treatment	Wt. Leaves	Difference
		grams	*grams*
12	M	7.52	-----
11	O	30.92	23.40
14	M-M	93.29	-----
13	M-O	153.82	60.53
5	M-M-M	143.11	-----
6	M-M-O	170.22	27.11

The second period had the greatest effect because it is during this period that most rapid leaf growth is made. When these results are compared with those in Table 1, it is evident that with increased moisture toward the end of the growing period leaf growth is greatly stimulated, while root growth does not increase proportionately.

Grain Production.—The production of grain depended more than any other part of the plant upon a plentiful supply of moisture during the last 30-day period of growth. Number 2 (O-O-M) shows that even though the plants had made a good growth during the first and second periods and that the stalk growth was normal, the plants were not able to produce ears as in No. 1 (O-O-O). In fact No. 3 (O-M-O) which was reduced in top growth by minimum water during the second period, produced more grain than No. 2 (O-O-M) which had optimum water during the first 60 days and minimum during the third period. It may be seen, too, that No. 6 (M-M-O) and No. 8 (M-O-O) produced more grain than No. 5 (M-M-M) and No. 7 (M-O-M) respectively where the difference in treatment was only during the third period. That from the standpoint of grain production the moisture supply during the third period is more important than during the second is further shown by comparing No. 6 (M-M-O) which yielded 138.0 grams, with No. 7 (M-O-M) which produced only 111.5 grams of grain. The effect of optimum during the first period is shown to be less than during later growth by the results of No. 4 (O-M-M) which produced only 107.6 grams. In each of these cases the plants had received two periods of minimum treatment and one period of optimum.

Plants Grown One or Two Periods.—Table 1 and figures 4 and 6 give a good idea of the growth produced during the first and second 30 day periods. The plants receiving plenty of moisture were stocky and well developed, while in most cases the plants having minimum water were small and had a pale green color. In some cases where the plants had minimum water during the first period, it was necessary to add a small amount of water at the surface to prevent them from dying. Considering the first and second periods, figure 7 shows that the minimum treatment is more serious in the second period than in the first. If No. 10 (O-M) is compared with No. 13 (M-O) it may be seen that No. 13 is slightly higher in total weight due to the great increase during the second period. During the first period No. 11 (O) produced 46.03 grams total weight of plant as compared with 14.28 grams of total plant in No. 12 (M). No. 9 (O-O) also produced more than twice the weight of No. 14 (M-M).

TABLE 6.—AVERAGE LEAF SURFACE IN SQUARE INCHES AT END OF EACH PERIOD FOR 1915, 1916, AND 1919

No.	Treatment	First period	Second period	Third period
A and B 1	O-O-O	1568	6568	5017
A and B 2	O-O-M	1678	6986	4140
A and B 3	O-M-O	1556	5995	5296
A and B 4	O-M-M	1679	6304	4621
A and B 5	M-M-M	551	4293	4263
A and B 6	M-M-O	437	3962	4309
A and B 7	M-O-M	522	6186	4163
A and B 8	M-O-O	496	5956	4917
A 9	O-O	1782	6834	----
A 10	O-M	1691	6159	----
A 11	O	1798	----	----
A 12	M	496	----	----
A 13	M-O	601	6235	----
A 14	M-M	613	4721	----

Measurements of Leaf Surface.—The leaves of all plants were measured at the end of each period and the surface area calculated. Table 6 shows that the area at the end of the first period was approximately three times as great where the plants had optimum moisture as where they had minimum moisture. At the end of the second period the leaf area of the plants receiving optimum was only about 50 per cent greater. During the third period the green leaf area decreased in all cases except in No. 6 (M-M-O) which had received minimum moisture during the first two periods and had then been increased to optimum.

During the second period the amount of water used was closely correlated with the amount of leaf area (figure 2). This was similar to the results reported by Montgomery[13] who showed that there was a closer correlation between the leaf area and the transpiration than between transpiration and dry weight.

