"REVIEWED"

CROP YIELD RESULTS FROM SIMULATED RAIN APPLICATIONS TO AGRICULTURAL PLOTS IN ILLINOIS

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ABSTRACT

Ten different levels of rainfall were applied (during 1987, 1988, and 1989) to agricultural plots in central Illinois to discern effects on corn and soybean yields. Increases in rainfall during a hot dry summer (June-August 1988) revealed sizable yield gains. For one inch of added rainfall, the yields increased 10 bu/acre for corn and 4 bu/acre for soybeans. In a summer of near average rain (1989), the increases were less, about 5 bu/acre for corn and 3 bu/acre for soybeans. *When summer rainfall exceeded 14 inches, yields of both crops were decreased.* The various rainfall tests revealed that rain increases done only on days when natural rainfall was $\leq$0.1 inch provided no detectable yield increases, whereas a 40% increase on all rain days (the largest increase tested) produced the greatest crop yield increase (up to the 14-inch optimum). Corn yields reacted very favorably to added rains on days with $\geq$1.0 inch of rain.

1. INTRODUCTION

Weather modification research in Illinois since 1970 has included efforts to estimate the effects of additional rainfall produced by weather modification on two major U.S. crops, corn and soybeans (Changnon, 1986). Several studies utilized weather-crop yield regression models to estimate the yield changes relating to use of differing levels of rainfall during various parts of the growing season. Phenological models have also been used to more accurately assess weather effects on crop yields. However, like all models, crop-weather models depend upon considerable information about applications that are not widely available and thus must include key assumptions. The most recent modeling involved a new regression model utilizing the 1960-1986 data to estimate yield effects from changed rainfall under current levels of farm practices and related technology (Garcia et al., 1986). How the model's yield predictions for 1987 and 1988 related to yields from agricultural plots where additional rainfall was applied has been investigated (Changnon et al., 1989).

The principal current investigation to assess the effects of altered summer rainfall on yields in central Illinois has involved use of agricultural plots at the University of Illinois experimental farms. One set of these plots allows for ten tests, with one including the actual summer (June-August) rainfall. The other nine tests involve application of a range of potential rainfall modification capabilities that can be envisioned for convective rainfall in the Midwest. These tests are itemized in Table 1.

This paper focuses on the yield results obtained from the nine rainfall simulations on these plots in 1987, 1988, and 1989. In each of the three years, the same varieties of corn (a Mo17 x B73 Cross, and a Williams variety of soybeans) were planted. Planting dates varied somewhat being 28 May 1987, 16 May 1988, and 14 May 1989. Different planting dates do have an effect on crop yields and the weather relationships, but these subtle effects could not be separated out in this 3-year sample. The results reveal that any effects of the different planting dates appear minimal. Problems related to wind damage to the corn test fields in 1987 unfortunately kept these data from being adequate for analysis. The plots utilized for corn and for soybeans each contained 30, 10'x10' plots. Each plot had its own sprinkler which was connected to a central pumping system where any level of water application can be made for any plot. For each treatment, there were 3 replications randomly chosen within the larger 30-plot area. Water increases for the 9 treatment models were applied as soon as each rain ended. The natural rainfall amount for a distinct rain event was used to calculate the amount of additional rain to be applied, and the different amounts. Thus, if a rain of 0.3 inch occurred, the 3 plots designed to receive a 10% increase received 0.03 inch from the pumping system immediately after the rain day ended. Further details about the techniques, the facility, and methods of planting are given in an earlier paper (Changnon and Hollinger, 1988). It should be noted that the fertilizer treatments and planting densities of both crops remained the same in all three years. Thus, the major between-year difference was the weather conditions.

2. RESULTS

The summer weather conditions of the three years sampled fortunately provided a wide range of differing conditions, particularly as it pertained to total rainfall. The 3-summer values appear at the bottom of Table 1, along with their departures from the 3-year normals for 1951-80. The rainfall values show an extremely wet 1987 with 17.8 inches, an extremely dry 1988 with only 5.2 inches, and a near normal 1989 with 11.0 inches. Summer temperatures were very near normal in 1987 and 1989, but extremely above normal in 1988 which was a part of a major Midwestern drought.

