An Analysis of Factors Influencing Corn Yields

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Abstract: The 1988 drought renewed interest in the relationship between weather and yields. Regression equations are estimated for U.S. average corn yields. Results illustrate that there is little carryover effect from a drought to yields in the following year—yields tend to rebound to near trend levels following a drought. Soil moisture recharge is an important consideration, but too much moisture in the spring can delay plantings, which typically reduces yields by exposing more of the critical growing stages of the crop to less favorable summer weather. The most important factor in determining corn yields in the year following a drought is weather during the growing season. Timely rains in July are the most critical, with July temperatures next in importance in most years. Other results show that average weather is not necessarily optimal for yields, and that there are more downward risks in yield responses to weather than there is upward yield potential.

Keywords: Corn, yields, weather, planting dates, 1988 drought.

The 1988 drought affected many agricultural production regions in the United States. National average corn yields fell from record levels of 119.4 bushels an acre in 1987 to 84.6 bushels in 1988, one of the largest percentage declines of the century. Unlike many other recent droughts which developed during the months of July and August, an unusual feature in 1988 was the severity of early-season weather through June.

Consequently, the 1988 drought intensified interest in the relationship between weather and yields. This article examines factors which could affect post-drought recovery of U.S. corn yields. Building from an adjusted trend model, the roles of soil moisture recharge, planting dates, and growing season weather are considered. Model forecasts of corn yields for 1989 also are presented.

Adjusted Trend Yields

Trend analysis is used as an initial indicator of yields. Trend terms are typically included in yield analysis to represent productivity gains. Trends also tend to be correlated with fertilizer application rates and, therefore, may also represent the effects on yields of fertilizer use.

However, a couple of additional factors are appropriate for inclusion in trend analysis for corn yields. First, yields will depend on the level of corn acreage. Farm program provisions determine the amount of acreage that program participants may plant. When individual farmers remove land from production to comply with program provisions, they typically idle their least productive acres. As lower yielding land is returned to production under less restrictive farm programs, average yields would be expected to be lower than those attained with that acreage idled. Thus, a greater level of acreage planted with corn would imply a lower average yield.

A second adjustment to a simple trend analysis for corn yields is used to account for the unusual situation in 1983. In that year, a substantial amount of land was idled from corn production under the PIK program, which would have typically been expected to raise average yields. However, the 1983 drought sharply reduced corn yields. To correct for spurious correlation between this reduction in acreage and lower yields, a dummy variable for 1983 is used in this analysis.

The resulting adjusted trend equation for corn yields is:

$$\text{(1)}\quad \underset{(5.5)}{\text{YIELD} = 97.7} + \underset{(8.1)}{2.37}\ \text{TREND} - \underset{(1.5)}{0.387}\ \text{ACRES} - \underset{(3.9)}{35.97}\ \text{D83}$$

$R^2 = 0.82$ RMSE = 7.2 Estimation period = 1965-1987

where:

YIELD = U.S. average corn yield per harvested acre (bushels per acre),

TREND = an annual trend variable equal to 0 in 1965, 1 in 1966, and so forth,

ACRES = acreage planted with corn in the United States (million acres), and

D83 = a dummy variable equal to 1 in 1983 and 0 elsewhere.

Numbers in parentheses below each estimated coefficient are t-statistics, R^2 is the coefficient of determination, and RMSE is the root mean square error (bushels per acre).

Each estimated coefficient has the expected sign. The coefficient of the trend term implies an annual increase in corn yields due to productivity gains of about 2.4 bushels an acre. For each additional million acres planted with corn, average yields for corn would be expected to fall by about 0.4 bushels an acre. The coefficient of the 1983 dummy variable implies that 1983 actual yields were nearly 36 bushels lower than would have been expected without the drought. The coefficient of determination means that 82 percent of the variation in corn yields is explained by this adjusted trend equation. The root mean square error is 7.2 bushels an acre.