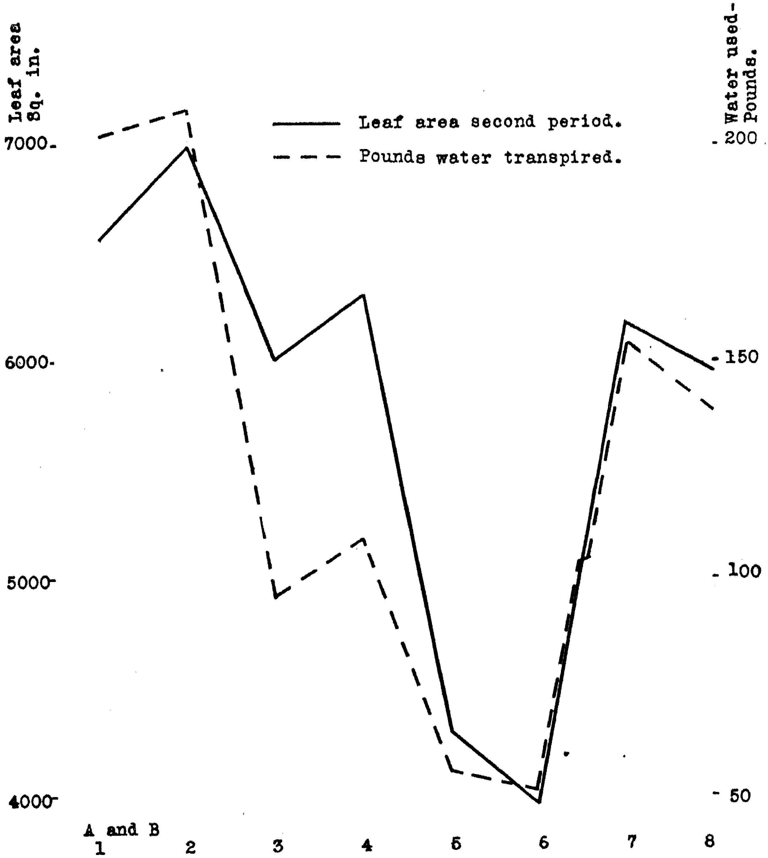

Fig. 2.—Curves showing the close relation between the leaf area and amount of water transpired. The variation in Nos. 3 and 4 is due to changing from optimum to minimum during second period.

TRANSPIRATION MEASUREMENTS

The units of water transpired in the production of one unit of dry matter varied greatly from year to year. Table 7 shows that during 1915 the average transpiration ratio for the total tops of plants of all treatments was 216, while those which were grown for the full 90 days averaged only 134. In 1916 the general average was 347 while the average of plants grown 90 days was 289. In 1919 the results were intermediate between the other two years, the general average being 258 and the average of plants grown 90 days 239. The relative amount of water transpired per unit of dry matter for the different years is shown in Table 7.

The transpiration ratio varied considerably during the different periods. It may be calculated from Table 7 that for the first period an average of 517 pounds of water was required to produce one pound of dry matter. This figure is undoubtedly too high owing to the unavoidable loss of water from the small area of exposed soil during the first period. The average for the second period was 239 and for the third period 204. It should be noted further that the plants getting optimum moisture during the second period required more water per unit of dry substance produced than those getting minimum treatment. The reverse was true during the third period.

TABLE 7.—POUNDS OF WATER TRANSPIRED IN THE PRODUCTION OF ONE POUND OF DRY MATTER IN THE TOPS OF PLANTS

Potometer	Treatment	1915	1916	1919	Average
A and B 1	O-O-O	135	279	260	225
A and B 2	O-O-M	132	354	268	251
A and B 3	O-M-O	131	272	228	210
A and B 4	O-M-M	140	327	225	231
A and B 5	M-M-M	126	259	210	198
A and B 6	M-M-O	132	265	206	201
A and B 7	M-O-M	128	311	254	231
A and B 8	M-O-O	149	248	263	220
Average	**for plants grown three periods**	**134**	**289**	**239**	**221**
A 9	O-O	147	410	283	280
A 10	O-M	137	377	211	242
A 11	O	637	645	276	519
A 12	M	729	352	468	516
A 13	M-O	163	408	---	285
A 14	M-M	138	358	206	234
General Ave	**rage**	**216**	**347**	**258**	**274**

One reason for the apparently low transpiration of these plants even during 1916 when the season was fairly warm and dry was the fact that the soil in which these plants were grown was quite fertile. Kiesselbach[10] has shown that high fertility may greatly reduce the transpiration ratio.

The reasons for the great variation in the water transpired during these different years is brought out in Tables 8 to 11. The year 1915 was one of exceptionally high rainfall and with a large amount of damp, cloudy weather. Table 8 shows that during the course of this experiment in 1915 there was only 54.1 per cent of the possible sunshine, while in

1916 there was 82 per cent. The temperature averaged only 69.9 degrees during 1915 and over 77 degrees during the other two years. The greatest difference in temperature was during the second period when the transpiration was highest. The relative humidity was also much higher during 1915. This is one of the most important factors in reducing transpiration. When the data for 1916 and 1919 are compared it will be seen that the reason for the lower transpiration in 1919 did not lie in the temperature but in the sunshine and humidity. The amount of sunshine was greater in 1916 and the average humidity lower.

TABLE 8.—AVERAGE DAILY PERCENT OF POSSIBLE SUNSHINE FOR THE DIFFERENT PERIODS FOR THE THREE YEARS OF THE EXPERIMENT*

	1915	1916	1919	
First Period	50.6	80.5	80.4	June 21 — Sept. 18
Second Period	48.6	83.4	82.4	June 19 — Sept. 15
Third Period	63.2	82.1	71.8	June 20 — Sept. 19
Average	54.1	82.0	78.2	

*Tables 8 to 11 by courtesy of Mr. George Reeder, U. S. Weather Observer, Columbia, Mo.

