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THE MICRO-CLIMATE OF ZEA MAYS IN CENTRAL IOWA

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During the past two years a project on the ecology of *Zea mays* has been carried on in an attempt to study the corn plant under average field conditions in Central Iowa. Importat activities of the plant were followed throughout the growing season to establish the trend, in order that deviations caused by measured habitat factors could be evaluated.

In initiating a set of experiments on field plants under non-controlled conditions, it is necessary to carefully measure the factors surrounding the plants. These become the conditions of the experiment for that year. Since there are no published data of a complete study of *Zea mays* under field conditions, the purpose of this paper is to present the conditions of such a field experiment.

Corn yields indicate that for Central Iowa 1929 may be considered an average year. Habitat factors during this nearly normal season are compared with those of an extremely dry season, 1930. Comparison of factors is also made within plots of different planting rates and of irregular stands.

A simple method of modifying the factors surrounding the corn plant is to vary the rate of planting from that which has been experimentally determined to be the optimum rate. Based on the work of Hughes, Robinson and Bryan,[1] for Central Iowa this optimum is three plants per hill with an interval of 42 inches between hills. They found that for the south central section of Iowa, slightly over three plants per hill at harvest gave high yield over a five-year period. For the northern section, five kernels planted and three and four-fifths per hill at harvest gave high yield for smaller, earlier maturing varieties, but no thicker stands were planted.

From twenty years' data at the Ohio Station, the three plant per hill rate at a 42-inch interval is reported as optimum. At the Nebraska Station, where rate of planting experiments have been almost continuous since 1911, Kiesselbach[2,3] reports three plants

1 H. D. Hughes, Joe L. Robinson and A. A. Bryan. High yielding strains and varieties of corn for Iowa. Ia. Agr. Exp. Sta. Bull. 265, 1929.

2 Kiesselbach, T. A. Corn investigations. Nebr. Agr. Exp. Sta. Res. Bull. 20. 1922.

3 Kiesselbach, T. A. Tillage practices in relation to corn production. Nebr. Agr. Exp. Sta. Bull. 232. 1928.

per 42-inch hill as the optimum rate for a full season corn as Hogue's Yellow Dent. However, Lincoln is near the western edge of the typical tall grass prairie region where rainfall overshadows other factors affecting corn production. Years unfavorable to corn production reduce the optimum rate from three to two and one. One plant per hill was the optimum rate in 1912 and 1913 and two the optimum in 1914, '17, and '25. At no time during the 14 years reported between 1911 and 1927, inclusive, was four the optimum rate. Five plants per hill gave a bushel higher yield than the three's in 1915 and six bushels higher in 1917.

For our experiments a selection from Reid's Yellow Dent was planted early (May 4, 1929, and May 2, 1930) at about twice the rate desired. It was thinned to the desired stand about three weeks after germination. The dimensions of the plots were five by 50, 40 inch hills. They were replicated six times in two ranges. The most important soil variation appeared within the length of the plots so that the plots 50 hills long served the purpose of twice the number of replications of 25 hill plots. The outer two rows of each plot were not included in the rate of growth and yield data.

In addition to plots, each thinned to the rate of 1, 2, 3, 4, or 5 plants per hill, there were six plots each thinned in regular order to the rate of one to five plants per hill (averaging three), and six planted at random. In the random plots there was the proper number of hills of each rate but their order was determined by drawing.

Thinning the plants resulted in an almost perfect stand. The few imperfect hills and the adjacent hills were omitted from the calculations.

ESTABLISHMENT OF THE STATIONS

Most experiments in which yield has been correlated with the environmental conditions surrounding the crop have been based on factor data from stations located some distance from the fields studied. Data from government weather stations have been used for most local experiments and for all generalizations on the relation of environmental conditions to crop distribution over large areas.

In order to show the discrepancies which may exist between climatic conditions as expressed by government records taken in the open in the typical government shelter and the immediate climate of the plant (micro-climate) determined by instruments in the field, comparisons were made among several sets of data.

