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Are Corn and Soybean Trend Yields Changing in Illinois?

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Abstract

Crop yields are influenced by a complex combination of factors, including weather, seed genetics, soil quality, and production management. Regardless, yields still tend to show a general trend over time, which is referred to as the "trend yield." There has been much debate over whether improved technology has caused trend yields to change in recent years. Many experts believe recent corn yield increases were caused by advancements in biotechnology for seed genetics. It has been suggested that a lack of research on soybean genetics has led to a plateau in the soybean trend yield. It has been widely accepted that these new trends began in the mid-1990s and that they should be used for estimating future yields. However, weather should be taken into consideration because it can have a large effect on trend yields. The purpose of this paper is to examine whether trend yields in Illinois for corn and soybeans have changed since the mid-1990s. The effect of both weather and technology on yields in Illinois is estimated over the period 1960-2008. The results of this research provide evidence that weather plays a significant and important role in determining yields.

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Are Corn and Soybean Trend Yields Changing in Illinois?

Crop yields are influenced by a complex combination of weather, seed genetics, soil quality, and production management. However, yields show a general trend over time called the "trend yield." Many farmers, crop scientists, and seed companies believe that advancements in biotechnology for seed genetics have caused corn trend yields to increase at an increasing rate in recent years. For soybeans, it has been suggested that a lack of research on soybean genetics has led to a plateau in the soybean trend yield. Researchers have unanswered questions about pod and flower abortion and other yield restricting problems. It has been widely accepted that these new trends began in the mid-1990s and that they should be used for estimating future yields. However, weather should be considered because it can have a large effect on trend yields estimated over short periods.

Today, there is a great need to have the ability to estimate future crop yields accurately. This research will help to satisfy this need by investigating the relationship between weather, technology, and crop yields. Having the ability to make accurate estimates is extremely important due to the high demands for both soybeans and corn. There is high demand for soybeans to produce biodiesel, soybean meal (high-protein animal feed), and soybean oil (widely used vegetable oil). There is high corn demand to produce ethanol and distiller's grains (high-protein animal feed) (Charles 2008). Biofuels are liquid fuels produced from biomass materials that are used primarily for transportation. Biomass is organic nonfossil material of biological origin constituting a renewable energy source. The most common biofuels are ethanol and biodiesel. In fact, more than half of the gasoline in the United States has an ethanol blend. In 2007, the United States consumed 6.8 billion gallons of ethanol and 491 million gallons of biodiesel. Government incentives have caused an increase in the consumption of ethanol due to the Renewable Fuel Standard (RFS) requirements of the Energy Policy Act of 2005. The RFS mandated that fuels contain a minimum volume of renewable fuels, with a yearly increase until 2022. The predictions for 2030 are that ethanol usage will increase to 24 billion gallons and 36 percent of corn production will be used for ethanol (What are Biofuels and How Much Do We Use? 2008). Therefore, in the near future it will be increasingly important to make accurate yield predictions in order to know in advance, if supply will meet demand. Having knowledge of which climate variables affect crop yields the most will also help in creating the most accurate yield estimation models.

Climate change is currently a highly debated topic. The results of this research on the relationship between weather, technology, and crop yields will be increasingly important in the near future. Creating accurate yield prediction models will be difficult if we do not understand this relationship. With climate change, our current models may no longer be accurate because they will be based on past weather patterns. In the future, this research will help farmers choose the best management techniques and help geneticists engineer the best seeds to fit the climate.

History provides examples of shifts to higher corn trend yields that prove it is possible for the increase in the trend yield to be caused by advancements in technology. Examples are the single cross hybrids in the late 1930s and nitrogen fertilizers in the late 1950s. Therefore, many experts believe improvements in the biotechnology for seed genetics today are responsible for the higher corn trend yield. Weather is a very important factor however, and it should be taken into consideration. It is possible that ideal weather for corn production has occurred since the mid-1990s and that it can account for the increased trend yield.

