Response of Corn Yield Components to Simulated Precipitation Augmentation

by

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ABSTRACT

Mobile rain shelters were used to protect corn (Zea Mays L.) from all natural rainfall during the summers of 1987, 1988, 1989 while providing water to the crop through an overhead sprinkler system mounted in the rain shelters. Water was applied to the crop to simulate typical dry, normal, and wet summers in central Illinois. Final yields were measured at harvest along with the various yield components (number of kernel rows/ear, number of kernels/row, total number of kernels/ear, kernel mass) that determine final yield. Yields were increased in each of the typical summers by increased rainfall. The greatest benefit of the increased rainfall was realized at pollination and the 2 weeks following pollination as expressed by an increase in the number of kernels/fertile ear. Neither the number of kernel rows/fertile ear nor the final mass of the kernels were affected by the rainfall treatments. In addition to larger fertile ears, some yield increase was realized by a reduction in the number of barren plants in the plant population under higher rainfall treatments.

1. INTRODUCTION

Crop-weather regression relationships have been used frequently to estimate crop productivity. In Illinois, these models have shown that an increase in rainfall due to weather modification would result in increased returns for producers (Garcia et al., 1990). Such modeling relies upon spatially and temporally averaged historical data, and introduces uncertainties in the results and fails to demonstrate the physiological response of the crop to the timing of enhanced rainfall (Changnon, et.al. 1989). Hence, we have sought through field trials and controlled rain (water) applications to define how various weather conditions and other management practices affect corn yields in Illinois.

Corn (Zea mays L.) yields are determined by a number of components that can be affected by management practices and weather at different times throughout the crops growth. The yield components include planting density, the number of kernel rows per ear, the number of kernels per row, and the kernel mass.

Planting density is determined to a great extent by the density of seeds planted. The density is modified to some extent by the soil moisture and temperature conditions during germination and emergence of the young plants. As planting density increases, the yield of each plant will tend to decrease as the plants compete for water and nutrients. Generally, as plant density increases, yields over a large area will also increase. However, there is an optimum population above which higher plant densities begin to decrease area yields due to large reductions in the yields of individual plants. These yield reductions occur in the form of increased barrenness, reduced numbers of kernel rows/ear, reduced numbers of kernels/row, and reduced kernel mass.

The total number of kernels/plant (determined by the number of kernel rows/ear and number of kernels/row) and kernel mass can also be reduced by unfavorable weather during different parts of the growing season. For example, the number of kernel rows/ear is determined approximately 30 days after planting (Hollinger, 1981). Therefore, stresses due to weather and/or plant competition during this period may result in reduced numbers of kernel rows.

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The potential total number of kernels/row, and thus the potential total number of kernels/ear, is determined during the period beginning 30 days after planting until approximately 2 weeks after pollination. Before pollination, the plant is developing kernel promorida which are actually female flowers. The number of flowers developed determine the potential maximum number of kernels that can be developed. If the plant experiences a stress during pollination or during the critical 2 weeks following pollination, the actual number of flowers fertilized and that ultimately develop kernels is reduced and final yield is reduced.

During the grain filling period (2 weeks after pollination to maturity) the final mass of each kernel is being determined. Stresses during this period will not result in abortion of kernels, but will result in reduced kernel size which translates into reduced yields.

This paper reports on a 3 year study to determine the response of the various yield components to precipitation augmentation through weather modification. The yield increases experienced are related to the yield components to determine the growth period when precipitation augmentation is realized by the crop.

2. METHODS

Moveable shelters were used to preclude any natural rainfall from plots of corn during the summers of 1987, 1988, and 1989. Water to the crop was applied through a sprinkler system mounted in the moveable shelters that allowed the application of different amounts of water on each of the plots. Six rainfall treatments were applied to the 3x3m ft. plots to simulate typical dry, normal, and wet summers in central Illinois (Changnon and Hollinger, 1988). Total June, July, and August rainfall applied to represent the typical summers is shown in Table 1.

Table 1. Total June, July, and August rainfall applied to represent typical dry, average, and wet summers in east-central Illinois.

Summer	Rainfall (mm)
Dry	160
Dry + 25%	200
Average	279
Average + 25%	349
Wet	381
Wet + 25%	476

Corn (hybrid MO17xB73) was planted on 28 May 1987 at a density of 83,980 plants/ha, 12 May 1988 at a density of 64,220 plants/ha, and 12 May 1989 and 26 May 1989 at populations of 64,220 and 83,980 plants/ha. Four rows at a spacing of 0.76m were planted in each plot. The crops were fertilized at normal recommended rates each year, and weeds removed from the plots by hand hoeing.

The center 2.4m of the 2 middle rows of each plot were harvest at maturity. The number of kernel rows/ear, the number of kernels/row were counted and the total number of kernels/ear computed by multiplying the number of kernel rows/ear by the number of kernels/row. Kernel weight was determined by dividing the total weight of grain harvested from each plot by the total number of kernels in each plot.