TABLE 9.—AVERAGE HOURLY TEMPERATURE DURING THE DIFFERENT PERIODS FOR THE THREE YEARS OF THE EXPERIMENT
(Degrees Fahrenheit)

	1915	1916	1919
First Period	71.09	78.18	79.40
Second Period	70.73	81.83	80.38
Third Period	67.87	71.90	73.08
Average	69.90	77.30	77.62

TABLE 10.—AVERAGE RELATIVE AIR HUMIDITY AT 7 A. M. FOR THE DIFFERENT PERIODS DURING THE THREE YEARS OF THE EXPERIMENT

	1915	1916	1919
First Period	89.7	82.3	84.4
Second Period	92.4	81.0	80.6
Third Period	90.0	84.4	89.6
Average	90.7	82.6	84.9

TABLE 11.—COMPARISON OF THE RAINFALL DURING THE GROWING PERIOD FOR THE DIFFERENT YEARS

Period	1915	1916	1919
First Period	5.32	1.39	3.21
Second Period	3.20	1.70	2.86
Third Period	8.77	2.58	4.50
Total	17.29	5.67	10.57

CHEMICAL COMPOSITION OF MAIZE PLANTS

It was considered desirable to do some work on the chemical composition of the plants produced under the different moisture conditions. The crops of 1916 and 1919 were selected for analysis. The different parts of the plants were air-dried, ground, and analyzed for nitrogen, phosphorus, potassium, calcium, and magnesium. The average of the analyses for the various parts of the plants for the two years are given in Tables 12 to 15.

TABLE 12.—AVERAGE PERCENTAGE COMPOSITION OF ROOTS

No. Potometer	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	0.685	0.172	1.229	0.484	0.225
A and B 2	O-O-M	0.912	0.190	1.041	0.623	0.258
A and B 3	O-M-O	1.077	0.230	1.083	0.564	0.247
A and B 4	O-M-M	1.077	0.249	1.297	0.692	0.277
A and B 5	M-M-M	1.261	0.233	1.018	0.744	0.301
A and B 6	M-M-O	1.204	0.243	1.005	0.673	0.303
A and B 7	M-O-M	1.122	0.242	1.270	0.621	0.241
A and B 8	M-O-O	0.802	0.224	1.099	0.564	0.236
A 9	O-O	0.758	0.222	1.343	0.532	0.239
A 10	O-M	1.272	0.224	1.651	0.631	0.299
A 11	O	1.628	0.146	-----	-----	-----
A 12	M	1.868	0.208	-----	-----	-----
A 13	M-O	0.990	0.148	1.455	0.628	0.333
A 14	M-M	1.518	0.493	0.876	0.797	0.288

TABLE 13.—AVERAGE PERCENTAGE COMPOSITION OF STALKS

No. Potometer	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	0.476	0.223	1.909	0.320	0.188
A and B 2	O-O-M	0.421	0.301	1.947	0.342	0.192
A and B 3	O-M-O	0.983	0.233	2.493	0.429	0.257
A and B 4	O-M-M	1.265	0.198	3.394	0.559	0.267
A and B 5	M-M-M	1.310	0.225	2.298	0.432	0.271
A and B 6	M-M-O	1.323	0.177	2.481	0.435	0.268
A and B 7	M-O-M	1.044	0.235	2.280	0.376	0.218
A and B 8	M-O-O	0.492	0.151	2.176	0.377	0.198
A 9	O-O	0.805	0.311	2.157	0.361	0.230
A 10	O-M	2.195	0.274	4.172	0.506	0.337
A 11	O	3.005	0.650	------	------	------
A 12	M	------	------	------	------	------
A 13	M-O	1.958	0.314	3.237	0.448	0.349
A 14	M-M	2.573	0.300	3.190	0.486	0.292

TABLE 14.—AVERAGE PERCENTAGE COMPOSITION OF LEAVES

No. Potometer	Treat-ment	Nitrogen	Phos-phorus	Potas-sium	Calcium	Magne-sium
A and B 1	O-O-O	0.910	0.199	1.713	0.689	0.265
A and B 2	O-O-M	1.016	0.244	1.894	0.696	0.268
A and B 3	O-M-O	1.521	0.325	2.013	0.601	0.248
A and B 4	O-M-M	1.391	0.298	2.318	0.749	0.273
A and B 5	M-M-M	1.902	0.230	2.054	0.675	0.293
A and B 6	M-M-O	1.968	0.252	1.969	0.665	0.267
A and B 7	M-O-M	1.404	0.214	2.053	0.701	0.257
A and B 8	M-O-O	1.374	0.211	1.838	0.652	0.240
A 9	O-O	1.708	0.216	2.535	0.686	0.280
A 10	O-M	2.017	0.356	3.261	0.707	0.250
A 11	O	3.666	0.450	4.359	0.858	0.388
A 12	M	3.722	0.487	------	------	------
A 13	M-O	2.368	0.276	2.809	0.707	0.299
A 14	M-M	2.519	0.372	2.963	0.795	0.276

TABLE 15.—AVERAGE PERCENTAGE COMPOSITION OF EARS

No. Potometer	Treat-ment	Nitrogen	Phos-phorus	Potas-sium	Calcium	Magne-sium
A and B 1	O-O-O	1.246	0.346	0.602	0.057	0.139
A and B 2	O-O-M	1.970	0.319	0.631	0.059	0.149
A and B 3	O-M-O	1.801	0.414	0.803	0.062	0.158
A and B 4	O-M-M	1.995	0.392	0.718	0.062	0.164
A and B 5	M-M-M	2.471	0.423	1.161	0.093	0.191
A and B 6	M-M-O	2.270	0.394	0.948	0.070	0.142
A and B 7	M-O-M	2.227	0.464	1.186	0.074	0.152
A and B 8	M-O-O	1.656	0.378	0.858	0.058	0.133
A 9	O-O*	2.637	0.566	1.704	0.138	0.210

*Only one sample.