Perhaps ideal weather for corn has occurred, but that certainly has not been the case for soybeans. Soybean yields may have hit a plateau since the mid-1990s. This is likely caused by two main reasons. First, corn and soybeans are genetically different plants, so they require different environments for growth. Second, greater attention has been paid to corn research due to the great demand for corn ethanol and feed. A joint effort involving research by crop geneticists, physiologists, agronomists, and breeders could enhance soybean yield potential. Nevertheless, it is unlikely that researchers would succeed in increasing average soybean yields more than a few tenths of a bushel in the next ten years. In fact, it may be impossible for soybeans to reach a comparable yield growth trend to corn.

The main challenge for researchers is the quest to understand the unique genetic framework of the soybean plant. Soybeans have about half the number of DNA as corn, and they are much more difficult to cross genetically. Making controlled genetic crosses between two corn plants is a much simpler process than crossing soybeans. This process is difficult with soybeans because you have to emasculate (take off the male parts) of the plant by hand. With corn, you only have to place pollen on the silks of the plant and bag it up. This results in a controlled pollination because no other pollen can enter and contaminate. Another difference between corn and soybeans is the quantity of the product you obtain when you make a cross. Crossing two soybean plants will result in a flower with three or four seeds. A corn cross will produce an ear with hundreds of seeds. With genetics research, it is easier to look for something in 200 seeds than it is in three seeds. This is a major advantage of performing genetic experiments with corn.

Another benefit to performing genetics research on corn is that corn is more efficient at photosynthesis than soybeans. Although soybean plants generally handle environmental stresses better than corn, soybeans tend to lose more grain than corn. In fact, soybeans sometimes fail to make grain altogether.

Finally, corn and soybean plants have distinct developmental phases. Corn is a determinate plant, which means it grows, develops, sets an ear, and produces a tassel only once. Therefore, if field conditions are right for corn during the important phases of development, then high yields will occur. On the other hand, soybeans are indeterminate plants. They continuously produce more flowers and pods during development. If stress hits early in development, soybeans can make up reproductive losses later in development. This results in soybean yields consistently being more stable than corn, year in and year out. This key difference in development can help to explain the difference in trend yields for the two plants.

With soybeans, it is important to understand that much of the reproductive potential, small flowers and pods, abort before reaching full development. Roughly, only 33% of the pods are harvested. Experts believe there is an incredible opportunity to increase yield quantity by gaining a greater understanding of pod and flower abortion and other yield restricting problems in soybeans (Leer 2004). To enhance the value of gaining a greater understanding of abortion, it is important to gain a greater understanding of the relationship between weather and soybean yields. After all, field conditions, possibly causing abortion, are caused by weather.

This paper proposes that the increase in the trend yield for corn in Illinois since the mid-1990s is not solely caused by advancements in biotechnology for seed genetics. In addition, the plateau in the trend yield for soybeans in Illinois since the mid-1990s is not solely caused by a lack of research on soybean genetics. Illinois was chosen because it is one of the most important corn and soybean producing states in the United States. Weather, which can be extremely variable, plays an important role in the actual yields from year to year. Therefore, the relationship between weather, technology, and crop yields should be taken into consideration when estimating future yields.

Objectives

One objective for this study is to estimate the relationships of weather and technology to crop yields for corn and soybeans in Illinois. The second objective is to discover which climate variables have the greatest influences on yields. The third objective is to obtain results that are the most accurate by utilizing data collected at the crop reporting district level, rather than the state level. The nine crop reporting district boundaries are illustrated in Figure 1. It is assumed that local data will better account for differences in soil quality and weather in different regions of Illinois. The data will account for local weather events, such as drought, that may only affect a limited area of the state.

