5-1954

The Effect of Limited Moisture Supply at Various Stages of Growth on the Development and Production of Hybrid Corn

Ralph E. Campbell
Utah State University

THE EFFECT OF LIMITED MOISTURE SUPPLY AT VARIOUS STAGES OF GROWTH ON THE DEVELOPMENT AND PRODUCTION OF HYBRID CORN

by

Ralph E. Campbell

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Agronomy

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

1954

ACKNOWLEDGMENT

The invaluable assistance and guidance in conducting these experiments and writing the thesis given by Dr. L. O. Fine is acknowledged with my most sincere thanks and appreciation. I am also grateful for the valuable suggestions and helpful criticisms of Dr. H. B. Peterson and Dr. Sterling A. Taylor.

Ralph E. Campbell

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF FIGURES

INTRODUCTION

Corn occupies from 25 to 30 percent of the crop land harvested in the United States. In recent years the acreage devoted to corn in this country has been decidedly greater than that devoted to any other cultivated crop. In 1944 its dollar value exceeded the combined values of wheat, barley, rye, grain sorghums, and cotton.

Although South Dakota lies on the northwestern fringe of the corn belt, the corn crop is one of the most important in that state. Corn production in that area is somewhat unstable because of drought. Corn often fails to reach full maturity before the first frost in the fall. This is particularly true when frost comes unseasonably early.

An irrigation project has been proposed for the James River Basin Area of South Dakota. It is a part of the Missouri River Basin Development Project. The introduction of irrigation into this area can somewhat lessen the dangers of drought and early frost. Moisture requirements of the corn crop can be met by proper water applications. In this way the threat of crop failure as a result of drought can be reduced. The corn maturity can be hastened through correct land management and irrigation practices, thus alleviating the danger of early frost.

Very little information is available regarding the management of corn grown under irrigation in the Northern Great Plains Region. The problems associated with corn production are peculiar to that area. More complete information is needed concerning the specific needs of the corn crop in the James River Basin.

The work reported here shows some of the relationships between the development and growth of corn and soil moisture supply. The objectives of the study were twofold: to determine the periods of corn development in which abundant moisture is most critical, and to determine the effects of a limited moisture supply at various growth stages upon the development and production of hybrid corn. The results of field and greenhouse studies are reported.

REVIEW OF LITERATURE

Introduction

Soil moisture influences upon plant growth are often difficult to measure because they are inseparably related to other growth factors, and because of the dynamic characteristics of the plant and the environment in which the plant exists. Many attempts have been made to determine the effects of moisture and its availability upon plant development and associated processes.

Effect on physiology

The reports on the effects of moisture supply on plant processes are many. A few of the more important papers are here reviewed. Eaton and Ergle (9) have made a fairly comprehensive review on the influence of low moisture supply on the accumulation of carbohydrates in plants. From their work they concluded that the grasses in general appear to accumulate carbohydrates when moisture limits growth. Drought appeared to depress carbohydrate utilization to a greater extent than photosynthesis in the cotton plant.

Miller (24), in studies with winter wheat, found that below certain moisture levels the rate of photosynthesis seemed to be reduced progressively with desiccation. Verduin and Loomis (42) found CO_2 absorbed by wilted corn leaves to average 37 percent of that absorbed by turgid leaves.

Grandfield (12) noted rapid accumulations of carbohydrate reserves in roots of alfalfa making limited growth because of low moisture supply. That is, accumulation exceeded utilization. He further stated that the increase in carbohydrates and nitrogen in buds was closely associated with reduction in free water. Willard (48), working with alfalfa, found periods of drought to be associated with unusual increases in the dry weight of the roots. Wadleigh and Ayers (43), in growing red kidney beans, found that high soil moisture tension caused a decrease in the starch content in the leaves but had no effect on the content of either the reducing or non-reducing sugars. They found that increased soil moisture stress greatly increased the nitrate content in the plant. The soluble organic nitrogen increased to a lesser degree; as a result the ratio of nitrate to soluble organic nitrogen increased.

Emmert (10), in studies with tomato plants, found that limited moisture availability reduced uptake of nitrates but reduced their utilization even more, so that there was an accumulation of nitrates in the plant. This reduced utilization may have resulted from a decrease in phosphate percentage. He found phosphate content lower in plants grown in dry soil, apparently resulting from a lack of availability of phosphorus in the dry soil.

Wadleigh and Richards (36) pointed out that for a given level of soil fertility, decreasing moisture supply was associated with a definite increase in nitrogen content of the plant tissue. A definite decrease in potassium content, and a variable effect on the content of phosphorus, calcium, and magnesium was associated with decreasing moisture supply.

In reporting studies with barley grown in sand cultures, Ratner (27) observed that with adequate moisture, high nutrient supplies resulted in excessive uptake of minerals by the roots. He concluded that restricting the water results in a change in the colloidal properties of the root tissues which inhibits the excessive absorption of minerals.

Effect on germination

Several authors are quite in agreement on seed germination requirements (2, 8, 17, 38). The effect of increased soil moisture stress is to delay the time required for germination and to reduce the percentage of seeds germinating. If stress is a result of high concentration of salt, reduced germination may be due to toxicity of specific ions (38). Onion seeds planted in fine, sandy loam soil (field capacity 20 percent, wilting percentage of 5.8) were unimpaired in percent germination with a moisture level of 8.2 percent. This moisture level slightly delayed emergence, however (2). Moisture levels of 7.2 and 6.1 percent decidedly decreased percent germination as well as delaying time of emergence. Other work has borne out these findings, except that the seeds of some crop plants germinate at higher soil moisture stress than others (8). Several of the crops, including cabbage, sunflower, sweet corn, turnip and radish, appeared to germinate at moisture percentages slightly below the reported wilting percentage. Hunter and Erickson (17) concluded that in order for seeds to germinate, each species has to attain a specific moisture content. The minimum moisture content for germination as found in this experiment was approximately 30.5 percent for corn, 26.5 percent for rice, 50.0 percent for soybeans, and 31.0 percent for sugar beet seeds. They found that the soil must be maintained at a moisture tension of not more than 12.5 atmospheres to germinate corn kernels, 7.9 atmospheres for rice, 6.6 atmospheres for soybeans, and 3.5 atmospheres for segmented sugar beet seed.

Moisture availability and plant growth

Movement of water in soil at a moisture content below field capacity is extremely slow. Probably water will not move more than a few centimeters toward the plant roots in quantity or at a sufficiently rapid rate to be of practical benefit. There appears to be little flow of liquid water at tensions greater than one atmosphere, and with moderate gradients of the moisture potential. Considerable soil moisture probably becomes available as the roots come in contact with it as a result of their elongation through the soil (19, 26).

Weaver (46) found the volume, but not necessarily the weight of corn roots in a dry soil to be almost twice that of roots in a moist soil. Shank (30) found the top : root ratio in hybrid corn to be practically unchanged in the moisture range between field capacity and permanent wilting percentage. He observed that top growth increased in relation to the roots at moisture levels above field capacity.

A constitution theory has been advanced by Baumann (3). His studies in water supply to crop plants showed the possibility of equally high yields in spite of different water supply. The water requirement of the plant during the whole growth period depends on the water supply to which the plant adapts itself during the early growth stage. Thus, the plant might be capable of adapting to a relatively zerophytic or hydrophytic constitution.

Van der Paauw (39) concluded that the rate of growth in length of leaves of oats was little influenced by moisture supply. This seems to be in disagreement to the result Davis (6) obtained in growing corn. Davis found that growth of leaves was slowed by decreasing moisture availability. Similar results were obtained with cotton plants by Wadleigh and Gauch (44). They found that leaf elongation virtually ceased at high soil moisture stress. Growth resumed when the stress was lowered by irrigation. "Rate of change in leaf length decreased in a straight line relationship with increased soil moisture stress."

Henrici (16) made observations on alfalfa crops in the semi-arid parts of South Africa. The plants are in a state of incipient drying or of water deficiency, except during the rainy periods. They do not show signs of wilting, however. Incipient drying with subsequent recovery occurs every warm day unless the crops are irrigated. He observed that if this process continues in a soil with insufficient moisture, death will ultimately occur.