Using temperature as an example, during the latter part of June, 1930, the average maxima were 96°F. in the five plant per hill station and 89 in the government station, and the minima were 67 and 64. The same relationship but a greater difference held for the first week in July. During the remainder of July and the first half of August the average was about the same in the two stations, but variations in the two stations of 10°F. in the daily readings were not uncommon. During late August and the first half of September, however, readings were lower in the corn stations.

Humidity was compared over a shorter period and showed even wider discrepancies than did temperature. It is obvious that wind and light readings must be taken in the particular situation studied. It is the writer's opinion that in studies on the effect of environmental conditions on plant growth, all factors must be determined in the particular community studied.

Climatic and edaphic factors in the normal rate of planting show important variations from year to year. The sum total of the reactions of the environment on the plant may be measured in terms of plant growth and development, but each factor must be measured in order to understand the relationship between them. During a given growing season important variations are evident, but these are caused by the reaction of the plants in the community. These modifications may be as wide as between seasons and are more difficult to measure because each field and different parts of the same field may vary, while yearly variations can usually be evaluated by combining yield data in a locality showing about the same modification from the normal for that year.

For purposes of comparison the following factors were measured in at least two stations located within the plots at the same time. For the continuous records, Julien P. Friez and Sons hygrothermographs and soil and air thermographs were used.

1. Air and soil temperature
2. Humidity
3. Wind
4. Evaporation
5. Light (Macbeth illuminometer and Clement's photometer)
6. Soil moisture

Comparison of Factor Data

In presenting the change in plant life conditions a comparison of the records shows that in regard to rainfall, temperature, and humidity, 1929, was an average season for Central Iowa, while 1930 was the driest season Iowa has experienced in over 30 years. Thus, there was opportunity during the first two years of the experiment to study the effect of widely contrasting environmental conditions, caused by seasonal variation as well as the effect of differences due to modified planting rates.

TEMPERATURE

The differences in air temperature during a given season were small but consistent. Figure 1 shows the 1929 variation in the threes and fives in day and night temperature. The smaller amount of night cooling throughout the season in the fives than in the threes is probably important. Records in 1930 show about the same interval between the ones and threes as between the threes and fives. As would be expected there is less fluctuation in the fives than in the threes. This temperature difference has an important effect on relative humidity since the absolute humidity was approximately the same in the fives and the threes, resulting in high relative humidity for the fives because of the lower temperature.

HUMIDITY

After about the first of July, 1929, the day relative humidity averaged about 15 per cent higher in the fives than in the threes. (Figure 1) This is accounted for by the increase in plant cover

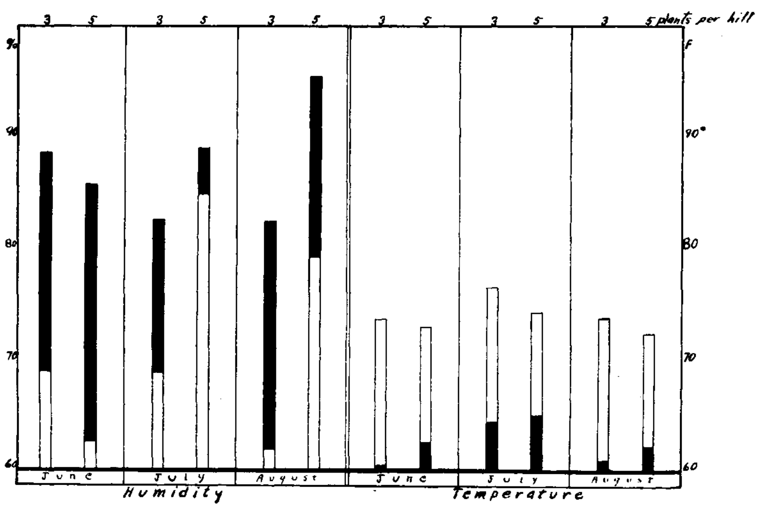


Fig. 1. Relative Humidity and Temperature, day (unshaded) and night (shaded) in corn plats of 3 and 5 plants per hill.