Figure 1. County and Crop Reporting District Geographical Boundaries
(National Agricultural Statistics Service 2008)

Data and Methods

The options for estimating the relationship between weather, technology, and crop yields can be classified into two groups. The first group consists of crop simulation models that directly evaluate the effects of weather and soil makeup on plant physiology. These models focus on the influences of physiological and biological factors that affect plant development throughout the growth cycle. While these models have a foundation in biological theory and experimental data, they are highly complex and difficult to generalize to combined areas such as crop reporting districts. Simulation models also tend to exclude the influence of technological advances over time and have somewhat poor explanatory power.

The second group consists of multiple regression models that estimate the relationship of weather and technology to crop yields. One advantage of multiple regression models is that they include both weather and technological aspects of yield variation over time. Regression models are also relatively simple to specify and estimate for combined areas, which is a great advantage when forecasting is the objective. Combining areas can create problems, however. For example, a monthly rainfall total of four inches can represent one inch of rain each week or one four-inch rain in the first week. Each scenario can have significantly different effects on crop yields. In addition, averages over large areas may not adequately reflect local weather conditions that affect crop yields. Even at the crop reporting district level, this issue may still pose a problem. Despite these drawbacks, multiple regression models have proven to be valuable in research due to their high explanatory power and ability to represent both weather and technology affects over time. Due to these advantages and the difficulty of applying crop simulation models to combined areas, this research utilizes the regression model method (Tannura, Irwin, & Good 2008).

The effects of both weather and technology on yields are estimated over the period 1960-2008. Climate data is recorded at the crop reporting district level in Illinois. The climate variables are September-April (pre-season), May, June, July, and August precipitation and June, July, and August temperature. The yield prediction model used in this research was adapted from a model developed by Thompson. The model used in this study includes fewer yet more precise parameters than the original Thompson model in order to maximize the degrees of freedom. The multiple regression equation used in this research is

(1) $(\text{Yield})_t = \beta_0 + \beta_1(\text{Year})_t + \beta_2(\text{September - April precipitation})_t + \beta_3(\text{May precipitation})_t + \beta_4(\text{June precipitation})_t + \beta_5(\text{June precipitation})^2_t + \beta_6(\text{July precipitation})_t + \beta_7(\text{July precipitation})^2_t + \beta_8(\text{August precipitation})_t + \beta_9(\text{August precipitation})^2_t + \beta_{10}(\text{May temperature})_t + \beta_{11}(\text{June temperature})_t + \beta_{12}(\text{July temperature})_t + \beta_{13}(\text{August temperature})_t + \varepsilon_t$ (Tannura et al. 2008)

where yield is measured in bushels, precipitation is measured in inches, and temperature is measured in degrees Fahrenheit. The year variable is represented by the number coinciding with the year in the 49-year period (i.e. 1960 = 1, 1961 = 2, … 2008 = 49).

The time trend variable in the model represents technological improvements over time. The gradual increase in corn and soybean yields since 1960 is called trend yield. Trend yield is due to technological improvements in seed genetics, fertilizers, producer management techniques, and other factors. The trend yield can be adequately represented in linear terms.

Therefore, the linear form was also used in the modified model to represent technological advances over time.

Knowing the functional form and importance of each variable is central for understanding the model. The pre-season precipitation variable represents soil moisture. The variable is believed to be important because it functions as a substitute for initial soil moisture level. Monthly weather from May through August was included in the modified model because it is widely known that weather during these months influences crop growth and yield potential the most. May precipitation was included in the modified model because it affects planting date, root development, and initial growth. The linear form of both pre-season and May precipitation was used because a clear quadratic relationship was not found. Quadratic relationships were clearly present in June, July, and August, so these variables were included in the model in the quadratic form. Precipitation during these months is highly influential on yields. The relationship between precipitation and yields was believed to be quadratic because precipitation can be too high or too low for maximum yield potential. An amount between extreme dryness and wetness is ideal. Limited rainfall stresses corn and soybean crops, and too much rainfall leads to flooding. Both situations lead to reduced yields.