Range of availability

Veihmeyer and Hendrickson (40, 41) have carried out rather extensive studies on the availability of soil moisture between field capacity and permanent wilting percentage. They have concluded that the soil moisture within this range for all practical purposes, is equally available to the plant. Somewhat similar findings have also been reported by others (22).

Wadleigh and Richards (36) point out that more osmotic work is required for the entry of water into a plant when the water is restrained by a force of 15 atmospheres than when it is restrained by a force of 0.1 atmospheres.

The greatest part of the available water is removed from the soil before there is an appreciable moisture stress increase. This is due to the hyperbolic nature of the relation between moisture content and moisture retention in a soil. This may in part explain the difference between conclusions drawn by Veihmeyer and Hendrickson and the findings of others (1, 7, 19, 23, 34, 45).

Dolgov (7) determined soil moisture availability to the plant by measuring the rate of transpiration of oat plants. He found that transpiration was greatest at field capacity and decreased to a minimum at the wilting point. Taylor (34) found a straight line relationship between plant growth and mean integrated soil moisture tension (35) using sugar beets, alfalfa and potatoes. Yields decreased uniformly as the mean integrated soil moisture stress increased from 0 to 4 atmospheres. Wadleigh and Gauch (44) measured the rate of leaf elongation on cotton plants as affected by soil moisture stress. They found that the rate of change in leaf length decreased in a straight line relationship with increased soil moisture stress. Growth of the plant was checked by a turgor deficit before any visible sign of wilting appeared. Similarly, Furr and Reeve (11) found that the rate of elongation of the central stem of the sunflower plant continuously decreased as the soil moisture was depleted from moisture equivalent to the wilting percentage. Elongation ceased at approximately the soil moisture content they identified as the first permanent wilting percentage. Later studies were made by Blair, Richards and Campbell (4) with dwarf sunflowers on six soils. Their work indicated that the rate of stem elongation was markedly reduced before half of the available soil moisture was depleted. The rate of stem elongation dropped to zero during extraction of the last quarter of the available water before attainment of the permanent wilting percentage. Keisselbach (20) found that no more water was transpired by corn plants of the same percentage growing in wet soil than by those growing in much dryer soil. This was true provided that the soil was not so dry that the plants wilted. Less water was used in producing a given dry weight on soil containing the smaller amount of water. The decrease in yield was proportionately greater, however.

Growth stages

Until recently the effects of moisture on plant growth at various stages of development have been studied only to a limited degree. Harris (14) did some work with wheat in 1914, using three stages of growth with a high and a low moisture level maintained. Concerning his moisture levels, Kramer (19) points out:

> Numerous attempts have been made to grow plants at various moisture contents between field capacity and permanent wilting percentage. It is impossible to half wet a soil, however, and it appears practically impossible to permanently maintain any intermediate moisture contents. If insufficient water is added to a soil mass to wet it all to the field capacity, a part of it will be wetted to the field capacity and the remainder will remain unaffected.

In some studies with oats, Van der Paauw (39) found that drought occurring "comparatively early" had the greatest effect on the straw yield. Drought beginning later had the most pronounced effect on the grain yield. Most serious damage on the grain occurred when drought prevailed in the period just before or during emergence of the panicle.

Haddock (13), in his work with sugar beets, concluded that the total amount of irrigation water required to produce a crop of sugar beets in Utah may be of less importance than the time at which the water is applied. He found that the most important time to keep beets growing actively, if there is a critical time in Utah, appears to be before August.

The effects of varying moisture supply on the corn plant at different growth periods were studied in pots by Miller and Duley (25). They found that the moisture supply from the time the plants set their ninth leaves until about tasseling had the greatest effect upon the total dry weight of the plant. Plants stunted by minimum moisture supply during the first stage, or until the ninth leaves were set, were able to recover. Time of maturity was somewhat prolonged, however. Low moisture caused greater root growth in relation to the tops than did optimum moisture in all periods. Optimum moisture in the third stage, from tasseling to maturity brought about considerably greater production of grain than did low moisture. The effect of moisture level on ear production was somewhat less in the second period and appreciably less in the first period of growth.

Kiesselbach (21) found that the way in which corn plants responded to drought depended upon the stage of growth in which the moisture deficiency occurred. Severe early drought resulted in stunted plant size and delayed silking in relation to time of tasseling. Some plants failed to silk and tassels were often partially or completely sterile. If water depletion occurs after pollination, the ears may shorten by drying back from the tips.

Howe and Rhoades[1] have reported some rather detailed studies on irrigation practices for corn production in relation to stage of plant development. Their experimental work was conducted in western Nebraska on a Tripp very fine sandy loam soil with about 7.2 inches of rainfall during the growing season. They found that six irrigations through the growing season gave maximum corn yield. Less than three irrigations were inadequate. They reported that adequate moisture supply was essential during tasseling and silking stages. Singleton (31) emphasized the importance of an abundant supply of soil moisture during the time of tasseling and silking.

Robins and Domingo (29) found that moisture depletion to near the wilting percentage during the tasseling and pollination period brought

---

1. Irrigation practice for corn production in relation to stage of plant development. Unpublished report.

about marked yield reductions. Such a water deficit occurring for one or two days caused a 22 percent yield reduction. The deficit occurring over a six to eight day period caused a yield reduction of about 50 percent. They reported that absence of available water after the tasseling and silking period reduced yields in relation to the maturity of the grain. Water deficits in growth stages before tasseling caused stunting of growth and retarded development.

METHODS AND RESULTS OF FIELD EXPERIMENT

Description of area

The Bureau of Reclamation Irrigation Development Farm, on which this experiment was conducted, is located in Spink County, South Dakota, approximately seven miles east of the town of Redfield, the county seat. The farm is about 86 miles east and 21 miles north of a point in the center of the state.

The principal drainage feature of the area is the James River, which runs within one half mile of the farm. It is from this river that the water required for irrigating the farm is pumped. The farm is on a higher elevation than the river flood plain and is relatively flat.

Spink County occurs on the western edge of the Chernozem region; the zonal soils here are considered to be Chernozems. Due to the flatness of the topography many intrazonal, solonetz soils occur. The soil on which the experiment was conducted is a Beotia silt loam, minimal profile (47). It is a well drained, zonal soil, developed in laminated lacustrine silts and clays, and found on nearly level to undulating topography in the Lake Dakota Basin.

> The term minimal as here used refers to a profile which is young from the standpoint of soil formation. Although some water has been leached through the profile, the main result has been the removal of only the most soluble constituents down to the horizon of lime accumulation (47).

The A horizon (0-6") when dry is dark gray to dark grayish-brown, very friable and noncalcareous.

The B_1 horizon (16-23") is light brownish-gray to light yellowish-brown when dry, very friable, non-calcareous silt loam of weakly developed medium prismatic primary structure breaking to moderately well developed coarse granular structure. The C_{ca} (23-56") is pale yellow, very friable, calcareous silt loam of weakly developed medium granular structure. The 56-66" depth is very friable calcareous silt loam of moderately well developed medium laminations.

Analyses characterizing Beotia silt loam are presented in tables 2, 3, and 4. Further analyses of the soil of the field used for these experiments are shown in table 1. These analyses differ slightly from those shown in tables 2, 3, and 4, since the latter characterize the soil generally, and table 1 shows the analyses of a specific field.

Table 1. Some chemical and physical analyses characterizing Beotia silt loam in field number 5, Redfield Development Farm, South Dakota*

Saturation percentage	52 percent
pH paste	5.9
saturated extract	6.1
Available potassium	800 lb./acre

* Analyses run by South Dakota State Soil Testing Laboratory.

Climatic conditions

Except for a low of 32° on May 18, the 1952 growing season opened on April 10. The last two weeks of April were very warm, causing rather high soil temperatures and rapid emergence of crops planted at that time. Soil temperatures at the 6" depth as high as 58°F. were recorded in early May. The air temperature dropped to 32° on September 19, but growth of all crops continued until maturity or until a hard freeze on October 3.