The main differences brought out by these analyses may be seen from Tables 16 and 17 which show the composition of plants, comparing the average of those having minimum with those having optimum during the second and third periods. In practically all cases minimum moisture content during the second period gave a higher nitrogen content and a higher mineral content than where optimum moisture was given. This is probably due to a greater salt concentration of the soil solution. The only exceptions to this statement were in the case of phosphorus in the stalks, nitrogen in the leaves, and potassium in the roots, although in the leaves the average percentage of magnesium in the second period and phosphorus in the third period was the same with both optimum and minimum treatments. The relatively small proportion of calcium to magnesium in the grain as compared with the other parts of the plants has long been known and was reported by Way[14] as early as 1847. The percentage of the various elements usually decreases with the age of the plants. (See Table 12 to 15.)

The results of these analyses are somewhat at variance with the results obtained by Widtsoe[15] showing that the percentage of ash in the above-ground parts of plants increased as the amount of irrigation water was increased, while the ash in the underground parts decreased. They found the percentage of protein to increase as irrigation decreased which corresponds to the results reported in this bulletin. The results here reported also correspond closely to those of Harris[4], obtained from an analysis of wheat plants grown with two different moisture contents during the different periods in the growth of the plants.

TABLE 16.—AVERAGE PERCENTAGE COMPOSITION OF PLANTS HAVING MINIMUM VS. OPTIMUM MOISTURE DURING MIDDLE PERIOD

Average of Potometers	Treatment 2nd Period	N	P	K	Ca	Mg
		Roots				
1, 2, 7, 8, 9, 13	O	0.878	0.200	1.239	0.575	0.255
3, 4, 5, 6, 10, 14	M	1.274	0.278	1.158	0.683	0.286
		Stalks				
1, 2, 7, 8, 9, 13	O	0.866	0.256	2.284	0.371	0.229
3, 4, 5, 6, 10, 14	M	1.608	0.234	3.005	0.474	0.282
		Leaves				
1, 2, 7, 8, 9, 13	O	1.463	0.227	2.140	0.688	0.268
3, 4, 5, 6, 10, 14	M	1.886	0.305	2.429	0.699	0.268
		Ears				
1, 2, 7, 8	O	1.775	0.377	0.819	0.062	0.143
3, 4, 5, 6	M	2.134	0.406	0.907	0.072	0.164

TABLE 17.—AVERAGE PERCENTAGE COMPOSITION OF PLANTS HAVING MINIMUM OR OPTIMUM MOISTURE DURING THIRD PERIOD

Average of Potometers	Treatment 3rd Period	% N	P	K	Ca	Mg
		Roots				
1, 3, 6, 8	O	0.942	0.217	1.104	0.571	0.252
2, 4, 5, 7	M	1.093	0.228	1.156	0.670	0.269
		Stalks				
1, 3, 6, 8	O	0.818	0.196	2.265	0.390	0.228
2, 4, 5, 7	M	1.010	0.240	2.480	0.427	0.237
		Leaves				
1, 3, 6, 8	O	1.443	0.247	1.883	0.652	0.255
2, 4, 5, 7	M	1.428	0.247	2.080	0.705	0.273
		Ears				
1, 3, 6, 8	O	1.743	0.383	0.803	0.062	0.143
2, 4, 5, 7	M	2.166	0.399	0.924	0.072	0.164

While the analyses from duplicate treatments did not always agree as closely as desired, it is believed that the average analyses from duplicate treatments on two different years should indicate in a general way, at least, the effect of high and low soil moisture upon the composition of the maize plant.

SUMMARY

1. In these experiments the effect of varying the moisture supply at different periods in the growth of maize plants was determined between the years 1913 and 1919. The work during 1913 and 1914 was largely used in developing the technique of the experiment and the results are not reported. On account of the War, the work was discontinued during 1917 and 1918.

2. The soil used was a fairly fertile creek bottom soil of a coarse silt loam texture. It had a calculated wilting coefficient of 7.6.

3. The corn plants were grown in potometers 24 inches in diameter and 30 inches deep, holding approximately 480 pounds of dry soil.

4. The growing period was taken as 90 days, which was divided into three 30-day periods. All possible combinations of optimum (28 per cent) and minimum (13 per cent) moisture were included in the plan of treatment.