Similar to precipitation, temperatures can be too cool or too warm for maximum yield potential. However, monthly temperatures have a much lower range and standard deviation than monthly precipitation. In other words, monthly temperatures from May through August are significantly less variable than precipitation. The narrow range of average temperatures during May through August suggests that a linear form for temperature variables may better reflect actual temperature-yield relationships than a quadratic form (Tannura et al. 2008).

The multiple regression model was run for corn and for soybeans to estimate the separate effects of weather and technology on yields. The regression model was run again with the addition of a dummy variable to create an interaction coefficient. Holding all other independent variables constant, the interaction coefficient represents the change in yield per bushel that occurs for every 1-unit increase in the technology trend at each break year. The technology trend is represented by a linear time trend. The test with the interaction coefficient estimated the effect of the technology trend on yield at each break year 1995-2003. The purpose of estimating the effect of the technology trend on yield at each break year is to test whether or not the p-value at each break year is statistically significant. If the p-value for a break year is statistically significant, then any change in yield per bushel is caused by the technology trend.

Results

One objective of this paper is to discover which climate variables have the greatest influences on yields. Refer to Table 1 for a full display of the corn p-value results for each climate variable included in the multiple regression model used in this research. Refer to Table 2 for a full display of the soybean p-value results. In this study, p-values are considered statistically significant at the 10% level. From Table 1, it is clear that temperatures in July and August are highly important factors affecting corn yields. The p-value for every district is statistically significant for these two variables. The table indicates that precipitation in June, July, and August is important as well, as only the p-values for District 60 are insignificant. From Table 2, it appears that only August temperature is highly influential on soybean yields. Again, precipitation in June, July, and August is shown to be important as well, as only about three p-values on average are insignificant for each variable. In the case of soybeans, the p-values for District 30 are insignificant for all climate variables except August temperature. The variation in significance for the p-values of the districts may be due to geographical differences in the soil in Illinois. Precipitation variables influencing corn in District 30 and soybeans in District 60 may be insignificant because these districts are located near the Mississippi River. Therefore, the soil in these districts may be of higher quality and retain water better than soil in other geographical areas. Having the ability to identify these differences from the results is another objective of this paper. This objective is achieved by using data at the local, crop reporting district level.

Table 1. Corn P-value Results for Climate Variables

	District 10	District 20	District 30	District 40	District 50	District 60	District 70	District 80	District 90
Pre-season Precipitation	0.49	0.91	0.96	0.29	0.06	0.82	0.27	0.19	0.87
May Precipitation	0.06	0.13	0.20	0.04	0.01	0.02	0.14	0.26	0.04
June Precipitation	0.00	0.00	0.02	0.00	0.00	0.18	0.07	0.07	0.06
June Precipitation^2	0.00	0.00	0.02	0.00	0.00	0.18	0.04	0.05	0.03
July Precipitation	0.00	0.02	0.00	0.00	0.00	0.11	0.00	0.09	0.02
July Precipitation^2	0.02	0.04	0.00	0.00	0.00	0.56	0.10	0.62	0.12
August Precipitation	0.21	0.76	0.07	0.30	0.25	0.78	0.56	0.06	0.38
August Precipitation^2	0.13	0.60	0.03	0.22	0.31	0.84	0.84	0.17	0.83
May Temperature	0.33	0.22	0.05	0.05	0.86	0.23	0.48	0.16	0.67
June Temperature	0.86	0.46	0.33	0.53	0.40	0.56	0.53	0.51	0.32
July Temperature	0.01	0.02	0.06	0.00	0.02	0.00	0.00	0.00	0.03
August Temperature	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Highlight indicates statistical significance, p-value < 0.10