Post-Drought Yield Recovery

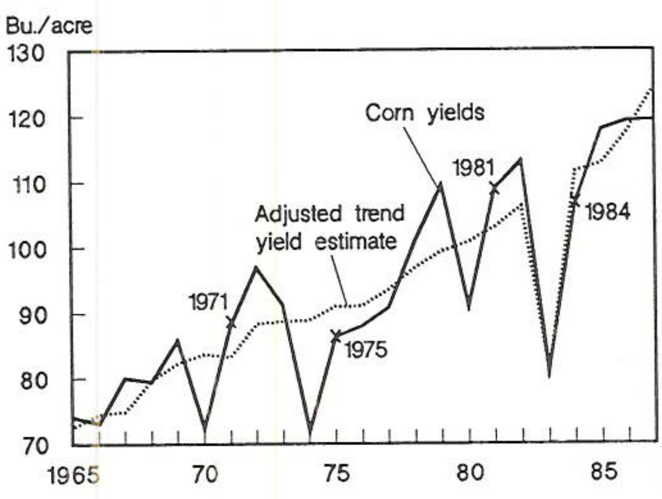
Figure A-1 shows actual U.S. average corn yields over 1965 to 1987 along with the adjusted trend estimates resulting from equation 1. Of particular interest, the 4 years in which droughts contributed to significant production shortfalls (1970, 1974, 1980, and 1983) were followed by years of significant recovery in corn yields.[1] Corn yields in 2 of the subsequent years (1971 and 1981) were above the trend estimate, while yields in the other 2 subsequent years (1975 and 1984) fell somewhat short of the trend estimate.

One possible cause of the differing yield recoveries in years following droughts is the degree of soil moisture recharge. Soil moisture is important for crop development because it is a reserve of water that can be used by the crop between rains. Soil moisture levels are depleted during droughts. Consequently, yields in years following droughts would be expected to rebound better when soil moisture levels were replenished prior to plantings.

[1] Factors other than droughts also contributed to some of these production shortfalls. For example, much of the 1970 production shortfall was caused by a corn blight, with about a third of the shortfall due to dry growing-season weather in Missouri and the Central Plains. In this analysis, however, each of these 4 production shortfall years is referred to as a drought year.

Figure A-1

Corn Yields and Adjusted Trend



To examine the soil moisture hypothesis, a 6-month total of average Corn Belt precipitation levels in October through March was calculated for each year.[2] Following the four droughts discussed above, these cumulative precipitation totals represent the potential for soil moisture recharge prior to the next growing season.

Surprisingly, table A-1 shows that the 2 post-drought years in which corn yields recovered to above the trend estimate (1971 and 1981) were preceded by October through March precipitation totals below the 1965 through 1987 average. Also, the 2 post-drought years in which corn yields fell short of the trend estimates (1975 and 1984) had precipitation in the preceding October through March above the longer-run average.

One possible explanation of these surprising results would be that the timing of plantings in years following droughts was affected by the amount of precipitation in the preceding October through March period. Table A-2 shows the portion of the Corn Belt corn crop planted by the middle of May for the 4 post-drought years being discussed. For the 2 post-drought years in which corn yields recovered to above the trend estimate and the preceding October through March precipitation totals were below average (1971 and 1981), mid-May plantings exceeded the average. The below

[2] Weather variables used in this article are from the Automated Weather/Yield System (3). The five-State Corn Belt (Illinois, Indiana, Iowa, Missouri, and Ohio) is the largest corn production region, usually accounting for over half of total U.S. corn production.

Table A-1--Soil moisture recharge potential, post-drought years

Year	October-March Corn Belt precipitation
	Inches
1970/71	13.4
1974/75	17.1
1980/81	9.3
1983/84	18.9
1964/65-1986/87 average	15.1

Table A-2--Early season corn plantings, post-drought years

Year	Corn Belt plantings by mid-May
	Percent
1971	78
1975	74
1981	61
1984	33
1965-87 average	60

average level of plantings by mid-May in 1984 may have resulted from the relatively large amount of precipitation in the preceding October through March and may have contributed to corn yields falling short of trend estimates that year. However, the shortfall in the 1975 corn yield recovery cannot be attributed to late plantings despite the above average level of precipitation in the preceding October through March.

The Roles of Planting Dates and Growing Season Weather

The results from the analysis of the adjusted trend yield estimates suggest that a more complex relationship between planting dates, weather, and corn yields exists.

Both precipitation and temperature during the growing season are important for crop development. Figure A-2 shows typical daily water use rates for 110 growing day corn plants (5). The largest water use occurs from about the 40th day following planting to about the 80th day, with peak water use near the 60th day of growth during tasseling and silking. For a corn crop planted on typical dates in May, most of the water needs would occur in July. However, a significant portion of the water use could occur in June if much of the crop is planted by mid-May.