5. Provision was made for harvesting the plants from certain potometers at the end of each 30-day period, thus giving a means of measuring the effect of each treatment during the different periods.

6. The plants were divided into four parts; (1) roots, (2) stalks, tassels and shanks, (3) leaves, (4) ears. Dry weights were obtained and chemical analyses were made for each part of the plant.

7. The moisture supply during the second period had a much greater effect upon the total production of dry matter than the moisture content at any other time.

8. The moisture supply during the first and third periods had about the same effect so far as total dry weight was concerned.

9. Maize plants almost completely recovered from the effects of drought at the beginning of the season and produced good yields provided moisture was at optimum after the first month.

10. A low moisture content during the last period gave an increased root development over optimum soil moisture.

11. The stalk growth was affected very little by changes in soil moisture during the last period except where the plants received optimum this period, preceded by minimum moisture.

12. The leaf growth responded more readily to changes in soil moisture content than any other part of the plant. Whenever the moisture content was optimum, leaf growth was stimulated.

13. The production of grain depended more than any other part of the plant upon a plentiful supply of moisture during the last 30-day period of growth.

14. Plants grown only one or two periods showed very strikingly the advantage of an optimum water supply during the early growth.

15. Measurements at the end of the first period showed that plants receiving optimum moisture had practically three times as much leaf surface as those receiving minimum moisture. At the end of the second period the leaf area of plants receiving optimum moisture for both periods was only about 50 per cent greater than those receiving minimum moisture, and at the end of the third period, only 18 per cent greater.

16. The units of water transpired in the production of one unit of dry matter in the tops of the plants varied greatly from year to year. The average was 216 in 1915, 347 in 1916, and 258 in 1919. The reasons for this great variation are to be found largely in the fact that the season of 1915 was very wet and cool, with a low percentage of sunshine. The season of 1919 was intermediate between the other two years so far as the factors affecting transpiration were concerned.

17. Chemical analyses showed that as an average of all cases minimum moisture content gave a higher nitrogen content and a higher mineral content than where optimum moisture was applied, during any period of growth.

18. The percentage of both nitrogen and mineral elements usually decreased with the age of plants. In most cases the decrease was more marked with optimum than with minimum moisture treatments.

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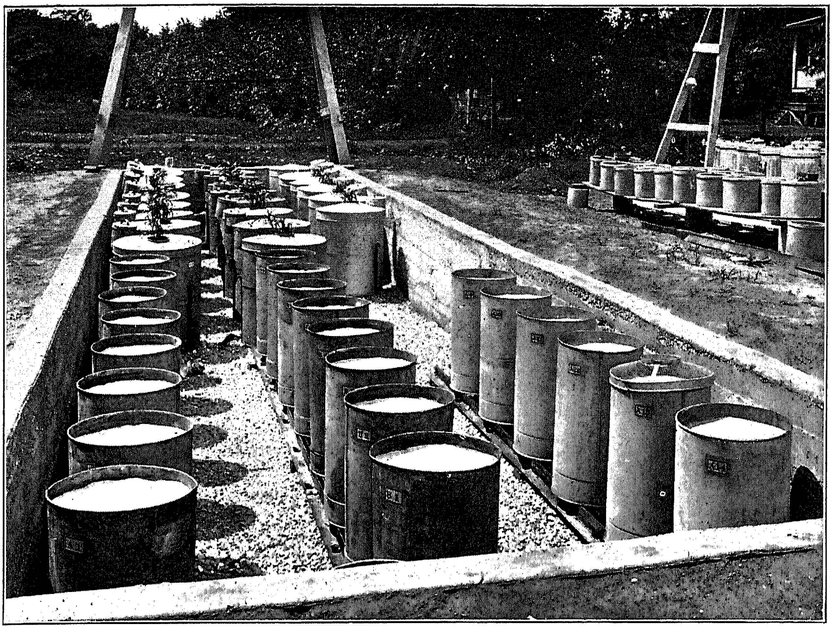
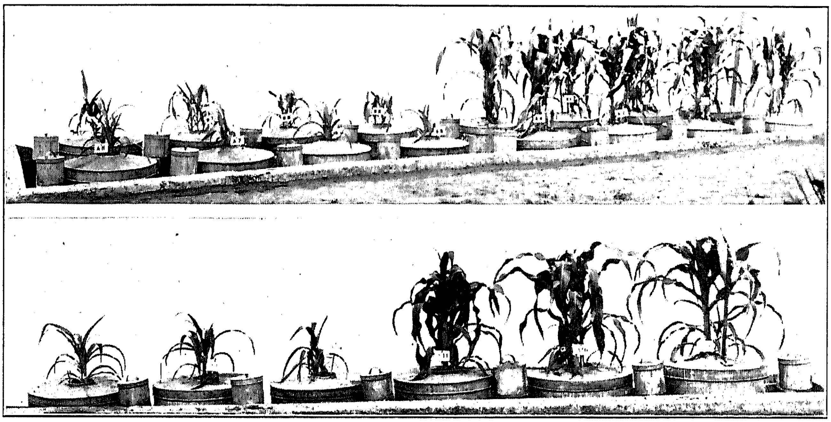


Fig. 3.—General view of pit where these experiments were carried on. Small cans in front were used in nutrition studies. The large potometers where crop is planted were used in moisture work.