with its added protection from drying out. An index of this increase in plant cover is the increase in the leaf area from 3700 to 4700 square inches per hill. The difference in relative humidity during the night was reduced to 10 per cent. This may be attributed to the increase in the night temperature of the fives over the threes. An increase in humidity of the fives over the threes in spite of a slight increase in temperature shows that there is an important difference in absolute humidity for August, 1929; six grains per cubic foot of aqueous vapor in the fives compared to 4.85 in the threes. The 1930 data computed on a maximum-minimum basis shows an average maximum of 83 per cent for the fives compared to 70 for the ones and an average minimum of 39.7 for the fives compared to 33 for the ones. All of the humidity readings were much lower during the dry 1930 season than during that of 1929. The average of the maximum readings alone should be higher than the night average, but was six per cent lower than the night average for the same month in 1929. The season's average humidity in the fives was 30 per cent higher in 1929 than in 1930.

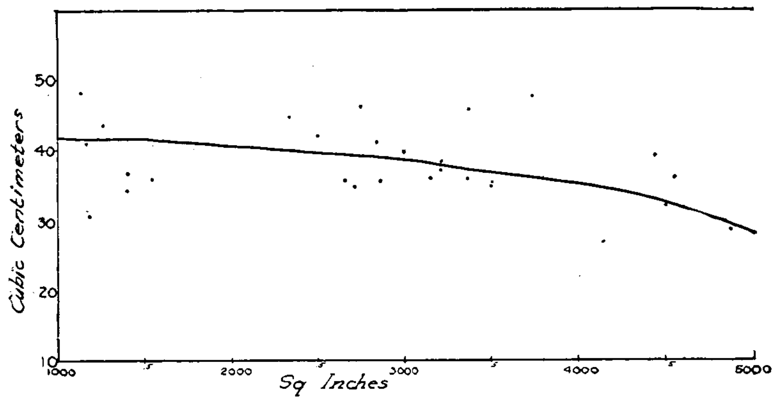
Wind Velocity

The wind velocity during July, 1929, was almost twice as great in the threes as in the fives. During the first half of July of that year, wind velocity averaged two and one-half miles per hour in the fives compared to one and one-fourth miles for the same period in 1930. In its effect on evaporation this increase somewhat counteracted the effect of an increase in temperature and a decrease in humidity of 1930 over 1929. The average for the entire season of 1930 was one mile per hour in the ones as compared to .6 miles in the fives. The curve of evaporation in cc. per day plotted on wind velocity gives a straight line showing direct correlation.

Evaporation

During midseason 1929, evaporation from Livingston cups was about 15 per cent higher in the twos than in the fives. Until the second week in July there was practically no difference, and during the middle of August, showers and cooler weather contributed to reducing evaporation in the two rates until it was not an important factor in increasing transpiration. An average daily evaporation of over 30 cc. in the threes during the most of July and the first part of August caused excessive transpiration, reducing the soil moisture below the moisture equivalent in all rates of planting. For the entire growing season evaporaton was over 50 per cent higher in 1930 than in 1929. Contributing to this increase was a humidity decrease of 25 per cent in 1930 and a temperature increase of 14 per cent.

The green leaf area in the different rates is an index of the protection from wind and also indicates a modified humidity effect. Figure 2 shows the curve resulting from evaporation in cc. plotted on leaf area in square inches.



Evaporation in CC per day plotted on green leaf area per hill 1930

Fig. 2.

SOIL MOISTURE

The record of soil moisture during the two seasons correlates more closely with the activities of the plant than does any other single factor. At no time in 1929 was the soil moisture reduced to the moisture equivalent. Especially between the hills was there sufficient available mosture. This indicates that in normal and wet seasons the distribution over the field is probably more important than number of plants per acre. A different distribution of plants (fewer plants per hill, placed closer together) might be effective in increasing the yield in those portions of the corn belt most favorable for corn production.