Temperatures also play an important role in crop development. Hot weather can stress the crop at critical stages of grain formation, as well as increase evaporation of moisture reserves from the soil, reducing water availability when it is most needed.

Early plantings typically would be expected to be beneficial for corn yields because June weather is usually more favorable for crop development. June tends to have more precipitation than July (table A-3). Additionally, the standard deviation of precipitation is smaller in June. Combined with the smaller water use of corn at early stages of crop development, this implies a smaller risk in June of shortfalls in meeting water needs. Average temperatures in June also tend to be cooler than in July, with standard deviations of temperature about equal in the 2 months. Thus, water evaporation and heat stress to the crop typically would be less in June.

Figure A-2
Typical Water Use Rate for Corn

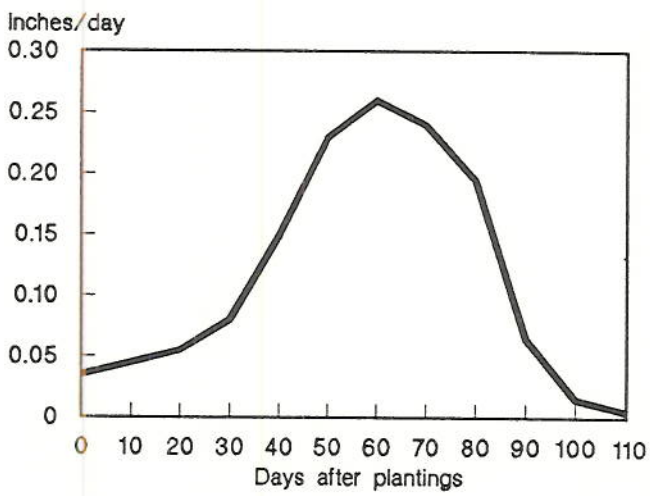


Table A-3--Corn Belt weather, 1965-87

Variable and month	Mean	Standard deviation
Precipitation	Inches	
June	4.2	0.8
July	3.9	1.1
Temperature	Degrees	
June	71.2	2.0
July	75.5	1.9

Econometric Model

To reflect the effects of growing season weather variables on yields, the adjusted trend model used earlier was augmented by adding Corn Belt precipitation and temperature variables for the months of June and July.[3] The timing of the daily water use rates suggests that weather is important throughout July, so July weather variables were used directly. However, the timing of water use in June depends on when the crop is planted. To reflect the effects of early planting, June weather variables were weighted by the portion of the Corn Belt crop planted by mid-May.

A quadratic form was used for the weather variables, initially with both linear and squared terms. Multicollinearity problems led to the removal of the linear temperature variables in the final model specification. The resulting equation is:

(2) YIELD = 110.1 + 2.17 TREND - 0.219 ACRES - 17.45 D83
(3.6) (10.4) (1.3) (2.7)

+ 15.70 MM JUNEP - 1.79 MM JUNEP2 - 0.0065 MM JUNET2
(1.5) (1.4) (1.6)

+ 13.05 JULYP - 0.98 JULYP2 - 0.0103 JULYT2
(1.8) (1.0) (2.7)

$R^2 = 0.96$ RMSE = 4.2 Estimation period = 1965-1987

where YIELD, TREND, ACRES, and D83 are as defined earlier and:

[3] Using monthly averages of weather variables may not capture all the effects of weather on yields because the timing of rainfalls and fluctuations in temperatures within the month are not represented.

MM = the portion of the Corn Belt corn crop planted by mid-May,

JUNEP = June precipitation in the Corn Belt (inches),

JULYP = July precipitation in the Corn Belt (inches),

JUNEP2 = the square of JUNEP,

JULYP2 = the square of JULYP,

JUNET2 = the square of June temperature in the Corn Belt (degrees F.), and

JULYT2 = the square of July temperature in the Corn Belt (degrees F.).

Again, numbers in parentheses below each estimated coefficient are t-statistics, R^2 is the coefficient of determination, and RMSE is the root mean square error.