A & B	8	7	6	5	4	3	2	1
	M	M	M	M	O	O	O	O



A	14	13	12	11	10	9
	M	M	M	O	O	O

Fig. 4.—End of the first 30-day period July 19, 1916. Potometers 1 to 4 and 9 to 11 had optimum treatment, 28 per cent water. Potometers 5 to 8 and 12 to 14 had minimum treatment, 13 per cent water.

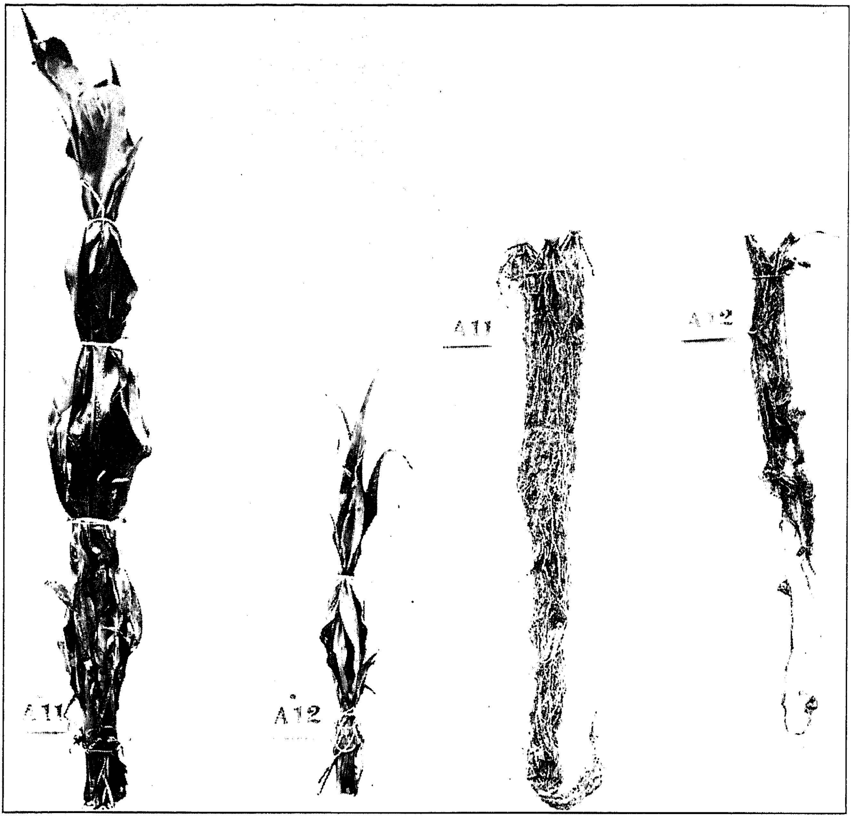


Fig. 5.—Showing a comparison of the growth of the tops and roots at end of first 30 days. A 11 had optimum moisture (28%). A 12 had minimum moisture (13%).

Fig. 6.—Corn Plants at End of Sixty Days' Growth, 1916.

A & B	8	7	6	5	4	3	2	1
	M-O	M-O	M-M	M-M	O-M	O-M	O-O	O-O

Fig. 7.—Plants at End of Second Period, 1916.

A 14	A 13	A 10	A 9
M-M	M-O	O-M	O-O

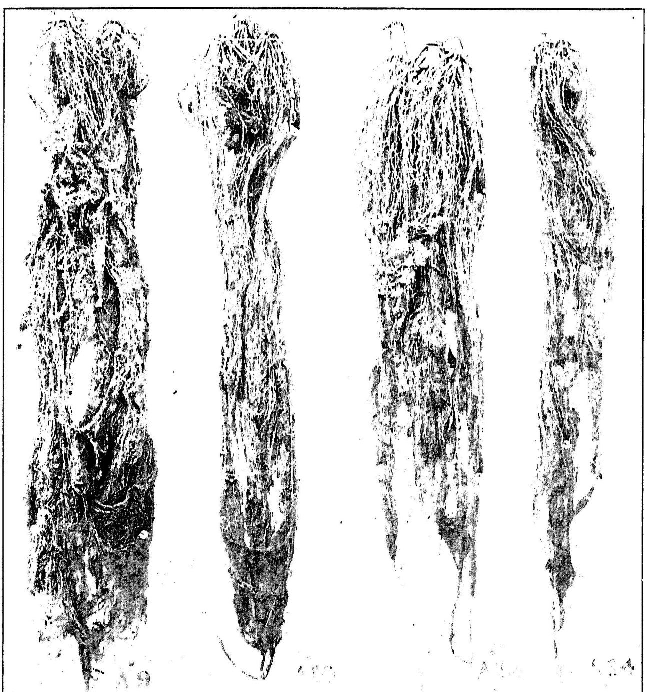


Fig. 8.—Corn Roots at End of Sixty Days' Growth.