The 10 rainfall applications to the plot included the actual rainfall and 9 rainfall enhancements of the actual rainfall. Treatments 2, 3, and 4 involved 10%,

Table 1. Crop Yields and Summer Weather Conditions in 1987, 1988, 1989.

Rainfall Applications		1987	1988	1989
	Corn Yields, bu/acre			
1.	Natural rainfall	-	48.3	219
2.	Increase all rain days by 10%	-	55.9	225
3.	Increase all rain days by 25%	-	62.7	232
4.	Increase all rain days by 40%	-	69.3	226
5.	Increases to 0.1 to 1.0 inch rain days by 10%	-	65.1	221
6.	Increases to 0.1 to 1.0 inch rain days by 25%	-	54.5	220
7.	Increases to 0.1 to 1.0 inch rains days by 40%	-	66.7	231
8.	Increase all >1.0 inch rain days by 10%	-	51.8	234
9.	Increase all >1.0 inch rain days by 40%	-	67.0	231
10.	Increase all $\leq$0.1 inch rain days by 40%	-	49.3	216
	Soybean Yields, bu/acre			
1.	Natural rainfall	32.7	15.1	45.1
2.	Increase all rains by 10%	26.1	16.9	48.4
3.	Increase all rains by 25%	30.7	18.7	54.6
4.	Increase all rains by 40%	23.7	20.8	52.8
5.	Increases to 0.1 to 1.0 inch rain days by 10%	32.1	17.1	45.7
6.	Increases to 0.1 to 1.0 inch rains days by 25%	27.6	16.7	48.2
7.	Increases to 0.1 to 1.0 inch rains by 40%	27.1	18.9	49.0
8.	Increase all >1.0 inch rain days by 10%	29.6	17.1	48.2
9.	Increase all >1.0 inch rain days by 40%	26.6	17.9	55.0
10.	Increase all $\leq$0.1 inch rain days by 40%	34.4	16.3	43.8
Summer rainfall/ departure (in.)		17.84 (+6.9)	5.24 (-5.70)	11.07 (+0.16)
Summer temperature/ departure (°F)		74.3 (+0.9°)	76.3°F (+3.1°)	73.33° (-0.1)

25%, and 40% increases, respectively, to all rain days during the summer. Treatments 5, 6, and 7 involved identical levels of increases but applied only to daily rains in the 0.1- to 1.0-inch category. Treatments 8 and 9 were increases of 10% and 40% to only rain days of 1 inch or heavier, and treatment 10 was an increase of 40% to all daily rains of 0.1 inch or less. These were designed to bracket a range of capabilities seen as potentially likely with a future Midwestern rain enhancement technology.

Results for Corn. In general, the lowest yields came with natural rainfall in both years (1988 and 1989) or with the natural rainfall plus a 40% increase in the very light, 0.1 inch or less, rains. The yield values and rainfall values are shown in Table 1 and figure 1. The highest yields in 1988 (a severe drought year) came with the maximum rainfall applications including: 1) an increase of 40% to all rains (69.3 bushels per acre) as top ranked; 2) an increase of 40% to the 1 inch rains which ranked second; and 3) an increase of 40% to the rains of 0.1 to 1.0 level, which ranked third. The results from 1988 show a good linear relationship of increased yields to increased rainfall (Fig. 1). The primary non-linear anomalies in 1988 were the two applications of additional rainfall only to the 1-inch or heavier rains. These two values are denoted on figure 1, showing they represent a relatively greater increase in yields than the amount of added rainfall received would indicate, as based on the other 8 outcomes.

Examination of the 1989 corn yield results (Fig. 1) when the natural rainfall was near average and all rain additions thus ran above average, reveals a different outcome. The highest values came with the additional water applied to 1-inch or nearer values, as shown in figure 1, and with the increase of 25% to all rains which ranks as the second highest yield outcome (Table 1). The results for corn yields and rainfall in 1989 suggest that the application of 15.5 inches of rain, the value for the natural rainfall plus 40% more water, was too much rainfall. It has long been recognized that the prairie soils of the Midwest can receive too much rain for optimum corn growth, and the data for 1989 suggests that this maximum was somewhere around 14 inches, recognizing that the temperatures of 1989 were near normal, and the effect of the distribution of the daily rainfall events during June-August.