The estimated coefficients of the non-weather variables in equation 2 have implications similar to the results of equation 1. The trend term implies an annual increase in corn yields due to productivity gains of about 2.2 bushels an acre. For each additional million acres planted with corn, average yields would be expected to fall by about 0.2 bushels an acre. The 1983 dummy variable coefficient implies that 1983 actual yields were about 17 bushels below what trend, acreage, planting dates, and weather would imply. The coefficient of determination means that 96 percent of the variation in corn yields is explained by equation 2. The root mean square error has been reduced to 4.2 bushels an acre in this equation.

Equation 2 also has smaller yield estimate errors than equation 1 for each of the 4 post-drought years discussed earlier. Yield estimate errors shown in table A-4 are labeled as "under" when the equation estimate is below the actual yield, and "over" when the equation estimate is above the actual yield.

When weather is included, yield estimates for 1971 and 1981 from equation 2 are higher than those from the adjusted trend equation, narrowing the gap in the yield under-predictions. This largely is due to beneficial effects of July weather in those years that was cooler and wetter than average. Equation 2 also reduces the over-predicted yield estimates for 1975 and 1984. July weather that was significantly drier than average in 1975 pushed the yield estimate from equation 2 below the actual yield. For 1984, hotter than average June weather and drier than average weather in both June and July lowered the yield estimate in equation 2 closer to the actual yield.

Table A-4--Yield estimate errors, post-drought years

Year	Equation 1	Equation 2
	Bu./acre	
1971	4.8 under	0.9 under
1975	4.6 over	4.2 under
1981	5.8 under	1.1 under
1984	4.9 over	4.1 over

"Under" means the equation estimate is below the actual yield; "over" means above actual.

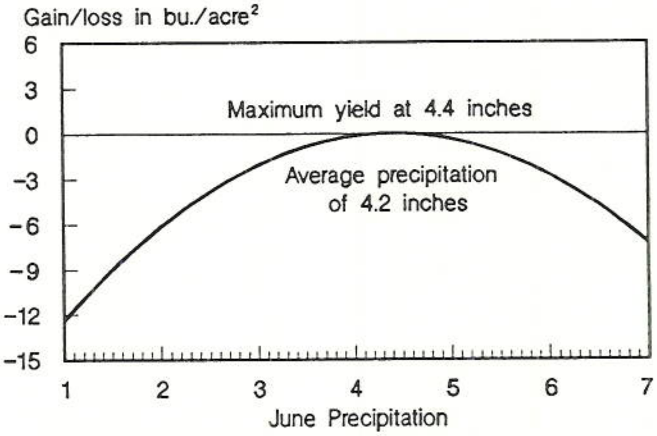
Effects of Weather Variables

Figures A-3 through A-6 show the effects of June and July weather variables implied by equation 2. Each figure shows the estimated gain or loss in yields resulting from departures from average in each weather variable. The effects of June weather variables (figures A-3 and A-4) are evaluated at the 1965-87 average level of corn crop plantings by mid-May of about 60 percent.

Corn Belt precipitation averages about 4.2 inches in June, near the optimal level for yields implied by equation 2 of 4.4 inches (figure A-3). While these precipitation levels are somewhat higher than the daily water use rates would imply the crop needs, the larger precipitation levels allow for additions of moisture to the soil and water loss to runoff and evaporation. Figure A-3 indicates that departures from the average in precipitation result in losses in yield potential. Within a range of one standard deviation of the average, yield losses corresponding to precipitation of 3.4 to 5.0 inches are less than 1 bushel per acre. However, yield potential drops more quickly for greater departures from average in June precipitation.

Although the quadratic form was used for the effects of June temperature, figure A-4 shows that the response of yields to changes in June temperature is nearly linear over the

Figure A-3
Corn Yield Response to June Corn Belt Precipitation[1]



1/ Assumes 60 percent of Corn Belt crop planted by mid-May.
2/ From average weather yields.

relevant range. Figure A-4 indicates that the response of corn yields to June temperatures is small. For temperature departures of one standard deviation from the June average of 71.2 degrees, yield gains and losses each equal about 1 bushel an acre corresponding to temperatures of 69.2 and 73.2 degrees.