All months of the growing season except June were below average in precipitation. This condition of low rainfall made ideal conditions

Table 2. Chemical analysis of Beotia silt loam, deep solum minimal, from Spink County, South Dakota, 1949

Horizon and Depth		Salts Bureau Cup Percent	pH paste	Carbonates Percent	Total Exchange Capacity me/100 gm	Exchangeable Cations me per 100 grams					Soluble Cations me per 100 grams	
						Ca	Mg	Na	K	H	Na	K
A_1	0-10"	.03	7.0	0.0	24.36	17.89	4.92	0.10	1.20	0.2	0.17	0.33
A_3	10-16"	.03	7.0	0.0	22.30	15.57	5.81	0.10	.82	**	0.17	0.14
B_1	16-23"	.04	7.3	0.0	21.85	14.85	6.18	0.24	.58	**	0.09	0.09
C_{1ca}	23-56"	.03	8.2	20.30	**	*	*	0.61	**	**	0.26	0.04
C_2	56-66"	.09	8.2	18.86	**	*	*	0.01	**	**	1.30	0.03

*Calcareous samples, cations not determined.
**Figures unavailable.

Analyst: G. B. Lee, Agronomy Department, South Dakota State College, Brookings, South Dakota.

South Dakota Soil number 49-SD-58-4.

Table 3. Mechanical analysis and organic carbon of Beotia silt loam, deep solum minimal from Spink County, South Dakota, 1949

Horizon and Depth		Organic Carbon Percent	Size classes and diameter of particles (mm): Very Coarse Sand 2-1 %	Coarse Sand 1-0.5 %	Medium Sand 0.5-0.25 %	Fine Sand 0.25-0.1 %	Very Fine Sand 0.1-0.05 %	Silt 0.05-0.002 %	Clay <0.002 %	Other Classes: Medium and Fine Silt 0.02-0.002 %	> 2 %
A_1	0-10"	2.95	0.3	0.6	0.2	1.0	7.1	66.5	24.3	32.5	0
A_3	10-16"	1.50	0.2	0.2	0.2	0.7	8.3	65.1	25.3	32.1	0
B_1	16-23"	0.90	0.0	0.0	0.0	0.4	6.1	70.0	23.5	35.8	0
C_{1ca}	23-56"	0.29	0.0	0.0	0.0	0.2	3.6	81.8	14.4	41.0	0
C_2	56-66"	0.25	0.0	0.0	0.0	0.4	4.9	80.5	14.2	43.0	.5

Analyst: Soils Laboratory, Bureau of Plant Industry, Soils and Agricultural Engineering, Beltsville, Maryland.

South Dakota soil number 49-SD-58-4

Table 4. Physical properties and soil organic matter of Beotia silt loam, deep solum, medial, 1950

Horizon and Depth		Bulk Density	Moisture Equivalent (% H_2O)	1/3 atmos. (% H_2O)	15 atmos. (% H_2O)	100 cm water (% H_2O)	% Organic Carbon	% Total Nitrogen	Carbon/Nitrogen ratio
A_1	0-8"	1.20	28.9	35.8	14.2	46.6	2.35	0.204	11.5
A_2	8-11"	1.26	26.1	31.2	14.9	41.3	1.03	0.117	8.8
B_1	11-16"	1.49	28.5	33.2	16.4	40.5	0.89	0.106	8.4
B_3	16-21"	1.28	27.6	33.7	13.5	42.4	0.75	0.086	8.7
C_{1ca}	21-31"	1.38	27.9	33.4	13.8	41.0	0.28	0.035	8.0
C_1	31-46"	1.31	37.4	43.7	16.5	51.3	0.31	0.038	8.2
C_{21}	46-60"	1.31	43.7	52.0	17.6	59.6	0.25	0.034	7.4
C_{22}	60-80"	1.32	43.2	51.7	32.2	59.5	0.19	0.037	5.1

Analyst: J. R. McHenry, Soil Laboratory, Bureau of Plant Industry, Soils and Agricultural Engineering.

South Dakota soil number S-50-SD-58-4-(1-9).

for a study such as the one here reported. The growing season was about normal as to temperature except for the warm early spring. A summary of the weather information at Redfield for 1952, compiled from climatological data (37) is presented in table 5.

Table 5. Climatic summary for Redfield, South Dakota, April through October, 1952

Month	Precipitation			Mean Temperature		
	1952	50 year Average	Departure From Average	1952	50 year Average	Departure From Average
April	0.22	1.97	-1.75	48.2	45.7	2.5
May	0.59	2.62	-2.03	56.5	57.5	-1.0
June	5.92	3.27	+2.65	69.4	67.2	2.2
July	0.97	2.36	-1.39	71.4	73.5	-2.1
August	1.38	2.53	-1.15	69.4	71.4	-2.0
September	0.05	1.68	-1.63	64.2	61.4	2.8
October	0.0	1.25	-1.25	44.3	48.5	-4.2
Total	9.13	15.68	-6.55			

The bright, warm days throughout May, June, July, and August were favorable for the development of corn. Although temperatures were not above normal for the season as a whole, they were slightly above for June and September. These two months usually are the most critical for corn development in South Dakota. Consequently, corn was fully matured by about the tenth of September.

Experimental plan

A field experiment was set out in a randomized block design using four replications. The plots were three rows (9 feet) wide, and ran the full length of the field, about 200 feet. Eight plots in each block were set side by side within the block. Four replications were set side by side in the experiment. An extra border row was put on each side. The entire experiment covered an area 300 feet wide by 200 feet long.

There was an abundant moisture supply throughout the month of June, consequently it was impossible to impose any moisture differential between the corn plots until the second week in July. Two moisture levels were planned: (1) Moisture in the root zone kept below two atmospheres tension (hereafter referred to as "M" moisture level); and (2) moisture tension in the root zone allowed to reach approximately ten atmospheres before irrigating (hereafter referred to as "O" moisture level).

The physiological development of the corn plant was divided into three stages for the purposes of this experiment. These stages were: (1) Early tasseling to "brown silk" or until kernels just began to fill; (2) brown silk to early roasting ear (21); and (3) early roasting ear to maturity.

The moisture treatments used are presented in table 6 showing the combinations of stage of growth and moisture level.

An adapted variety of hybrid corn, recommended for the Spink County area, was chosen for the experiment. The corn, Funk's G-6, was planted with a four-row corn planter in rows 36 inches apart on May 13, 1952. The planter was set to place the seed eight inches apart in the row. It was planned to thin the stand later to allow about 12 inches between plants, but this was found unnecessary. The stand obtained was about 14,500 plants per acre.

All plots were side dressed with ammonium nitrate fertilizer at a rate of 50 pounds nitrogen per acre at the time of second cultivation,

Table 6. Moisture treatments at three stages of growth used in field experiment with hybrid corn

Treatment No.	High moisture through growth stages	Low moisture through growth stages	Moisture Stage 1	level Stage 2	through Stage 3
1	1, 2, 3	None	M*	M	M
2	1, 2	3	M	M	O*
3	1, 3	2	M	O	M
4	1	2, 3	M	O	O
5	2, 3	1	O	M	M
6	2	1, 3	O	M	O
7	3	1, 2	O	O	M
8	None	1, 2, 3	O	O	O

* M - high moisture level. O - low moisture level.

when the corn was about two feet high. This was done to insure adequate and uniform fertility throughout the experiment. Corn grown on the farm has consistently failed to respond to application of phosphate fertilizer; consequently, it was assumed that the available soil phosphorus was adequate for maximum growth.

Moisture control and irrigation

Fiberglass electrical resistance units[1] were installed in all plots of two replications. They were placed in the corn rows at 9", 18", and 27" depths. The resistance readings of these units were recorded periodically, using the Berkeley Scientific Company model 300 Ohmeter. Because of the unreliability of these moisture block data, they are not included in this paper. The variability in readings

1. Units developed by E. A. Coleman, California Forest and Range Experiment Station.

between plots and the unreliability of the readings made these units unsatisfactory for determining the need for irrigation. Thus, other means had to be used. Corn fields on the farm were using water at the rate of about 0.2 inches per day. It was estimated that about 2 to 2.5 inches of water were applied per irrigation. Irrigations were made approximately weekly. On this basis the soil reservoir could be kept full enough to insure an adequate moisture supply for the growing crop. Periodic checks of the soil confirmed these assumptions.

A moisture differential was imposed from July 16 until the grain was approximately mature. The irrigations were made to correspond with the growth stages. Thus, on August 5, the beginning of the second or brown silk to early roasting ear stage, treatments 1, 2, 5, and 6 were irrigated. Only treatments 1 through 4 had been irrigated through the first period. Appearance of the experiment and the mode of irrigation is illustrated in figure 1.