In general, the results from the two years of rain simulations indicate a moderately strong relationship of corn yields to the summer rainfall, with a seemingly linear increase up to approximately 14 inches of rain during the June-August period. Undoubtedly the distribution of the daily rainfall events had an effect, but the results do allow one to estimate the value of a rainfall increase on corn yields. For example, in the hot dry summer of 1988, an inch of rainfall, say from 6 to 7 inches, appeared to increase corn yields by about 10 bu/acre. In 1989, the addition of 1 inch of rainfall, say from 11 to 12 inches, appeared to provide approximately 5 additional bu/acre.

A third interesting aspect of the outcomes of both years relates to the yield values obtained with the rainfall increases (10% and 40%) applied only to the one inch and heavier rain days. In both years, the results indicate relatively great yield increases, as shown in figure 1. Tests 8 and 9 resulted in relatively higher corn yields than the data on total rain for the other 8 trials would have predicted. This suggests that the capability to increase rainfall on days when the rain is relatively heavy would be of considerable value. In 1989 there were two such days of heavy rains over an inch, one on June 23 and another one on June 26. In 1988, the drought year, there was only one day, on July 19. Rain in late June and July are very critical to increased corn yields.

Soybeans. The soybean yields associated with the natural rainfall and the 9 tests of increased rain are shown for the three years in Table 1. In 1987, an extremely wet year, the highest yields came with the actual rainfall and the 40% increase only to the light rains (less than 0.1 inch). As the rainfall was increased, the yields decreased such that the maximum possible rainfall increase, 40% to all rain, which produced a total of nearly 25 inches of rain, resulted in the lowest soybean yield attained, 23.7 bushels per acre. Any rainfall increase applied in a summer as wet as 1987 is not desirable for soybeans. There is no explanation available for the odd outcome achieved with the 25% increase in 1989.

Inspection of the 1988 soybean results reveal a very different outcome. In this hot, dry summer, the peak soybean yields of 20.8 bu/acre, came with the heaviest summer rainfall, 40% of water added to all summer rain days. The second greatest yield increase came with 40% added to all rain days of 0.1 to 1.0 inch per day. As shown in figure 2, the soybean yield outcomes were a strong linear relationship with the amount of summer rainfall, ranging from a low of 15 bu/acre with 5.2 inches of rain, up to nearly 21 bu/acre with 7 inches. The apparent increase in soybean yields with one inch of rain in such a summer was approximately 4 bu/acre.

The soybean yields in 1989, when there was near average precipitation and temperatures, also varied considerably, but were much higher than in 1987 (too wet) or 1988 (too dry). The peak yield in 1989 (55 bu/acre) came with the 40% increase to only the 1 inch rain days, with the next two highest yields achieved with the 25% and 40% increase to all rains. The distribution of the yield outcomes, as revealed in figure 2, suggests a curvilinear relationship yields with the summer rainfall. Drawn on figure 2 is a curve drawn to approximately fit the data points for the three years. The data points suggest that at about 14 inches of rainfall, a reversal occurred with a decrease in yields as the summer rains became heavier; note that the total rain with 40% increases, 15.5 inches, had a lower yield