Corn Belt precipitation in July averages 3.9 inches. The results of equation 2 imply the optimal level for yield potential is about 6.6 inches (figure A-5). Thus, when July precipitation exceeds the average level, there are significant potential gains for corn yields. Also, because most of the critical growing stages occur in July, indicated yield losses for precipitation levels below average are larger than in June. Potential yield losses also exceed potential yield gains. Within a range of one standard deviation below and above the average, yield losses corresponding to precipitation of 2.8 inches are about 7 bushels per acre, but yield gains corresponding to 5.0 inches of precipitation are about 5 bushels an acre. Further, although the estimated potential gain in yields is over 7 bushels an acre for the estimated optimal July precipitation of 2.7 inches above the average, a precipitation shortfall of 2.7 inches below average is estimated to cause asymmetric yield losses of over 21 bushels an acre.

The July total of daily water use rates of about 7 inches differs slightly from the implied optimal level of precipitation in equation 2 of 6.6 inches and differs substantially from average July precipitation. This suggests that the corn crop obtains a significant amount of its water needs in July from moisture already in the soil.

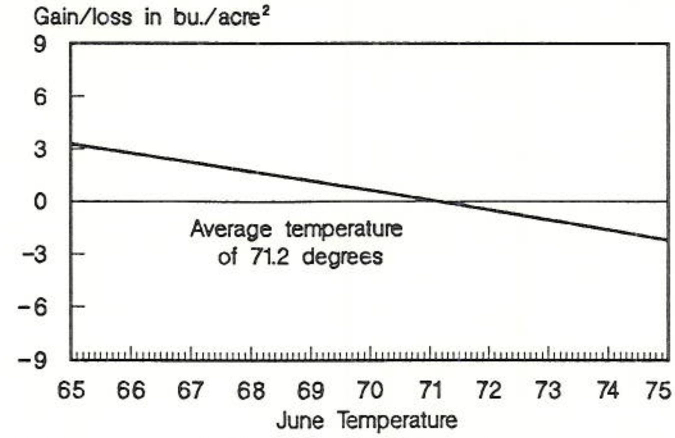
As with June temperatures, figure A-6 shows that the response of corn yields to July temperatures is nearly linear over the relevant range. The response of corn yields to temperature in July is larger than in June. For temperature departures of one standard deviation from the July average of 75.5 degrees, yield gains and losses each are about 3 bushels an acre corresponding to temperatures of 73.6 to 77.4 degrees.

Effects of Planting Dates

The effects on corn yields of June precipitation and temperature shown in figures A-3 and A-4 were derived from the interaction terms in equation 2 between the weather variables and the mid-May plantings variable, with 60 percent (the average proportion) of the crop assumed planted by mid-May. Figure A-7 illustrates the effects that the timing of plantings has for corn yields for different combinations of June weather. As expected from the earlier discussion of water use rates and average June and July weather, if June weather is average, yield potentials improve when a larger portion of the corn crop is planted by mid-May.

Figure A-4

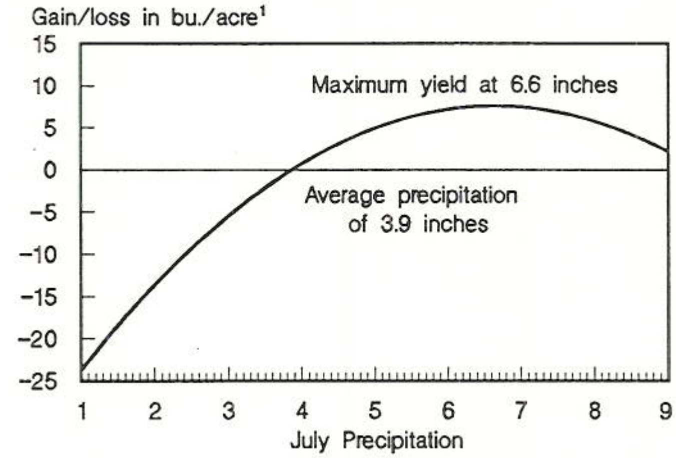
Corn Yield Response to June Corn Belt Temperature[1]



1/ Assumes 60 percent of Corn Belt crop planted by mid-May.
2/ From average weather yields.