Table 2. Soybean P-value Results for Climate Variables

	District 10	District 20	District 30	District 40	District 50	District 60	District 70	District 80	District 90
Pre-season Precipitation	0.23	0.29	0.57	0.41	0.02	0.93	0.38	0.19	0.64
May Precipitation	0.36	0.17	0.98	0.80	0.03	0.24	0.05	0.36	0.23
June Precipitation	0.01	0.02	0.83	0.06	0.01	0.56	0.01	0.03	0.20
June Precipitation^2	0.02	0.04	0.83	0.05	0.01	0.69	0.01	0.04	0.32
July Precipitation	0.76	0.05	0.56	0.02	0.00	0.00	0.01	0.04	0.23
July Precipitation^2	0.54	0.07	0.70	0.11	0.01	0.02	0.07	0.44	0.52
August Precipitation	0.01	0.01	0.28	0.00	0.52	0.00	0.21	0.01	0.01
August Precipitation^2	0.04	0.02	0.48	0.01	0.98	0.02	0.67	0.09	0.09
May Temperature	0.41	0.07	0.26	0.68	0.86	0.98	0.83	0.63	0.88
June Temperature	0.11	0.78	0.15	0.09	0.91	0.08	0.86	0.99	0.58
July Temperature	0.59	0.81	0.14	0.55	0.87	0.10	0.42	0.30	0.50
August Temperature	0.29	0.18	0.01	0.00	0.05	0.00	0.00	0.00	0.00

Note: Highlight indicates statistical significance, p-value < 0.10

The final objective of this paper is to estimate the relationships of weather and technology to crop yields for corn and soybeans in Illinois. The results of the regressions including the interaction coefficient show that the majority of the p-values for the interaction coefficients in all nine districts combined are greater than 0.10 for both corn and soybeans. Specifically, 74.07% of the p-values for corn are insignificant, and 88.89% of the p-values for soybeans are insignificant. In addition, the change in yield per bushel caused by the technology trend is very small for all break years in all districts. The absolute value of the range of the interaction coefficients for corn is 0.00-0.40. The absolute value of the range of the interaction coefficients for soybeans is 0.00-0.10. Refer to Table 3 for a full exhibit of the corn interaction coefficient and p-value results for break years, 1995-2003. Refer to Table 4 for a full exhibit of the soybean results. Tables 5-10 present the regression model estimates for corn and soybean yields in Illinois, 1960-2008.

Conclusions

The results of this study show that since the mid-1990s in Illinois, the increase in the trend yield for corn is not solely caused by advancements in biotechnology for seed genetics, and the plateau in the trend yield for soybeans is not solely caused by a lack of research on genetics. The p-values for the majority of the interaction coefficients in the nine crop reporting districts combined are greater than 0.10 for both corn and soybeans. Therefore, the results are statistically insignificant. Even if all the p-value results were significant, the change in yield per bushel caused by the technology trend is very small for all break years, 1995-2003. The absolute value of the range of the interaction coefficients for corn is 0.00-0.40. The absolute value of the range of the interaction coefficients for soybeans is 0.00-0.10. These ranges are hardly wide enough to represent a substantial impact from technology on yield since the mid-1990s. The results of this research provide evidence that weather plays a significant and important role in determining yield.

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Appendix

Table 3. Corn Interaction Coefficient and P-value Results for Break Years, 1995-2003