In 1930 soil moisture content was a critical factor. As early as July 2, it was reduced to the permanent wilting percentage in the first six inches in the threes, fours, and fives (Table I). Since the

Table I — Soil Moisture Above Moisture Equivalent (8.5%)

RATE	JUNE 18				JUNE 25				JULY 2				JULY 14			
	0–6	6–1	1–2	2–3	0–6	6–1	1–2	2–3	0–6	6–1	1–2	2–3	0–6	6–1	1–2	2–3
1	12.0	15.5	16.2	14.6	14.5	13.3	14.4	12.2	4.8	10.3	9.9	8.8	2.5	7.4	7.9	9.0
2	10.5	14.0	10.9	10.9	13.1	12.9	12.0	9.8	1.7	6.5	10.3	12.7	1.8	9.8	12.8	13.1
3	11.8	14.7	15.0	12.5	12.4	13.5	12.2	10.5	–2.9	7.5	9.1	7.5	–1.4	3.6	3.5	3.6
4	11.7	13.9	12.6	9.8	11.5	11.0	9.7	8.2	.4	6.2	7.3	5.7	– .4	1.8	2.1	3.6
5	9.2	11.3	13.7	10.0	12.0	11.4	9.5	8.7	.6	5.9	7.6	7.1	–2.5	1.4	2.8	4.8

Rate	July 21				July 26				August 11				August 20			
	0–6	6–1	1–2	2–3	0–6	6–1	1–2	2–3	0–6	6–1	1–2	2–3	0–6	6–1	1–2	2–3
1	0.1	7.3	9.0	10.4	– .5	6.2	6.0	5.6	4.2	5.8	5.4	4.3	1.7	7.2	6.0	5.0
2	– .5	.5	7.4	9.9	– .3	6.1	6.7	5.7	6.4	6.3	6.3	5.0				
3	–3.5	2.6	3.5	4.2	–5.9	1.2	.2	.8	–2.6	– .2	–1.3	– .4	–2.4	– .5	–1.5	– .2
4	–2.7	.6	– .4	1.8	–4.9	0.0	.4	.9	– .8	.4	0.0	.0				
5	–3.7	1.6	.5	2.2	–5.8	1.2	– .8	– .8	–1.9	1.7	1.4	– .3	–2.5	.7	– .3	–1.6

samples were taken eight inches from the plant the reduction at this depth showed that the water had been removed by the well-developed root system of the denser stands. A three plant hill excavated at this time showed a sufficient mass of roots feeding from this depth to materially decrease the moisture supply.

On July 21, at a depth of one to two feet, soil moisture first reached the moisture equivalent in the fours and fives (Table I). A week later the threes were included and the following week practically all available moisture had disappeared from the two to three foot level. Below four and one-half feet the clay subsoil held available water all summer. Only the more vigorous growing plants (mostly twos and threes) were putting down enough feeders to obtain any considerable part of this water.

Light

Light readings were made with the Macbeth illuminometer, reading in foot candles. Direct sunlight at noon gave average readings of 8,000 foot candles. Since about one-half of the leaf surface is shaded from the sun, light readings were taken on the shady side of the hill with the exposure disc at half of the height of the plant and facing away from the sun. Readings were also taken with the disc on the ground in the shade of the hill. With full size plants these readings averaged 82 per cent of the values at half the stalk height. The 1929 results are 563 foot candles in the twos, 466 in the threes, and 375 in the fives. The 1930 readings show the same proportional decrease from the ones to the fives: 633, 505, 489, 403, 346.

While these readings are lower than might be expected, they are not critical. However, in the more dense planting, light intensity on the shady side of the plant is reduced below the minimum for a longer time in the morning and evening than on the sunny side or in the more sparse planting.

Response of the Plants under Varied Conditions

Transpiration

Transpiration rate in the plants of the stand was measured by the cobalt chloride method. Two factors are involved in the reduction of the rate from the ones to the fives: the reduction due to the change of climatic factors surrounding the plant and the reduction due to reduced absorption because of lack of available soil moisture.