Figure A-5

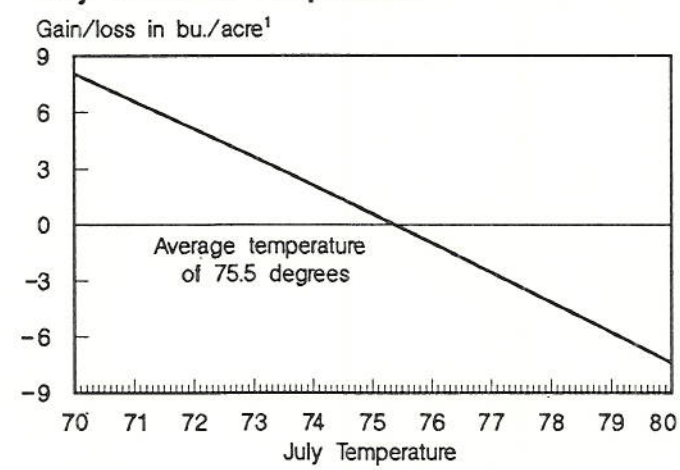
Corn Yield Response to July Corn Belt Precipitation



1/ From average weather yields.

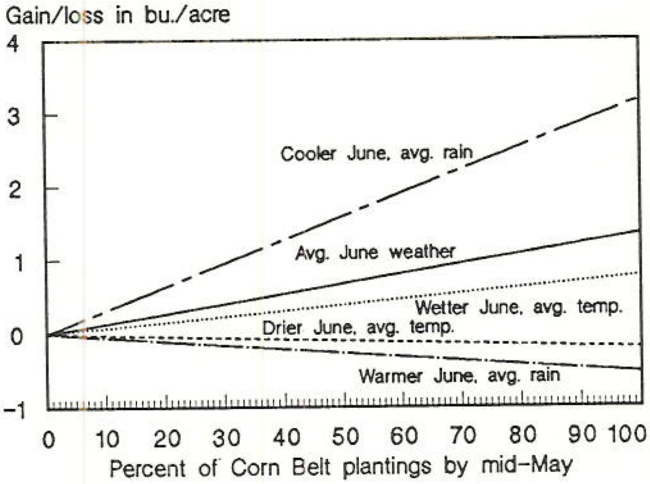
Figure A-6

Corn Yield Response to July Corn Belt Temperature



1/ From average weather yields.

Figure A-7
Corn Yield Response to Percent of Plantings by Mid-May



Somewhat different implications for the effects of planting dates result, however, if June weather varies from average. Figure A-7 also shows the effects of planting dates on yields for four alternatives to normal June weather. Each alternative weather scenario is derived by separately varying June precipitation and temperatures by one standard deviation above and below their averages, with other weather held at average levels.

June weather that is cooler than average is better for crop development, making early plantings beneficial. Consequently, larger yields result when a higher proportion of the crop is planted by mid-May. Warmer June weather is less favorable for crop development and reduces yields from those attained with average weather. At a level of one standard deviation above average, a warmer June lowers yields for additional portions of the crop planted by mid-May and makes early plantings marginally detrimental.

Both wetter and drier weather in June at one standard deviation from average are marginally inferior to average June weather for yields. Early plantings are still beneficial for yields if June weather is one standard deviation wetter than average. However, a drier June at one standard deviation from average makes early plantings marginally detrimental.

Much larger yield variations can result with early plantings if June weather differs by more than one standard deviation from average. For example, with 97 percent of the Corn Belt corn crop planted by mid-May last year, these relationships imply that the hot, dry weather in June 1988 (1.1 standard deviations warmer and 3.9 standard deviations drier) reduced corn yields by nearly 20 bushels an acre from yields estimated with average weather and only 60 percent of the crop planted by mid-May.

Implications for 1989

The regression equations presented in this article were used to forecast potential corn yields for 1989. Farmers have indicated that they intend to plant 73.3 million acres of corn this year. With this level of plantings, the adjusted trend yield estimate of equation 1 implies a national yield of 126 bushels an acre. Implicit in this trend yield estimate are assumptions that weather and the timing of plantings are average.

Using equation 2, estimates of 1989 corn yields can be made with alternative assumptions regarding weather and planting dates. About 70 percent of the Corn Belt corn crop was planted by mid-May this year, 10 percent ahead of the 1965-87 average. With this plantings date information, average weather for June and July would result in an estimated 1989 corn yield of nearly 125 bushels an acre.