3. RESULTS

Mean yields of the low plant density treatments (64,220 plants/ha) increased as the summer rainfall increased (Table 2). The same trend of increasing yields occurs in the high plant density treatment (83,980 plants/ha), however, the increases are not as consistent as those observed in the low population. The point when the rainfall treatments affected final yield can be found by studying the yield components that comprise the final yield. These yield components for the 6 rainfall

Table 2. Corn yield components and final yield for each rainfall and plant density treatment.

Yield Component	Rainfall (inches) 6.30	7.87	11.00	13.75	15.00	18.75	Population Mean
Plant Density	65,364	65,364	64,556	65,364	64,017	65,364	65,005
Barren Plants	1,346	808	1,346	1,613	808	808	1,121
Nubbins	3,498	4,308	3,228	1,077	808	2,151	2,511
Kernel rows/ear	15.0	15.0	15.0	15.7	16.0	15.8	15.4
Kernels/row	38.0	37.7	38.8	39.4	40.1	41.0	39.2
Kernels/plant	569.8	566.0	582.3	618.1	641.8	647.7	604.3
Kernel/weight (g)	0.283	0.289	0.296	0.296	0.300	0.299	0.294
Yield (mg/ha)	10.52	10.68	11.14	11.97	12.34	12.65	11.55
Plant Density	82,846	84,192	83,923	86,075	84,998	84,192	84,371
Barren Plants	7,800	7,262	10,759	6,993	4,303	3,498	6,769
Nubbins	8,608	7,262	5,380	5,380	1,882	3,498	5,335
Kernel rows/ear	12.6	13.1	12.7	13.3	14.8	14.4	13.5
Kernels/row	33.3	33.3	32.4	34.3	34.5	34.6	33.7
Kernels/plant	419.2	435.8	411.1	456.5	510.9	497.6	455.2
Kernel/weight (g)	0.243	0.246	0.247	0.245	0.243	0.245	0.245
Yield (mg/ha)	8.52	9.01	8.52	9.64	10.57	10.26	9.41

treatments are also shown in Table 2. Plant density, number of barren plants, and number of plants with incompletely formed ears (nubbins) are expressed on a per acre basis. The number of kernel rows/ear was determined by computing the sum of the kernel rows/ear for each plot and dividing by the total number of plants in the plot (includes barren plants and plants with nubbins for ears).

Increased plant density had the greatest effect on the various yield components. The higher plant density resulted in an increase in barrenness and number of nubbins, and decrease in number of kernel rows/ear, kernels/plant, and kernel mass. This effect is due to the increased plant competition for water, nutrients, and light at the higher plant densities.

Computing the number of rows and kernels/ear on the total plant population results in an underestimation of the actual number of kernel rows/ear and total number of kernels on the fully fertile ear. The numbers of kernel rows/ear, number of kernels/row, and the number of kernels on the fertile ears are computed by dividing the number of kernels/plot less then number of kernels contributed by the nubbins by the number of plants with fully developed ears (Table 3). The number of kernels/row on the fertile ears is slightly less than the number of kernels/row computed by the number of kernels harvested/plot divided by the total number of plants in the plot. This difference is due to the kernels harvested from the nubbins.

The nubbins do not have any defined rows, therefore, in determining the number of kernel rows/ear a nubbin was reported as having 0 rows and 'X' kernels, where X is the number of kernels on the nubbin. Therefore, the number of kernels rows/fertile ear (Table 3) is greater than the number of kernel row/ear reported in Table 2.

Barrenness as defined as plants with no ears on them and plants with only small nubbins as ears, decreased as rainfall increased regardless of population. The higher populations resulted in greater barrenness over all rainfall treatments. The fact that barrenness decreased with increasing rainfall indicates that the plants in higher populations and lower rainfall treatments were competing for the available water. Therefore, one benefit of precipitation enhancement by weather modification is healthier plants resulting in decreased barrenness.

The number of kernels/fertile plant increased with increased rainfall in the low plant density treatment (Table 3). This increase in the number of kernels is due to a corresponding increase in the number of kernels/row. The increase in kernels/row indicates that the response to the increased rainfall occurred during the period of silking to 2 week following silking.

The determination of the number of rows/ear occurs when the plant is between the 5 to 10 leaf stage of growth (approximately 30-40 days after planting). During this early growth stage soil moisture is usually not a limiting factor in east-central Illinois and the plants are small enough that there is only a limited competition for sunshine at the lower plant density treatment. The reduced number of kernels rows/ear in the higher plant density treatments indicated that at these populations, there was some competition occurring for nutrients or sunshine. It is not likely that water was limiting during the early growth stages, because the number of kernel rows/ear are relatively constant across the rainfall treatments.