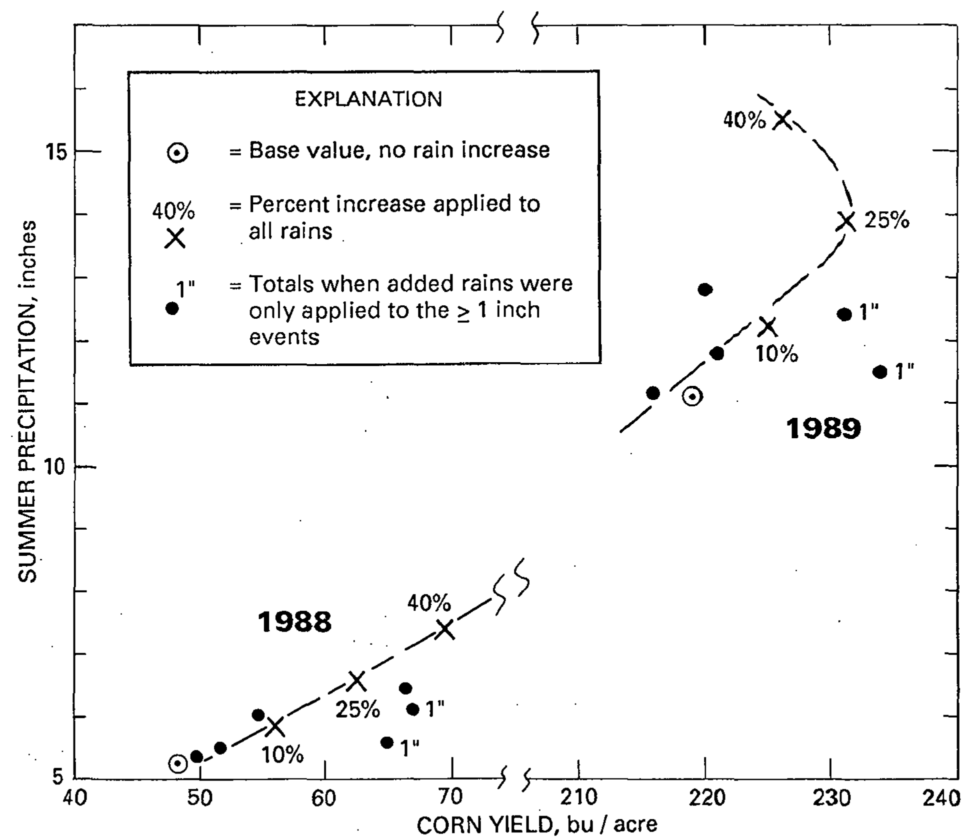

Figure 1. The relationship of total summer rainfall in 1988 and 1989 with corn yields at agricultural plots in central Illinois. The 9 rain increases were based on 9 simulated rainfall increases.