If June and July weather are not average, somewhat different yields could result, however. Table A-5 shows estimated 1989 corn yields for different weather combinations derived from equation 2. Weather that is one standard deviation below average is defined as "low," while weather one standard deviation above average is defined as "high." For the range of weather shown, estimated 1989 average corn yields would be 112 to 134 bushels an acre. However, weather combinations required to attain yields toward the ends of that range are less likely to occur. Most weather combinations in table A-5 result in yield estimates above 120 bushels an acre, reflecting the ability of corn yields to rebound following droughts if subsequent growing season weather is favorable.

Table A-5 also illustrates that corn yields are more sensitive to weather in July than in June. July precipitation is most critical, typically followed by July temperatures. This relationship appears to hold even when plantings are ahead of average, although to a lesser extent. Yield impacts due to weather changes within one standard deviation of average give ranges of about 1 bushel an acre corresponding to June precipitation and about 2-1/2 bushels an acre corresponding to June temperatures. These impacts compare to yield ranges of 12 bushels an acre for July precipitation changes and 6 bushels an acre for July temperature changes within one standard deviation of average.

Finally, table A-5 reflects a result illustrated earlier that while there is some potential for higher yields if weather is better than average, the magnitude of reductions in yields due to less favorable weather is greater. For example, if July precipitation were to exceed average levels by one standard deviation and other weather were average, the corn yield estimate would be improved by nearly 5 bushels an acre, to over 129. A shortfall in July precipitation of one standard deviation with other weather normal, however, would push

Table A-5--1989 Corn yield estimates for different June and July weather assumptions

July weather assumption		Low June precipitation			Average June precipitation			High June precipitation		
Precipitation	Temperature	Low June temp.	Average June temp.	High June temp.	Low June temp.	Average June temp.	High June temp.	Low June temp.	Average June temp.	High June temp.
						Bu./acre				
Low	Low	120.4	119.2	117.8	121.5	120.2	118.9	121.1	119.8	118.5
Low	Average	117.5	116.2	114.9	118.6	117.3	116.0	118.2	116.9	115.6
Low	High	114.5	113.2	111.9	115.6	114.3	113.0	115.2	113.9	112.6
Average	Low	127.7	126.4	125.1	128.8	127.5	126.2	128.4	127.1	125.8
Average	Average	124.7	123.5	122.1	125.8	124.5	123.2	125.4	124.1	122.8
Average	High	121.7	120.5	119.1	122.8	121.5	120.2	122.4	121.1	119.8
High	Low	132.5	131.2	129.9	133.5	132.3	130.9	133.1	131.9	130.5
High	Average	129.5	128.2	126.9	130.6	129.3	128.0	130.2	128.9	127.6
High	High	126.5	125.3	123.9	127.6	126.3	125.0	127.2	125.9	124.6

Assumes planted acreage of 73.253 million acres and a mid-May plantings percent in the Corn Belt of 70 percent. "Low" means weather variable is below its average by one standard deviation; "high" means above average by one standard deviation.

estimated yields down more than 7 bushels an acres, to under 118.

Conclusions

The regression equations presented in this article have illustrated some important characteristics about how corn yields are affected by planting dates and weather. Results from the adjusted trend analysis indicate that there is little carryover effect from a drought to yields in the following year—yields tend to rebound to near trend levels following a drought. While soil moisture recharge is an important consideration, too much moisture in the spring can delay plantings. This would typically reduce yields by exposing more of the critical growing stages of the crop to less favorable weather in the summer.

This analysis indicates that the most important factor in determining corn yields in the year following a drought is weather during the growing season. A regression equation incorporating information about planting dates and variables of growing season weather implies that timely rains in July play the most critical role, with July temperatures next in importance in most years.

Planting dates are important for corn yields. On average, earlier plantings increase yields because June weather is typically more favorable for corn than July weather. However, earlier plantings can hurt corn yields if June weather is particularly hot and dry, as in 1988.

Other results show that average weather is not necessarily optimal for crop development and yields. While average precipitation in June is near the estimated optimal level, average precipitation in July falls short of the estimated optimal amount. This result suggests that the corn crop draws a significant amount of its water needs in July from moisture already in the soil. Finally, corn yields show more downward risks due to poor weather than upward yield potential due to good weather.

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