A 9	A 10	A 13	A 14
O-O	O-M	M-O	M-M

Fig. 9.—Series A and B. 1-8, end of third 30 days growing period showing the condition of corn when harvested, 1916.

A & B	8	7	6	5	4	3	2	1
	M-O-O	M-O-M	M-M-O	M-M-M	O-M-M	O-M-O	O-O-M	O-O-O

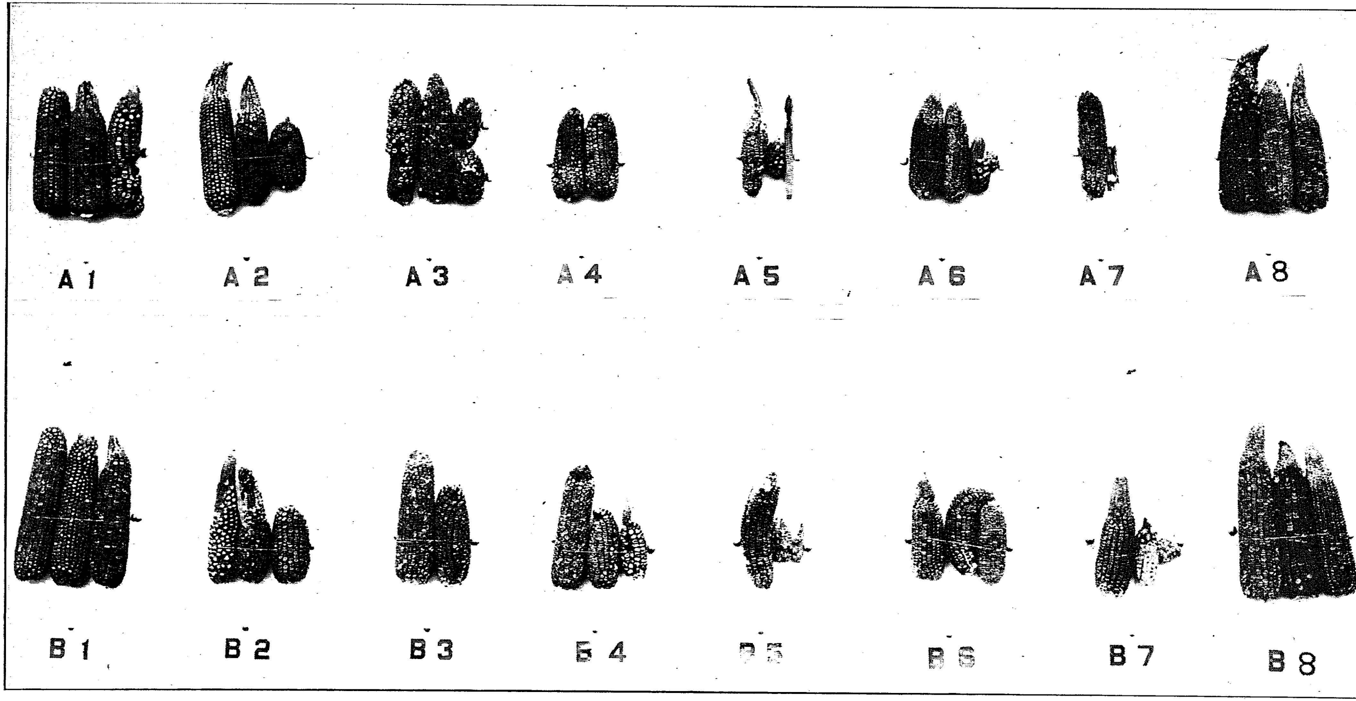


Fig. 10.—Ears Produced on 1916 crop of corn. Treatments as shown in Plate VII.

	1	2	3	4	5	6	7	8
A & B	O-O-O	O-O-M	O-M-O	O-M-M	M-M-M	M-M-O	M-O-M	M-O-O

Fig. 11.—Crop from Series A, 1919. Note large ears on those plants receiving optimum moisture during third period. The leaves are also broader and more succulent on these plants.