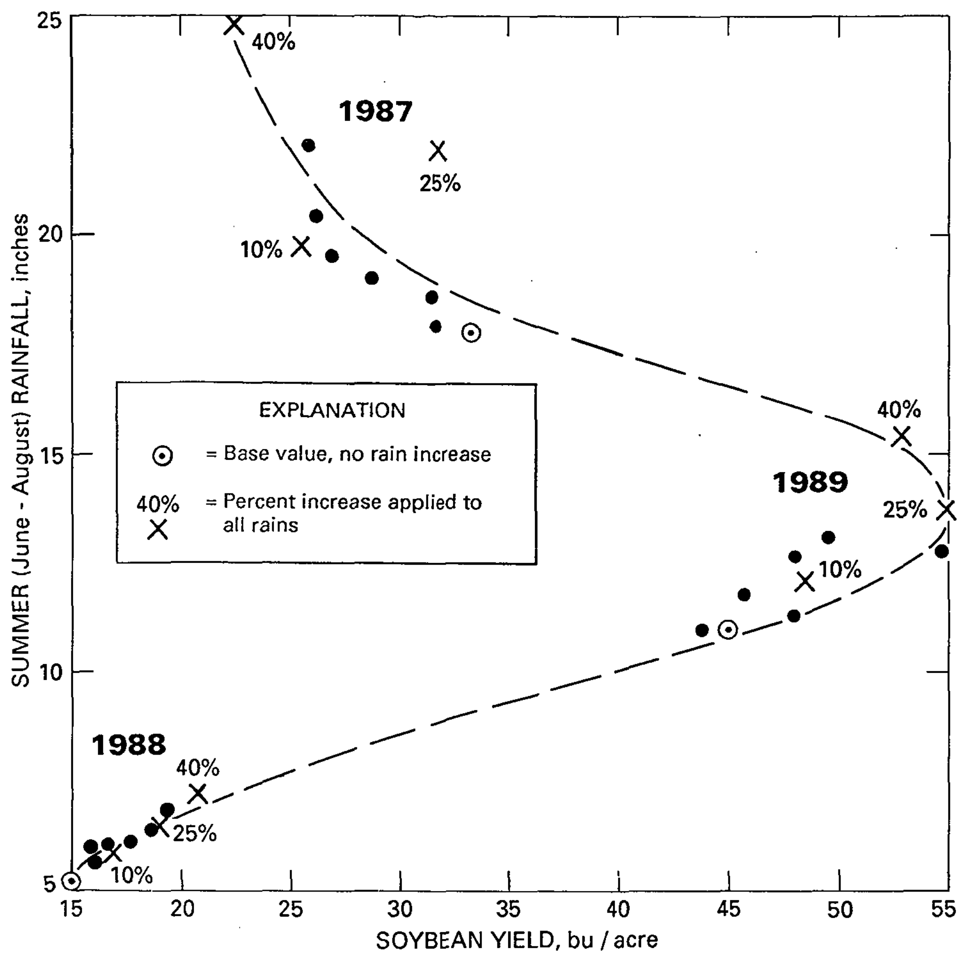

Figure 2. The relationship of total summer rainfall in 1987, 1988, and 1989 with soybean yields at agricultural plots in central Illinois. The 9 rain increases were based on 9 simulated rainfall increases.

than did the 14 inches based on a 25% increase in the summer rain. The 1989 data points for summer amounts less than 14 inches suggests that a 1-inch rain increase, say from 11 to 12 inches, resulted in about 3 bu/acre increase in yields.

3. SUMMARY

Inspection of the corn and soybean outcomes with the simulated rain increases in three summers reveals certain common findings. First, increases of rainfall on only days when light rains occurred 0.1 inch or less, produced no perceptible changes in yield in either crop. Thus, a modification capability limited to such days has no agricultural value. Second, given the limited data sample and given the temperatures and conditions in these three years, there is an indication that summer rainfall amounts in excess of 14 inches leads to decreases in both corn and soybean yields. Prior research established that the prairie soils of central Illinois can contain only so much water and thereafter ponding and saturated soils produce detrimental effects to both crops. A third finding for both crops (given this limited sample) is that given that natural rainfalls are less than 14 inches, a 40% increase in all rain events was the best possible outcome tested. That is, a 40% increase to all rain events increases the yields of both crops more than any other type of simulated increase tested. Although not unexpected, this outcome confirms past modeling studies.

The results for both crops suggest that the relative value of 1 inch of rain (or any amount of rainfall) is much greater when the summer rainfall is low. For example, 1 inch of rain when summer totals is between 5 and 7 inches produced a 10 bu/acre increase in corn, whereas with summer total rainfall between 11 and 13 inches, the impact of an additional inch of rain was approximately 5 bu/acre to corn. Soybean responses to an inch of rain (given the summer total was <14 inches) were less than with corn. In the hot, dry summer of 1988, an additional inch of rainfall produced approximately 4 additional bu/acre of soybeans, whereas in the wetter near normal summer of 1989, the increase was about 3 bu/acre. Every additional inch of rain above a summer total of 17.8 inches (1987) produced about a 3 to 4 bu/acre decrease to 20 inches; thereafter, the decrease in yields with additional rainfall became much greater.

The results for both corn and soybeans suggest the following guidelines relative to weather modification planning. First, increases in rainfall on days when a 0.1 inch or less is produced appear to be of negligible value to crop yields. Summer rain events that produce <0.1 inch are typically of short duration, 15 minutes or less at a point, and are often followed by clearing and a rapid return to pre-rain temperatures. Hence, we conclude that most of this light rainfall is evapotranspirated and very little enters the root zone of corn and soybeans. However, increases in rain on days when rainfall is more than 0.1 inch show positive yield benefits, and the greater the increase, the greater the crop yield benefit, at least up to totals that are too much for soils to handle, apparently about 14 inches for the summer (with near normal temperatures). Furthermore, for the corn production, results suggest that increases of 10% or more to days when 1 inch or more of rain occurs are particularly beneficial to crop yields.

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