The dates of irrigation of the various treatments are presented in table 7. Treatments 7 and 8 were given a very light application of water on August 5 to prevent complete loss of the crop. Sufficient moisture was stored by the September 3 irrigation to carry the crop to maturity.

On August 6, counts were made on all plots to determine what percentage of silks were mature. Number of brown silks per 50 plants in each plot was recorded.

<u>Harvest</u>

All plots were harvested on September 30. The center row of each plot was used for yield determinations. Two sections of row each 60 feet long were picked, one toward the top of the row, the other toward

Figure 1. View of field experiment and method of irrigation, Redfield, South Dakota, 1952.

the bottom. The purpose of harvesting these two sections of row was to detect any possible moisture differential between the top and the bottom of the row.

Yields were calculated as bushels of shelled corn per acre at 15 percent moisture on the basis of 56 pounds shelled corn per bushel.

Counts were made on the number of ears harvested from each plot. Moisture content of the ear corn was also determined. A representative sample of 10 ears from each 60-foot plot was selected, and a 1-inch thick section was taken from each ear for the moisture determinations. These samples were weighed immediately, then later dried at 65°C. for 48 hours. The moisture content was calculated as percent water in the ear corn.

Table 7. Dates of irrigation of various treatments in field corn experiment, 1952

Treat-ment No.	Moisture levels at growth stages 1, 2, & 3, resp.			Date of irrigation		
1	M	M	M	July 16, 24, 29	August 5, 12, 20	Sept. 3
2	M	M	O	" " " "	" " " "	
3	M	O	M	" " " "		" "
4	M	O	O	" " " "		
5	O	M	M		" " "	" "
6	O	M	O		" " "	
7	O	O	M		August 5 (light)	" "
8	O	O	O		August 5 (light)	

Twenty ears from each plot were used for determining shelling percentage, which was calculated as percent shelled corn in ear corn.

Results

Corn grew rapidly without benefit of irrigation during favorable growing conditions in the spring and early summer. Low moisture plots began to suffer from lack of sufficient moisture after the second week of July, however. Plant growth was slowed and development retarded. By August 6th, two-thirds of the ears on high moisture plots had mature silks. On the other hand, just over one-third of the silks were browned on the low moisture plots. The brown-silk counts taken are shown in table 8.

Moisture content of the ear corn at harvest was used as an index to corn maturity. These data are presented in table 9. An analysis of the moisture data showed no difference between the two subplots within

Table 8. Number of brown silks per 50 corn plants in various treatments on August 6

Moisture Level	Treatment No.	Number of brown silks Rep 1	Rep 2	Rep 3	Rep 4	Average
High	1	35	31	37	24	32
	2	31	29	29	35	31
	3	33	44	40	37	38
	4	36	34	25	29	31
	Average	34	34	33	31	33
Low	5	16	3	5	34	14
	6	21	6	25	27	20
	7	22	8	15	28	18
	8	7	10	22	33	18
	Average	16	7	17	30	18

each plot. The data in table 9 are averages of four replications including two subplots in each plot.

Table 9. Corn maturity, shown as moisture content of ear corn at harvest from Redfield field experiment, 1952

No.	Treatment in St. 1	in St. 2	in St. 3		Moisture in ear corn %
1	M	M	M		26.1
2	M	M	O		26.3
3	M	O	M		24.7
4	M	O	O		22.0
5	O	M	M		33.4
6	O	M	O		29.8
7	O	O	M		32.1
8	O	O	O		26.2
				L. S. D. (05)	5.4

A statistical analysis of these data, the F value of which are presented in table 13, showed treatments to be significantly different at the one percent level (32). The effect of moisture level in the first stage was highly significant. Corn harvested from treatments 1 to 4 had an average moisture content of 24.0 percent, as compared to 30.4 percent in that from treatments 5 to 8. In other words, high moisture in the first stage of growth hastened maturity. On the other hand, maturity was delayed by high moisture level in the third stage. The average moisture contents of the corn from the M and the O plots in the third growth stage were 29.1 percent and 25.3 percent, respectively. These were significantly different at the 1 percent level. Soil moisture differences in the second growth stage had no appreciable effect upon maturity.

Ear counts were taken on all plots harvested. These data, presented in table 10, are averages of four replications.

Table 10. Ear counts of corn harvested from plots receiving various moisture treatments. Data indicate number of ears harvested per 60 feet of row

Treatment No.	Number of Ears	Treatment No.	Number of Ears
1	55	5	47
2	55	6	51
3	55	7	52
4	50	8	45

The differences between treatments in number of ears harvested were slight and proved to be insignificant in an analysis of variance.

Shelling percentages were likewise unaffected by soil moisture treatment at the three stages of growth involved, according to an analysis of variance. A tendency was shown for grain harvested from treatments one to four to have a slightly higher percentage, however. The shelling percentage data are presented in table 11. Each figure is an average of four replications.

Table 11. Shelling percentage of corn from 1952 field experiment with variously treated moisture plots

Treatment No.	Shelling Percentage	Treatment No.	Shelling Percentage
1	84.6	5	83.1
2	84.6	6	83.8
3	85.0	7	83.4
4	84.4	8	83.2

Yields from each plot were calculated and are presented as bushels per acre of shelled corn at 15 percent moisture. Yield calculations are based on an assumed shelling percentage of 80. Thus, 70 pounds of ear corn is equal to 56 pounds of shelled corn. Since the overall shelling percentage of corn from this experiment was 84, the yields shown may be as much as 5 percent below actual yields of shelled corn.

Yields obtained from this experiment are presented in table 12. This table is divided into two parts. Yields are shown by individual treatment on the left. On the right the treatments are grouped to show the effect of moisture level in each growth stage without regard to treatment in the other two stages of growth. Yields shown for each individual treatment are averages of four replications. Each replication includes two sub-plot samplings in each plot.

Table 12. Yields in bushels of shelled corn at 15 percent moisture as affected by soil moisture treatment at various growth stages. Redfield field experiment, 1952

No.	Treatment			Corn produced bu/acre	Stage at which moisture level was imposed	Moisture level	Treatments grouped for comparison	Average Yield
1	M	M	M	101.5	Stage 1	M	1, 2, 3, 4	96.6
2	M	M	O	95.9		O	5, 6, 7, 8	66.0
3	M	O	M	100.0				
4	M	O	O	89.1	Stage 2	M	1, 2, 5, 6	82.5
5	O	M	M	58.2		O	3, 4, 7, 8	80.1
6	O	M	O	74.6				
7	O	O	M	67.5	Stage 3	M	1, 3, 5, 7	81.8
8	O	O	O	63.8		O	2, 4, 6, 8	80.9
L. S. D. (.05) = 22.6						L. S. D. (.05) = 11.3		

The mean square for treatment was found to be significant at the 1 percent level, in a statistical analysis of these yield data. In breaking this down to individual degrees of freedom, the source of variation was found largely due to differences between moisture treatment in stage one. As can be seen in table 12, moisture differences in stages two and three had very little effect on yields produced. The replication X treatment interaction was also significant. The analysis showed no significant difference between samples taken at the top of the row and those from the bottom.

Table 13. F values from analysis of variance of data from field corn experiment

Source of Variance	D. F.	Brown silk Counts August 6	Number Ears Harvested	Maturity	Shelling Percent-age	Grain Yield
Treatment	7	4.08**	1.08	5.34**	0.92	5.09**
Moisture level in						
Stage 1	1	25.63*	1.69	25.14**	0.11	31.70**
Stage 2	1	---	.19	1.85	0.00	0.20
Stage 3	1	---	.28	9.13**	0.68	0.03
Replications	3	1.91	.31	1.60	3.83*	2.82
Rep. X Treat. (Error A)	21	---	3.00**	3.13**	---	6.15**
Position	1	---	.06	0.79	---	0.08
Treat. X Position	7	---	1.77	0.52	---	2.31

* Significant at the .05 level.
** Significant at the .01 level.

Figure 2. Comparison of yield obtained from treatments 4 (left) and 5 (right) in field experiment.