District 10			District 20			District 30		
Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value
1995	0.25	0.10	1995	0.00	0.99	1995	0.16	0.33
1996	0.20	0.14	1996	-0.01	0.95	1996	0.24	0.13
1997	0.26	0.04	1997	0.05	0.74	1997	0.27	0.08
1998	0.34	0.01	1998	0.11	0.42	1998	0.28	0.07
1999	0.27	0.03	1999	0.05	0.73	1999	0.25	0.10
2000	0.30	0.01	2000	0.04	0.75	2000	0.29	0.05
2001	0.40	0.00	2001	0.12	0.34	2001	0.27	0.06
2002	0.37	0.00	2002	0.17	0.19	2002	0.21	0.15
2003	0.33	0.00	2003	0.25	0.08	2003	0.20	0.19
District 40			**District 50**			**District 60**		
Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value
1995	-0.07	0.56	1995	0.17	0.19	1995	-0.19	0.18
1996	-0.09	0.47	1996	0.14	0.25	1996	-0.18	0.19
1997	-0.06	0.61	1997	0.15	0.20	1997	-0.13	0.30
1998	0.00	1.00	1998	0.25	0.03	1998	-0.06	0.62
1999	-0.03	0.81	1999	0.20	0.07	1999	-0.07	0.55
2000	-0.01	0.89	2000	0.15	0.18	2000	0.02	0.86
2001	0.02	0.83	2001	0.19	0.09	2001	-0.01	0.96
2002	0.05	0.64	2002	0.22	0.05	2002	0.01	0.94
2003	0.11	0.31	2003	0.25	0.03	2003	0.01	0.95
District 70			**District 80**			**District 90**		
Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value
1995	-0.01	0.95	1995	-0.08	0.53	1995	-0.06	0.63
1996	-0.05	0.68	1996	-0.04	0.71	1996	-0.04	0.72
1997	0.01	0.95	1997	-0.02	0.88	1997	-0.01	0.96
1998	0.11	0.30	1998	0.10	0.41	1998	0.06	0.60
1999	0.12	0.24	1999	0.11	0.36	1999	0.08	0.44
2000	0.17	0.09	2000	0.11	0.40	2000	0.15	0.19
2001	0.20	0.05	2001	0.03	0.83	2001	0.04	0.76
2002	0.19	0.06	2002	-0.01	0.92	2002	-0.02	0.87
2003	0.18	0.08	2003	0.11	0.36	2003	0.02	0.87

Note: Highlight indicates statistical significance, p-value < 0.10

Table 4. Soybean Interaction Coefficient and P-value Results for Break Years, 1995-2003

District 10			District 20			District 30		
Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value
1995	-0.05	0.38	1995	-0.05	0.31	1995	0.02	0.62
1996	-0.06	0.20	1996	-0.07	0.14	1996	0.02	0.58
1997	-0.06	0.17	1997	-0.07	0.14	1997	0.02	0.57
1998	-0.07	0.11	1998	-0.08	0.06	1998	0.01	0.85
1999	-0.10	0.03	1999	-0.09	0.02	1999	-0.03	0.52
2000	-0.08	0.05	2000	-0.09	0.02	2000	-0.03	0.53
2001	-0.09	0.04	2001	-0.06	0.12	2001	-0.03	0.37
2002	-0.10	0.02	2002	-0.05	0.22	2002	-0.05	0.18
2003	-0.09	0.05	2003	-0.04	0.40	2003	-0.07	0.09
District 40			**District 50**			**District 60**		
Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value
1995	-0.02	0.60	1995	0.02	0.61	1995	-0.01	0.88
1996	-0.03	0.53	1996	0.00	0.93	1996	0.00	0.92
1997	-0.04	0.35	1997	-0.02	0.67	1997	0.00	0.92
1998	-0.03	0.46	1998	-0.02	0.68	1998	0.00	0.98
1999	-0.06	0.13	1999	-0.03	0.38	1999	-0.02	0.46
2000	-0.05	0.17	2000	-0.04	0.30	2000	-0.01	0.78
2001	-0.06	0.13	2001	-0.05	0.21	2001	0.00	0.95
2002	-0.06	0.14	2002	-0.04	0.27	2002	0.00	0.95
2003	-0.05	0.18	2003	-0.05	0.21	2003	-0.02	0.47
District 70			**District 80**			**District 90**		
Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value	Break Year	Interaction Coefficient	P-value
1995	0.04	0.26	1995	0.01	0.69	1995	0.01	0.89
1996	0.02	0.54	1996	0.01	0.69	1996	0.00	0.90
1997	0.01	0.72	1997	0.00	0.97	1997	-0.02	0.49
1998	0.03	0.34	1998	0.01	0.84	1998	-0.03	0.30
1999	0.02	0.45	1999	0.01	0.81	1999	-0.02	0.62
2000	0.03	0.24	2000	0.02	0.62	2000	0.01	0.70
2001	0.03	0.30	2001	0.01	0.87	2001	0.01	0.87
2002	0.03	0.32	2002	0.00	0.87	2002	-0.01	0.70
2003	0.01	0.72	2003	0.02	0.57	2003	-0.01	0.81