The effects of enhanced rainfall through weather modification on final yield can be evaluated by studying those components that contribute to the actual final yield (mass and number of kernels/fertile plant, and mass and number of kernels/nubbin), and those components that reduce the final yield from a potential maximum yield. Maximum potential yield is the product of the total number of plants, the number of kernels/fertile ear, and the measured kernel mass for each treatment. The effects of the rainfall treatments on barrenness and number of nubbins and the associated yield reductions are shown in Table 4. At the lower plant densities, increasing the typical summer rainfall by 25% in dry years reduced the barrenness, while increased rainfall in the average and wet summer rainfall treatments tended

Table 3. Number of kernel rows/ear, number of kernels/row on the fertile ears, and the number of kernels per nubbin.

Yield Component	Rainfall (inches) 6.30	7.87	11.00	13.75	15.00	18.75	Population Mean
			Low Plant Density				
Kernel rows/ear	16.2	16.3	16.1	16.3	16.3	16.5	16.3
Kernels/row	37.7	37.4	38.6	39.5	40.3	41.0	39.1
Kernels/plant	611.5	609.9	622.2	643.6	657.7	675.9	636.8
Kernels/Nubbin	69.5	56.8	82.0	57.7	51.7	72.7	64.6
			High Plant Density				
Kernel rows/ear	15.7	15.8	15.7	15.5	16.0	15.7	15.7
Kernels/row	32.8	32.6	32.2	34.0	34.3	34.4	33.4
Kernels/plant	515.5	515.5	504.9	526.9	549.2	539.4	525.2
Kernels/Nubbin	56.1	107.0	51.3	85.1	76.5	72.9	75.4

Table 4. Effects of enhanced precipitation on yield components and their contribution to final during typical dry, average, and wet summers. Numbers in the table have units of Mg/ha. (Note: Negative numbers indicate yield decreases and positive numbers indicate yield increases.)

	Rainfall Treatment								
	Dry	Dry+25%	Diff	Avg	Avg+25%	Diff	Wet	Wet+25%	Diff
	Low Plant Density								
Yield Potential	11.31	11.52	+0.21	11.89	12.45	0.56	12.63	13.21	0.58
Barrenness	-0.23	-0.14	0.09	-0.25	-0.31	-0.06	-0.16	-0.16	0.00
Nubbin number	-0.54	-0.69	-0.15	-0.52	-0.19	40.33	-0.15	-0.39	0.24
Nubbin size	0.07	0.07	0.0	0.08	0.02	-0.06	0.01	0.05	0.04
Kernel mass/ear	10.42	10.42	0.15	11.05	11.94	0.89	12.31	12.61	0.30
Actual Yield	10.54	10.69	0.15	11.13	11.96	0.83	12.32	12.66	0.34
	High Plant Density								
Yield Potential	10.38	10.68	0.30	10.47	17.11	0.69	11.34	11.12	-0.22
Barrenness	-0.98	-0.92	0.06	-1.34	-0.90	0.44	-0.57	-0.46	0.11
Nubbin number	-0.96	-0.73	0.23	-0.60	-0.58	0.02	-0.22	-0.40	-0.18
Nubbin size	0.12	0.19	0.07	0.07	0.11	0.04	0.04	0.06	0.02
Kernel mass/ear	8.32	8.83	0.51	8.45	9.51	1.06	10.52	10.20	10.20
Actual Yield	8.44	9.02	0.58	8.52	9.62	1.10	10.56	10.26	-0.30

to either increase or not change barrenness. At the higher plant densities, barrenness was reduced by increasing the rainfall by 25% during dry, average and wet summers.

The number of nubbins decreased in the average summer with increasing rainfall, while the increase in rainfall in the dry and wet summer treatments resulted in more nubbins at the low plant density. At the high plant density, the number of nubbins was decreased in the dry summer, unchanged in the average summer, and increased in the wet summer when an additional 25% of rainfall was applied.

Increased rainfall resulted in larger fertile ear and nubbin size in all treatments regardless of the population with the exception of the average rainfall treatment with low plant density and the high plant density treatment in the wet summer rainfall treatment. In the first instance, the size of nubbins was reduced while in the second the size of the fertile ear was reduced. In both cases, the reduction was due to reduced numbers of kernels on the ear or nubbin.

4. SUMMARY

Three years of controlled rainfall experiments in rain shelters were conducted at Champaign, Illinois to determine the effect of enhanced rainfall due to weather modification during typical dry, average and wet summers on final corn yields. Final corn yields were increased by an additional 25% of rainfall in each of the typical summer scenarios at both high and low plant densities, except for the wet summer at high plant densities. The increase in final yields were due to decreased barrenness, reduced numbers of incompletely formed ears, and increased fertile ear size. These responses indicate that the greatest effect of increased rainfall was felt at the time of pollination and the 2 weeks following pollination.

The experiments show that a benefit to Illinois agriculture could be realized by a reliable weather modification technology in all summers. The greatest benefits occur in the average years with lesser benefits in the drier and wetter summers.

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