Figure 2 illustrates a plot yield of treatment 4 (left) which received adequate moisture supply until the time of silk browning. In comparison is the yield of a plot receiving treatment 5 (right) in which the crop was deprived of adequate moisture supply from the time of tasseling to the time most plots had reached the silk browning stage. The corn in treatment 5 was slightly delayed in maturity and much of it was incompletely pollinated. The ears were generally quite small in comparison to treatment 4. Some of the kernels near the ends of the ears harvested from treatment 4 were somewhat shrunken.

Figure 3. Comparison of yield obtained from treatments 1 (left) and 7 (right) in field experiment.

Yield produced from treatment 1, which had adequate moisture throughout the growing season, is illustrated in figure 3 (left). The yield of treatment 7 (right) was deprived of a readily available moisture supply from the time of tasseling until most plots had reached the early roasting ear stage. Not only did limited moisture supply in treatment 7 reduce yield, but caused a delay in maturity as well.

The correlation coefficient was determined relating treatment yields in each replication to the brown silk count of August 6 in the corresponding plots. A very close correlation was found. The correlation coefficient was 0.844 which is highly significant for the 32 pairs of samples tested.

A close negative correlation existed between the brown silk count and moisture content of the ear corn at harvest time. The correlation coefficient was - 0.622, which is highly significant.

METHODS AND RESULTS OF GREENHOUSE EXPERIMENT

Experimental plan and procedure

A greenhouse pot experiment was set up in the Agronomy Department Greenhouse at South Dakota State College in Brookings. The purpose of this experiment and the objectives to be reached were similar to those of the field study at Redfield. The moisture supply in this experiment, however, could be more closely regulated. The various levels could be imposed at an earlier stage of growth than was possible in the field experiment. Thus, it was possible to observe the effect of limited moisture supply in the growth period preceding tasseling.

In the greenhouse experiment three physiological stages were chosen: (1) seedling to tasseling; (2) tasseling to early roasting ear stage; and (3) early roasting ear stage to maturity. The time of imposing the second and third growth stages was determined by the development of those plants which had received high moisture treatment from the beginning of the experiment. The retarding effects of the low moisture supply made this necessary.

Two moisture regimes were maintained as in the field experiment. Under "M", or high moisture level, soil moisture in the pot was maintained at a stress of less than two atmospheres. Under "O", or low moisture content, soil moisture tension was allowed to reach approximately 10 atmospheres before the soil received irrigation.

The treatment designations were the same as those used in the field experiment shown in table 6. The eight treatments were replicated five times. The pots were set out on the greenhouse bench in a randomized block design, four pots across the table. Each replication was two pots deep and the fifth replication was set across the end. All pots were re-randomized twice through the duration of the experiment to minimize errors due to position.

The soil for the experiment was brought from the Redfield Farm from the same field on which the field experiment was conducted. The soil was passed through a one-half inch screen, mixed and placed in 3 gallon pots with 11 kilograms of dry soil per pot.

Temperature in the greenhouse was maintained at about 72°F. throughout the experiment. The normal day length was about 10 hours. Additional lighting was supplied by four 150-watt reflector flood lamps. These lights were turned on from 10:30 P.M. to 3:30 A.M. daily. Circulation of air was increased by the use of an electric fan.

Sufficient water (2700 ml.) was added to each pot to wet all the soil in the pot to about 25 percent moisture. Soil moisture was maintained near this level until the plants were about six inches tall.

Sokota 224 hybrid corn was planted on September 29, 1952, with five kernels per pot. The stand was later thinned to three plants per pot.

The moisture differential for stage 1 was imposed on October 17. By December 6 most plants in high moisture pots were tasseling so the moisture regime of the second stage was imposed. Treatments were considered tasseling when two of the three plants in the pots had tassels showing. Moisture conditions of the third stage were imposed on December 30.

Soil moisture was measured by means of nylon electrical resistance units (5) placed at a depth of six inches. Depth of the soil in the pot was about ten inches. The resistance units were placed in 25 of the 40 pots. The units had been calibrated, using a sample of the same soil as used in the experiment, by means of the pressure membrane apparatus (28). A curve was constructed relating electrical resistance to soil moisture tension.

After the initial application of 2.7 liters of water, one liter or occasionally two liters were applied per irrigation. The amount of water applied to each treatment and the stage of growth in which it was applied are presented in table 14. Figures are averages of five replications. In no treatment did the total application vary between replications from the average by more than two liters.

Table 14. Average water applications per culture to various moisture treatments in greenhouse corn experiment

Treatment	Stage at which water was applied				Application
	Germination to Seedling	Stage 1 Seedling to tasseling	Stage 2 Tasseling to roasting ear	Stage 3 Roasting ear to maturity	
	liters	liters	liters	liters	liters
1 M M M	3.7	13.5	11.0	8.0	36.2
2 M M O	3.7	13.5	11.0	4.0	32.2
3 M O M	3.7	13.5	6.0	5.2	28.4
4 M O O	3.7	13.5	6.0	4.0	27.2
5 O M M	3.7	4.0	6.5	4.6	18.8
6 O M O	3.7	4.0	6.5	2.0	16.2
7 O O M	3.7	4.0	3.0	5.8	16.5
8 O O O	3.7	4.0	3.0	2.0	12.7

Periodic measurements on plant growth were made and records were kept on tasseling and silking. All pots were harvested on January 17, 1953. Data on both stover and grain yields were obtained.

Results

Percentage germination of the corn seed was high and plants grew uniformly until October 17 when the moisture differential was imposed. This was 20 days after planting.

Growth of the plants receiving low moisture treatment was somewhat retarded. Some wilting occurred during the day when the time for irrigation was approached, and the coil of new leaves seemed unable to open properly. The appearance of plants subjected to the two moisture levels is illustrated in figures 4 and 5. These photographs were taken at the time the moisture conditions of the second stage were imposed.

When moisture supply was depleted in treatments 3 and 4 at the onset of the second stage, the tassels stopped shedding pollen and died back, and silks stopped developing and died. These effects appeared before the plant showed signs of wilting or of otherwise suffering from lack of moisture. This bore out observations made on the field experiment.

Although growth was resumed to a limited degree on treatments 5 and 6 at the onset of stage 2, complete recovery was not affected. The plants had been permanently stunted in growth and considerably retarded in development. When the tassels appeared they were usually darkened and shrunken. Complete sterility was assumed since no pollen was shed.

When water was again supplied to treatment 3 at the beginning of the third stage, it was not effective in restoring growth. Plants in treatment 7 reacted to increased moisture supply at the onset of stage

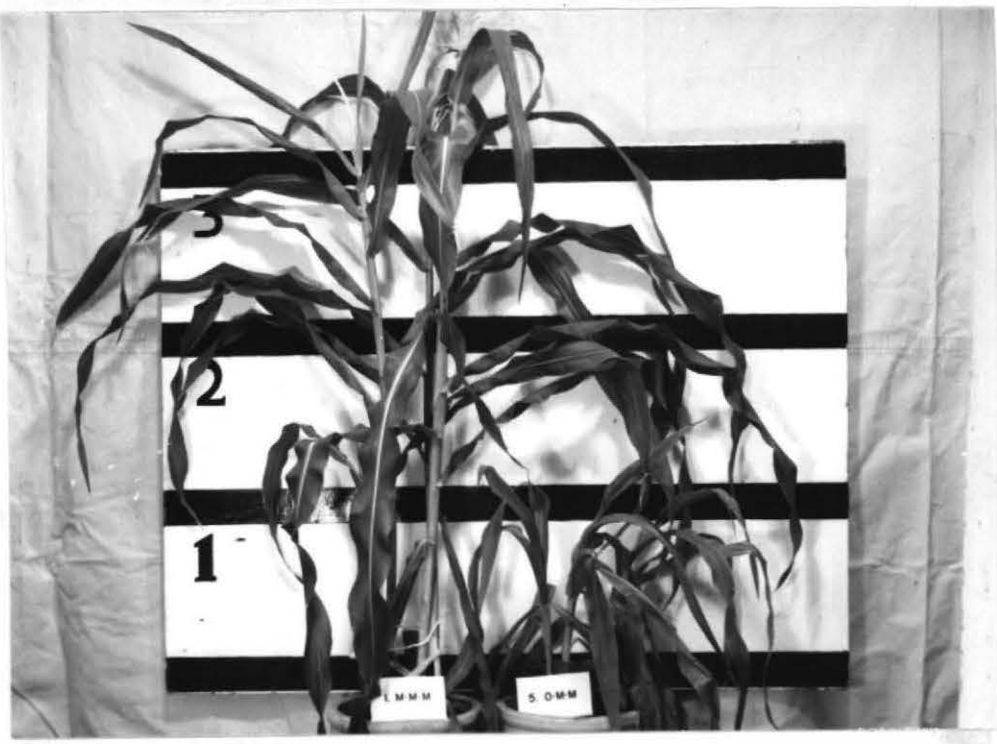


Figure 4. Appearance of moisture treatments 1 (high moisture) and 5 (low moisture) at end of stage 1. December 5, 1952.