A & B	1	2	3	4	5	6	7	8
	O-O-O	O-O-M	O-M-O	O-M-M	M-M-M	M-M-O	M-O-M	M-O-O

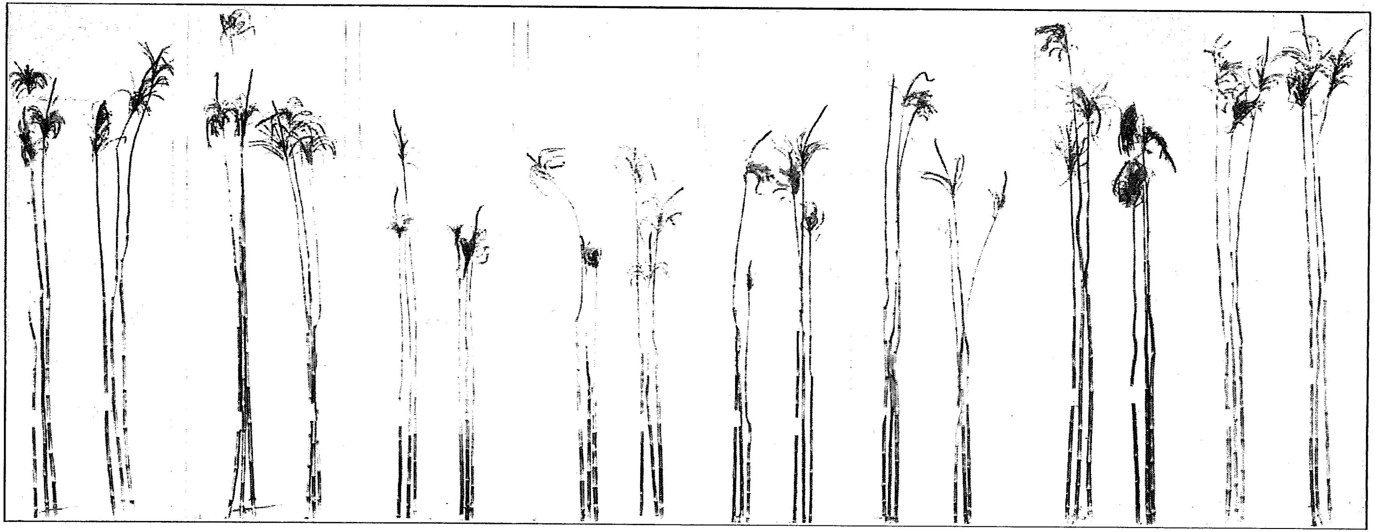


Fig. 12.—Stalks from 1919 crop. Note differences in size and height of stalks and also relatively short internodes from Nos. 3, 4 and 5.

	1	2	3	4	5	6	7	8
A & B	O-O-O	O-O-M	O-M-O	O-M-M	M-M-M	M-M-O	M-O-M	M-O-O

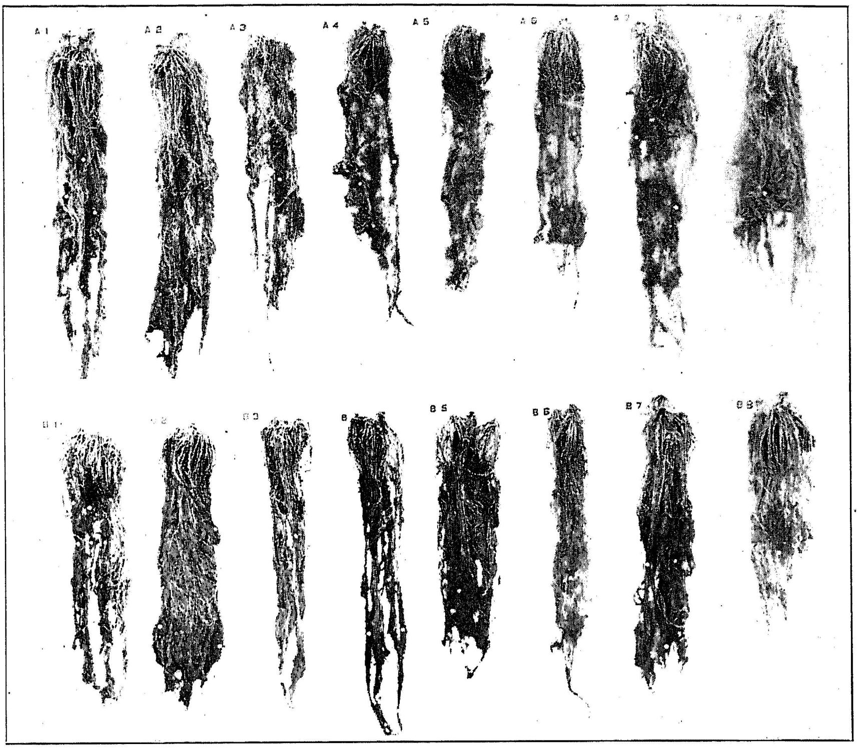


Fig. 13.—Corn roots from different treatments at end of third period. Treatments same as shown in Figure 9.

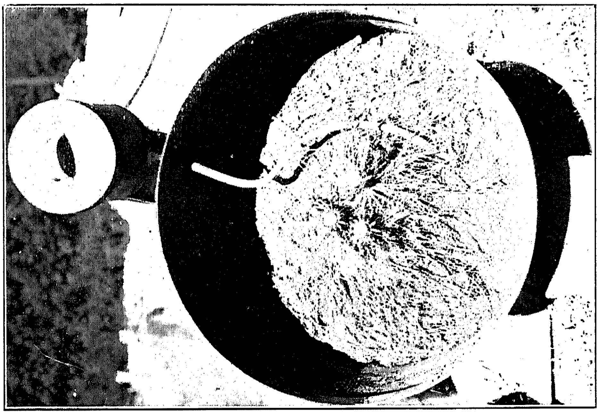


Fig. 14.—A 2, 1919, showing root distribution throughout the whole mass of soil in the potometer.