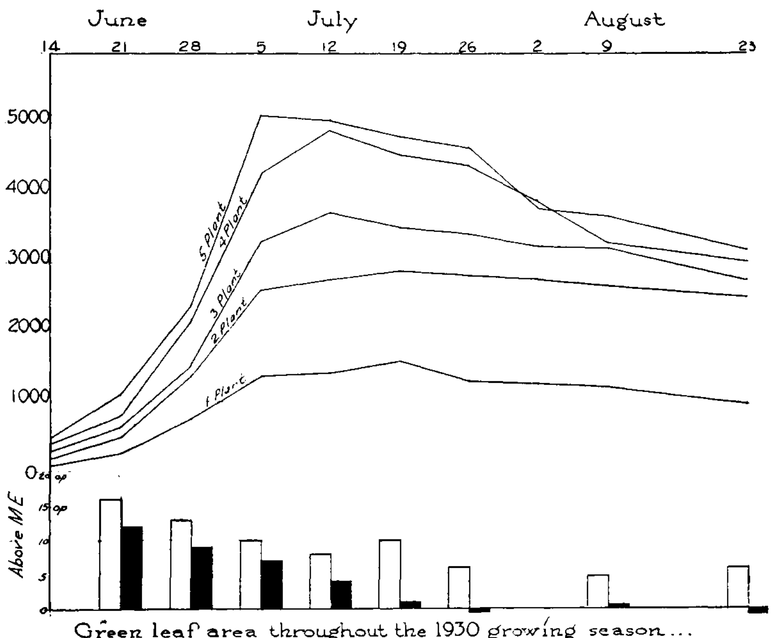
Climatic factors are more conducive to transpiration in the ones than in the fives. Humidity has been shown to be lower and wind velocity higher in the ones. Day temperature is slightly higher. Climatic phytometers were used to measure the water loss in the ones, threes, and fives. The containers were brought back to optimum weight every three days so water supply was not a factor in the transpiration rate. The phytometer cans were placed on the ground, the plants (corn), when the experiment ended, reaching to one-half the height of the surrounding corn. Loss from transpiration per square inch of leaf surface for the period was 11, 7, and 5 cc. in the ones, threes, and fives respectively. Reduction in rate of transpiration in the plants of the stand is affected both by climatic factors and the rate of absorption. Especially during dry weather is transpiration important as an index of absorption.

During the second week in August when there was no available moisture between one and three feet in the threes, fours, and fives, the transpiration rate in the lower leaves in the ones, threes, and fives, respectively, was 80, 120, and 250 seconds (time for change of color). The reduction in the fives was caused by increased protection of the plant cover as shown in figure 2 (evaporation plotted on leaf area) and by the reduced soil moisture. The normal transpiration from the top leaves of the plants in the fives greatly reduced the transpiration from the lower, less active leaves, since the plant was operating on a shortage of water. The reduction of transpiration, due to lack of soil moisture alone in the fives over that in the ones, is shown by the rate in the actively growing upper leaves which, in round numbers, was 50, 60, and 70, read in seconds necessary for cobalt chloride paper to change color.

Rate of Photosynthesis

The picramic method, as modified by Doctor Long of Carnegie Institute, was used in determining the rate of photosynthesis. The leaf punches were taken at daylight in the morning and at 3:45 in the afternoon. Since these data were not corrected for translocation or respiration and since there was considerable loss of fructose in the determination, the increment of photosynthate obtained falls far short of the amount actually made. However, the figures obtained give a good basis for comparison. Averages of results from July 24 to August 1, 1930, give the following figures: .81, .94, .73, .46, and .31 grams per square meter of leaf area for the day. This is at the beginning of the period when the fours and fives showed a shortage of water and the threes were beginning to show such a shortage. The 1929 data taken at the same plant age gave the following results for the average of bottom, middle, and top leaves: 1.55, 1.31, and .86 grams for the twos, threes, and fives, respectively. This is almost twice the 1930 rate with less reduction in the thicker planting.