Figure 5. Appearance of treatment 5 at end of stage 1, illustrating stunted growth and weak stalks due to low moisture supply. December 5, 1952.

3 in much the same way as they did in treatment 5 and 6 in the second stage. Some plants tasseled, but the tassels were completely sterile.

High moisture on treatment 5 in stage 3 gave the plants very little advantage over those of treatment 6 which had low moisture.

In table 15 are presented growth measurements of the plants receiving various moisture treatments. The first measurement was made near the end of the first stage. The second and third measurements

Table 15. Over-all and leaf-tip measurements of corn grown in greenhouse pots with various moisture treatments. Heights are in inches

	Nov. 14	Dec. 10		Dec. 30		Jan. 17	
Treatment	Over-all	Over-all	Leaf. tip	Over-all	Leaf-tip	Over-all	Leaf-tip
1	46	46	55	48	56	47	57
2	46	48	56	50	58	48	58
3	43	39	51	38	52	38	52
4	44	43	53	41	53	41	53
5	27	19	34	26	36	27	36
6	25	18	33	26	37	26	36
7	27	19	33	20	34	21	33
8	26	17	33	19	35	19	34

were made during the second stage and the last at harvest time. The over-all height measurement is from the soil surface to the uppermost point of the plant as it stands naturally. The leaf-tip measurement is from the soil surface to the tips of the leaves as they are extended to their full length upward. Measurements are the averages of all plants in each treatment in the experiment. Thus, each figure represents

15 individual measurements.

Silking, tasseling and ear development data are presented in table 16. Counts of silks, tassels and ears are total for the 15 plants in each treatment. Data were taken until harvest time.

Table 16. Tassel and silk development on various moisture treatments. Counts are of 15 plants in each treatment

Treatment No.	Total No. Tassels	No. of Sterile Tassels	% of Sterile Tassels	No. of Plants with Silks	No. of ears with grain at Harvest
1	15	1	6	15	15
2	15	0	0	15	14
3	14	5	36	13	0
4	14	2	14	14	3
5	12	10	83	12	0
6	10	9	90	5	1
7	9	9	100	4	0
8	4	4	100	3	0

All plants were harvested January 17. Both stover and ear yields were recorded. The grain was undeveloped on many ears. The ear weights were recorded, since they are a good indication of plant development.

Corn grain produced was also determined and shelling percentages calculated. Shelling percentages are shown in table 17. They were calculated by dividing the total weight of shelled corn produced on all replications of the treatment X 100 by the weight of ear corn produced. The ear data are presented in table 17. Weights are in grams per pot and are averages of the five replications.

The striking ear yield differences were due largely to the degree of development of the ears as were the weights of shelled corn. The moisture percentage of the ear corn also illustrated the effects of moisture supply. Especially notable was the maturing effect of reduced moisture supply from early roasting ear stage to harvest (treatment 2).

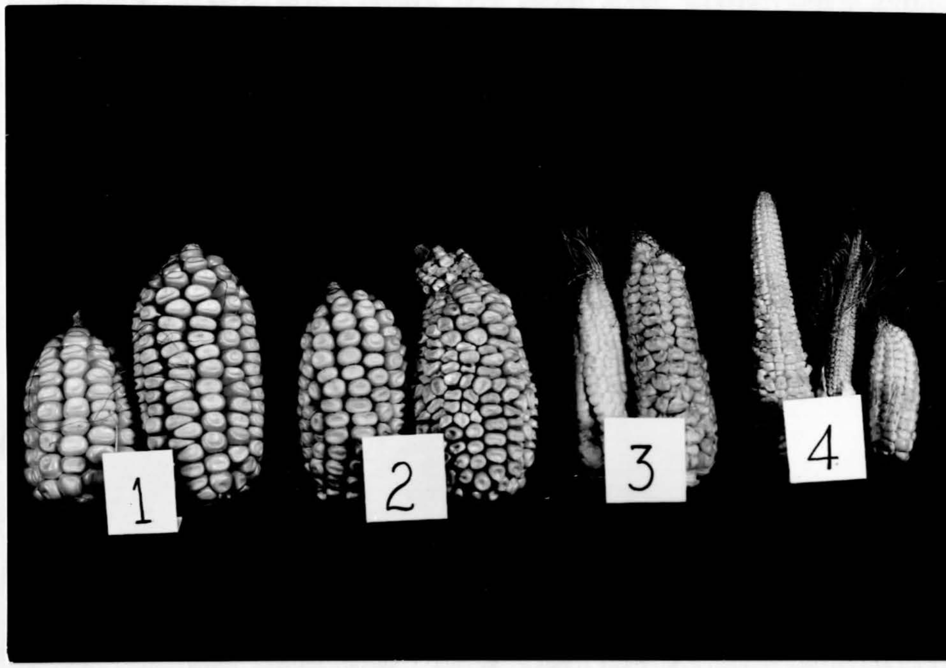
Table 17. Data on ears harvested from various moisture treatments in greenhouse corn experiment

Treat-ment	Dry ear weights at harvest grams	Fiducial interval for ear weights	Moisture content of ear corn %	Wt. shelled corn grams	Shelling percentage
1	55.8	26.1	57.2	43.4	77.9
2	54.5	7.3	37.5	39.9	73.3
3	5.5	2.6	85.2	0.0*	0.0
4	4.0	0.8	84.9	0.3	8.3
5	3.7	2.9	86.9	0.0	0.0
6	1.1	1.6	86.3	0.1	11.9
7	0.9	1.5	89.6	0.0	0.0
8	0.06	0.2	92.0	0.0	0.0

* No kernels produced.

The differences in development of ears under the various moisture treatments are illustrated in figure 6. These photographs were taken at harvest time. The cards on which the numbers appear are approximately one inch high.

The differences in ear corn yield within treatments between replications were small. A statistical analysis of the ear weight data bears this out. Treatment differences, on the other hand, were found to be highly significant (table 19). An L. S. D. of 10.0 was calculated for the treatment means. This L. S. D. was considered inadequate for testing



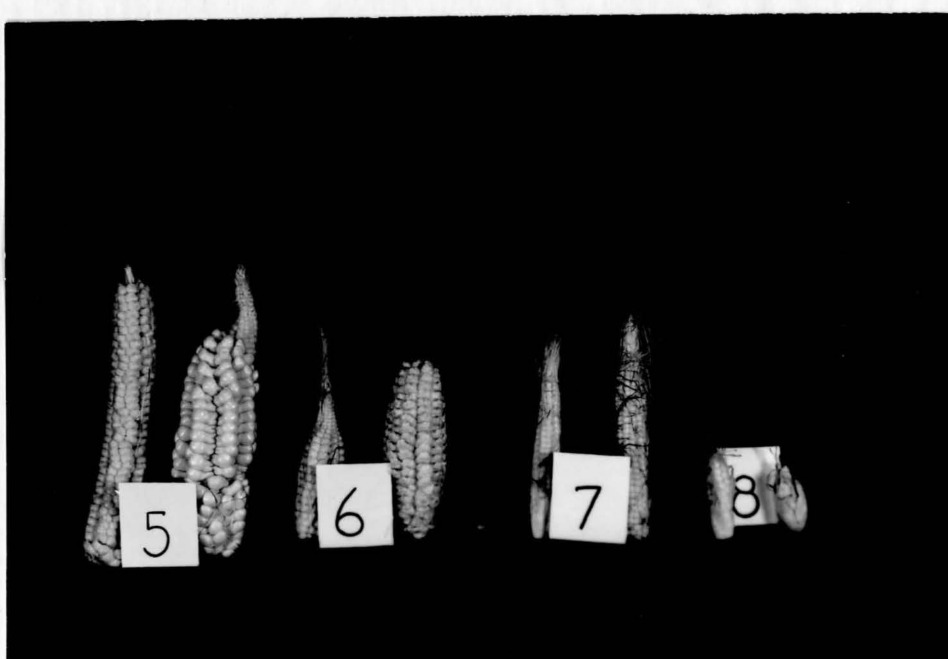


Figure 6. Condition of ears harvested from various moisture treatments as indicated, of greenhouse corn experiment. January 17, 1953.

the treatment differences, since the yields of the various treatments were of a different order of magnitude. The fiducial interval (32) was calculated for each treatment. This interval calculated at the 5 percent level is given in column 2 of table 17.