The plants in comparable plots were measured every week and the results tabulated for the rate of growth data. The slide shows that there was practically no difference in height growth till about July 8 with the fives having a slight advantage. From this time the ones and twos increased over the fives till the twos, which averaged about two and one-half inches more than the ones, showed an increase of 18 per cent over the fives. Green leaf area per hill in the fives increased over the other rates but was cut down much more rapidly by reduced water supply, chiefly caused by excessive firing (Figure 3). The important break even in a dry year is between the fours and the fives. The measurable increment of carbohydrate



Green leaf area throughout the 1930 growing season...
Soil moisture above the moisture equivalent in 1's and 5's at each date.

Fig. 3.

made per day per hill (using average photosynthate figures as of July 26, 1930) was .61, 1.73, 1.60, 1.26, and .87 for the ones to fives, respectively. Although these are not total values, the relation of these values to the grain yield in bushels is important: 37.2, 47.8, 47.3, 37.7, 36.8, respectively, in the ones to fives. We must remember, however, that even in a dry year as in 1930, the total dry weight of stalks is higher in the fives than in the ones or twos, so that there may be practically no correlation between rate of photosynthesis and yield of grain.

Table II—Rate of Growth and Yield, 1929-1930

Plants Per Hill	At Age of 100 Days: Height	Stalk Diam.	Leaf Area	No. Ears	Dry Wt. Ears	Yield Bu. Acre	Per Cent Nubbins	Per Cent Shell	No. Ears Per Plant	Av. 20 Longest Cm.	Av. Ear Wt.
1–1930	88.9	1.35	1220	1.01	309.8	37.2	15.6	83.6	1.4	22.9	.85
2–1929*	101.0*	2.82*	1508*	1.60*		60.3*	14.6*	84.6*	1.2*		.80*
2–1930	90.9	1.21	1340	1.63	539.3	47.8	23.0	83.2	.85	20.8	.77
3–1929*	110.4*	2.35*	1432*	1.30*		71.1*	24.6*	84.0*	1.3*		.37*
3–1930	85.2	1.05	1073	1.60	391.1	47.3	52.3	83.9	.8	19.7	.33
4–1930	83.8	1.01	817	1.45	254.0	37.7	67.4	82.2	.68	18.5	25
5–1929*	107.5*	2.02*	1305*	.98*		61.0*	59.8*	84.1*	.82*		.25*
5–1930	79.8	.76	676	1.43	111.9	36.8	83.3	82.5	.62	16.3	.20

In table 2 is shown the yield of three average hills of the ones, threes, and fives on August 20, 1930 (108 days). The dry weight of ears per hill at 100 days from the ones to fives, respectively, was 310, 539, 391, 254, and 112. The ones were at least 10 days ahead of the fives at this stage. The entire reproductive process was delayed probabily because of lack of water. Green weight values at 100 days give about the same order from ones to fives as later yield data. On September 11, the kernels in the threes, fours, and fives had more completely filled, bringing the dry weights up to about the same order as the yield: 308, 406, 385, 229, and 237.

An average ear from each of the five rates shows the fertilization range: from about 98 per cent in the ear from the ones to about 50 per cent in the ear from the fives. The delay in germination in the thicker plantings brought germination into a period of more intensive drought. Increased precipitation within this time might contribute to better fertilization in the dense than in the thin stands.

For a season of approximate average yield (1929), height of the plant was greater in the plots of three plants per hill than in the 2's and 5's, but stalk diameter and leaf area per plant were greater in the 2's. However leaf area per hill was 40 per cent greater in the 3's than in the 2's, which increase accounted for increased photosynthesis in a three-plant hill over that in a two plant hill of approximately 20 per cent. Yield per acre in 1929 was 71 bushels in the optimum rate of planting (3 plants) compared to about 60 bushels in each of the other two rates.

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