Stover yields were taken on all pots and are shown in table 18. Yields were calculated on a dry weight basis.

Table 18. Dry stover yields of greenhouse corn experiment. Data are averages of five replications

Treatment No.	Plant Wt., grams	Treatment No.	Plant Wt., grams
1	100	5	48
2	89	6	37
3	91	7	35
4	92	8	26

Table 19. F values from analysis of variance of data from greenhouse corn experiment

Source of Variance	D. F.	Ear Yields	Stover Yields
Treatments	7	50.5**	42.6
Moisture level in			
Stage 1	1	5.58*	285.0**
Stage 2	1	4.73*	4.6*
Stage 3	1	0.016	5.0*
Replication	4	1.31	1.13

* Significant at the .05 level.
** Significant at the .01 level.

Statistical analysis of the data shows a highly significant difference between treatments. The L. S. D. for treatments at the .05 level was calculated to be 14. Comparisons made between yields due to moisture differences at the three stages of growth showed that low moisture in each stage caused a significant reduction in yield (see table 19).

Correlations between stover yield and plant at the time of harvest were determined. Both over-all and leaf-tip heights showed a high correlation with plant weight. The correlation coefficients for over-all height and leaf-tip height were 0.944 and 0.972, respectively.

DISCUSSION

An examination of the data in table 8 shows some inconsistency in the mature silk counts. The variability between replications of the high moisture plots was slight. There was, on the other hand, considerable variability in mature silk counts between the replications of the low moisture treatments. This variability was attributed to a moisture gradient in the field on which the experiment was conducted. The soil moisture gradient was made evident also in differences in growth between plots. The plants in the low moisture treatments of replication 2 were considerably stunted in growth by August 6. In the other extreme these same treatments showed little or no visible effects of moisture stress in replication 4.

These differences resulting from the field moisture gradient carried through the growing season and showed up as a replication X treatment interaction. The analysis of variance on grain yields, maturity and number of ears harvested, showed this interaction to be significant. This interaction was also supported by close correlation between grain yields and brown silk counts, and by the negative correlation between moisture content of the ear at harvest and brown silk counts.

The data from the field experiment indicate that if the corn plant has adequate moisture supply until the grain is in the early roasting ear stage, soil moisture depletion thereafter will not retard maturity, nor will yields be appreciably depressed by such depletion.

This is in agreement with the findings of Robins and Domingo (29).

Although the September 3 irrigation increased the moisture content of the ear corn, or rather retarded drying, it had no effect on the grain yield.

Ear counts, according to the analysis of variance, were unaffected by moisture treatment. However, a replication X treatment interaction appeared, as a result of the initial moisture gradient in the field.

In running the analysis of variance on the moisture content of ear corn data and on the shelling percentage data, a transformation was used, as well as the conventional analysis. The transformation used is described by Snedecor (32) and converts percentages into angles (Angle = arc sin $\sqrt{\text{percentage}}$). The F values resulting from the two methods of analysis differed only slightly. The F values derived in the analysis of the transformed data are those presented in table 13.

The grain yields in the field experiment were closely correlated with the number of browned silks as of August 6. This correlation and the indication that yields were largely determined by the soil moisture level in the first stage, is in agreement with the findings of other investigators (25, 29). The stage of development in which readily available soil moisture is most critical is during the period of pollen shedding and fertilization.

Moisture supply was controlled more closely in the greenhouse than was possible in the field experiment. As a result the growth in the low moisture pots was more severely curtailed than in the low moisture plots of the field experiment, and at an earlier period of development.

When moisture supply was depleted in the pots, top growth and development essentially stopped. Growth in height of the plant was largely determined by the moisture supply in the early stages. Thus, treatments five and six resumed growth only to a limited degree when abundant moisture was made available after December 6. Development was resumed to a limited extent, however, but was retarded and the tassels were scrawny, sterile and darkened. Some ears, although extremely retarded, may have developed mature grain if given sufficient time (see treatment 5 in figure 6). The apparent discrepancy between the effects of treatment 5 in the field experiment and the same treatment in the greenhouse experiment can be attributed to the difference in drought severity. As has been mentioned, the growth and development essentially stopped in the greenhouse when moisture was depleted. The drought condition was not so extreme in the field experiment, nor was yield as markedly reduced.

In the greenhouse experiment it was noted that when moisture supply was depleted, the tassel and silk development were severely affected before the plant showed any other visible effects of drought.

The corn grain at the upper end of the ear failed to fill properly on some plots in the field experiment. A similar condition has sometimes been attributed to, or associated with a potassium deficiency (33). It is said to be due to iron accumulations which clog the fibrovascular bundles at the nodes, thus preventing proper translocation of nutrients and water. This condition of shrunken, chaffy kernels seemed to be more prevalent on treatment 4 where moisture supply was limited in the second and third stages of growth and was attributed to this lack of moisture supply rather than to any nutrient imbalance.

Several effects of limited moisture supply on corn at various stages of growth have been fairly well established (21, 25, 29, 31).

In order to germinate, corn seed must attain a moisture content of about 30.5 percent. The soil in which it is germinated must have a moisture tension of not more than 12.5 atmospheres (17).

Indications are that the effects of limited moisture supply in the early stages of growth will be to stunt the growth of the corn plant. Although the plant may not overcome the stunting effect, it may continue to develop and produce pollen and grain when the moisture supply is replenished if the drought has not been too severe. The maturity will be delayed somewhat, however, and the yield somewhat reduced. This agrees with the findings of Kiesselbach (21), but fails to support Baumann's constitution theory (3).

If drought occurs at the time of tasseling and fertilization, the tassel and silk will be the first to suffer. If moisture depletion occurs early in this period before the silk appears, the silk will be delayed. If the water deficiency is severe, the developing silk will die back. A new ear may be produced to replace the dead one if the drought condition is alleviated.

High soil moisture tension occurring after pollination has been completed may cause the grain near the upper end of the ear to shrink. The grain will shrink on the ear and become chaffy if the water depletion is more severe.

Ears will be more quickly "cured" to the desired moisture content for picking if the soil moisture supply is allowed to be depleted after ears are fully developed. Irrigation after August 20 hastened the maturity with no measurable effects upon yields in the field experiment here reported. Moisture depletion in stage 3 of the greenhouse experiment considerably reduced the moisture content of the ears produced in treatment 2 with no ill effects upon dry matter yield.

Many questions still remain concerning the effects of soil moisture depletion on corn growth and development. The limitations of the studies reported in this paper are recognized. More accurate soil moisture measurement in relation to the corn plant is desirable. More information is also needed regarding the degree of availability of the soil moisture and its effect at various short periods of growth. Nutrient balance in relation to short periods of drought also needs some further study.

SUMMARY AND CONCLUSIONS

Two experiments were conducted on Beotia silt loam soil using hybrid corn.

A field experiment was conducted near Redfield, South Dakota. Two soil moisture regimes were maintained in combination with three physiological growth stages. High soil moisture tension maintained from tasseling until the brown silk stage resulted in retarded plant development. Thus maturity was delayed and yields were reduced.

The data showed no significant variation resulting from high soil moisture tension maintained between pollination and early roasting ear stage. High soil moisture tension maintained from early roasting ear stage to maturity hastened maturity, but had no statistically significant effect on either yield, shelling percentage, or the number of ears harvested.

Two moisture regimes were imposed at three stages of growth in a greenhouse experiment. These growth stages were seedling to tasseling, tasseling to early roasting ear stage, and early roasting ear stage to maturity.

The effects of high soil moisture tension at all stages of growth were more pronounced in the greenhouse than comparable treatments in the field.

Moisture level in the first stage of growth was more influential in determining plant growth and development than in any other stage. High soil moisture tension in the first stage decidedly stunted growth and interrupted the plant's development beyond recovery. High soil moisture tension in each of the second and third growth stages brought about additive reductions in stover and ear yields. Moisture depletion in the third stage hastened maturity but had no significant effect on yield of ears when the ears were well developed at the onset of this stage.

It appears evident that moisture limitations during some growth stages affect the development of corn differently than at other stages. The effects of limited moisture supply in the early growth stages are to limit growth and retard development. If drought is severe at the time of tasseling and silk development, the tassels may become sterile and silks will die. Thus, grain yields are limited. Ears may be smaller and kernels may be incompletely filled if moisture becomes limiting after fertilization is complete. If drought occurs after kernels are filled, maturity may be slightly hastened by this lack of water.

LITERATURE CITED

(1) Army, T. J. and Kozlowski, T. T. Availability of soil moisture for active absorption in drying soil. Plant Physiol. 26:353-362. 1951.

(2) Ayers, A. D. Seed germination as affected by soil moisture and salinity. Agron. Jour. 44:82-84. 1952.

(3) Baumann, H. [The constitutional adaptation of crop plants to the water supply.] Abs., Soils and Fert. 13: No. 577. 1950.

(4) Blair, G. Y., Richards, L. A., and Campbell, R. B. The rate of elongation of sunflower plants and the freezing point of soil moisture in relation to permanent wilting. Soil Sci. 70:431-439. 1950.

(5) Bouyoucos, G. J. Nylon electrical resistance unit for continuous measurement of soil moisture in the field. Soil Sci. 67:319-330. 1949.

(6) Davis, C. H. Absorption of soil moisture by maize roots. Bot. Gaz. 101:791-805. 1940.

(7) Dolgov, S. I. On the availability of soil moisture to the plant. Abs., Soils and Fert. 11: No. 65. 1948.

(8) Doneen, L. D. and MacGillivray, J. H. Germination (emergence) of vegetable seed as affected by different soil moisture conditions. Plant Physiol. 18:524-529. 1943.

(9) Eaton, F. M. and Ergle, D. R. Carbohydrate accumulation in the cotton plant at low moisture levels. Plant Physiol. 23:169- 1948.

(10) Emmert, E. M. Effect of drought on the nutrient levels in the tomato plant. Soil Sci. 41:67-70. 1936.

(11) Furr, J. R. and Reeve, J. O. The range of soil-moisture percentages through which plants undergo permanent wilting in some soils from semi-arid irrigated areas. Jour. Agr. Res. 71:149-170. 1945.

(12) Grandfield, C. O. Food reserves and their translocation to the crown buds as related to cold and drought resistance in alfalfa. Jour. Agr. Res. 67:33-46. 1943.

(13) Haddock, J. L. The influence of plant population, soil moisture, and nitrogen fertilization on sugar content and yield of sugar beets. Agron. Jour. 41:79-84. 1949.

(14) Harris, F. S. Effects of variations in moisture content on certain properties of a soil and on the growth of wheat. Cornell (N. Y.) Agr. Exp. Sta. Bul. 352. 1914.

(15) Haynes, J. L. Effect of availability of soil moisture upon vegetative growth and water use in corn. Agron. Jour. 40:385-395. 1948.

(16) Henrici, M. Effects of excessive water loss and wilting on the life of plants with special reference to karoo plants and lucerne. So. Afric. Dept. Agr. Bul. 256. 1946. Abs., Soils and Fert. 12: No. 47. 1949.

(17) Hunter, J. R. and Erickson, A. E. Relation of seed germination to soil moisture tension. Agron. Jour. 44:107-109. 1952.

(18) Kramer, P. J. Soil moisture as a limiting factor for active absorption and root pressure. Amer. Jour. Bot. 28:446-451. 1941.

(19) ______ Soil moisture in relation to plant growth. Bot. Rev. 10:525-559. 1944.

(20) Kiesselbach, T. A. Neb. Agr. Exp. Sta. 23 Ann. report. (p. 125). 1910.

(21) ______ Progressive development and seasonal variations of the corn crop. Neb. Agr. Exp. Sta. Res. Bul. 166. 1950.

(22) Magnese, J. R., Degman, E. S., and Furr, J. R. Soil moisture and irrigation investigations in eastern apple orchards. U. S. Dept. Agr. Tech. Bul. 491. 1935.

(23) McDermott, J. J. The effect of the moisture content of the soil upon the rate of exudation. Amer. Jour. Bot. 32:570-574. 1945.

(24) Miller, E. C. A physiological study of the winter wheat plant in different stages of its development. Kansas Agr. Exp. Sta. Tech. Bul. 47. 1939.

(25) Miller, M. F. and Duley, F. L. The effect of a varying moisture supply upon the development and composition of the maize plant at different periods of growth. Mo. Agr. Exp. Sta. Res. Bul. 76. 1925.

(26) Moore, Ross E. Water conduction from shallow water tables. Hilgardia 12:383-426. 1939.

(27) Ratner, E. I. [The distribution of water and minerals in plants and the absorbing activity of roots.] Abs., Soils and Fert. 12: No. 525. 1949.

(28) Richards, L. D. A pressure-membrane extraction apparatus for soil solution. Soil Sci. 51:377-386. 1941.

(29) Robins, J. S. and Domingo, C. E. Some effects of severe soil moisture deficits at specific growth stages in corn. Agron. Jour. 45:618-621. 1953.

(30) Shank, D. B. Effects of phosphorus, nitrogen, and soil moisture on top-root ratios of inbred and hybrid maize. Jour. Agr. Res. 70:365-377. 1945.

(31) Singleton, H. P., et al. Soil, water, and crop management investigation in the Columbia Basin Project. Wash. State Agr. Exp. Sta. Bul. 520. 1950.

(32) Snedecor, G. W. Statistical Methods. 4th ed. Ames: Iowa State College Press, 1946.

(33) Stinchfield, R. H. Editorial comment. Better crops with plant food. 36(5):32. 1952.

(34) Taylor, S. A. A continuous supply of soil moisture to the growing crop gives highest yields. Utah Agr. Exp. Sta. Farm and Home Sci. 12:50-51. 1951.

(35) _______ Estimating the integrated soil moisture tension in the root zone of growing crops. Soil Sci. 73:331-339. 1952.

(36) Truog, E. Ed. Mineral nutrition of plants. Univ. Wisc. Press. 1951.

(37) U. S. Weather Bureau, Climatological data, South Dakota. 57(4-10). 1952.

(38) Uhvits, Rachel. Effect of osmotic pressure on water absorption and germination of alfalfa seeds. Amer. Jour. Bot. 33:278-285. 1946.

(39) Van der Paauw, F. Water relations of oats with special attention to the influence of periods of drought. Plant and Soil 1:303-341. 1949.

(40) Veihmeyer, F. J. and Hendrickson, A. H. Soil moisture conditions in relation to plant growth. Plant Physiol. 2:71-82. 1927.

(41) _______ Soil moisture in relation to plant growth. Ann. Rev. Plant Physiol. p. 285-304. 1950.

(42) Verduin, J. and Loomis, W. E. Absorption of CO_2 by maize plant. Plant Physiol. 19:278-293. 1944.

(43) Wadleigh, C. H. and Ayers, A. D. Growth and biochemical composition of bean plants as conditioned by soil moisture tensions and salt concentration. Plant Physiol. 20:106-132. 1945.

(44) Wadleigh, C. H. and Gauch, H. G. Rate of leaf elongation as affected by the intensity of soil moisture stress. Plant Physiol. 23:485-495. 1948.

(45) Wadleigh, C. H., Gauch, H. G. and Magistad, O. C. Growth and rubber accumulation in guayule as conditioned by soil salinity and irrigation regime. U. S. Dept. Agr. Tech. Bul. 925. 1946.

(46) Weaver, J. E. Investigations on the root habits of plants. Amer. Jour. Bot. 12:502-509. 1925.

(47) Westin, F. C. and Buntley, G. J. Descriptive legend for the Spink County, South Dakota, Basic Soil Survey. 1951.

(48) Willard, C. J. Root reserves of alfalfa with special reference to time of cutting on yield. Jour. Amer. Soc. Agron. 22:595-602. 1922.