Note: Highlight indicates statistical significance, p-value < 0.10

Table 5. Regression Model Estimates for Corn Yields in Illinois, 1960-2008

Independent Variable or Statistic	Coefficient Estimates: District 10	District 20	District 30
Constant	278.94 **	299.82 **	206.13 *
	(95.62)	(100.77)	(117.98)
Annual Time Trend	2.08 ***	2.01 ***	2.11 ***
	(0.11)	(0.12)	(0.12)
Pre-season Precipitation	0.28	-0.05	-0.02
	(0.40)	(0.45)	(0.42)
May Precipitation	-1.65 *	-1.78	-1.14
	(0.85)	(1.15)	(0.86)
June Precipitation	14.62 ***	14.83 ***	9.95 **
	(3.15)	(3.75)	(4.15)
June Precipitation^2	-1.36 ***	-1.47 ***	-1.00 **
	(0.29)	(0.39)	(0.42)
July Precipitation	11.79 ***	13.62 **	15.88 ***
	(3.75)	(5.58)	(4.43)
July Precipitation^2	-1.01 **	-1.31 **	-1.28 ***
	(0.41)	(0.60)	(0.38)
August Precipitation	-3.53	-0.92	7.22 *
	(2.74)	(3.02)	(3.90)
August Precipitation^2	0.37	0.14	-0.87 **
	(0.24)	(0.26)	(0.38)
May Temperature	0.44	0.59	1.09 *
	(0.44)	(0.47)	(0.53)
June Temperature	-0.15	-0.65	0.88
	(0.88)	(0.88)	(0.88)
July Temperature	-2.12 **	-2.10 **	-1.90 *
	(0.81)	(0.90)	(0.99)
August Temperature	-1.72 **	-1.68 **	-2.60 ***
	(0.63)	(0.70)	(0.78)
R^2	0.93	0.91	0.91
Standard Error (bu./acre)	9.76	10.34	11.34
Regression F-statistic	34.29 ***	28.91 ***	28.50 ***

Note: One, two, and three stars denote statistical significance at the 10%, 5%, and 1% levels, respectively. Parenthesis indicate standard error.

Table 6. Regression Model Estimates for Corn Yields in Illinois, 1960-2008

	Coefficient Estimates		
Independent Variable or Statistic	**District 40**	**District 50**	**District 60**
Constant	345.29 ***	377.61 ***	419.91 ***
	(86.06)	(88.90)	(83.74)
Annual Time Trend	2.06 ***	1.60 ***	2.07 ***
	(0.09)	(0.10)	(0.10)
Pre-season Precipitation	0.38	0.82 *	-0.08
	(0.36)	(0.42)	(0.34)
May Precipitation	-1.48 **	-2.30 **	-1.83 **
	(0.71)	(0.82)	(0.76)
June Precipitation	13.76 ***	11.95 ***	5.25
	(3.09)	(3.55)	(3.86)
June Precipitation^2	-1.45 ***	-1.36 ***	-0.53
	(0.34)	(0.39)	(0.39)
July Precipitation	11.31 ***	15.16 ***	4.77
	(2.27)	(3.27)	(2.93)
July Precipitation^2	-0.81 ***	-1.14 ***	-0.18
	(0.20)	(0.31)	(0.31)
August Precipitation	4.19	3.71	1.64
	(4.00)	(3.21)	(5.75)
August Precipitation^2	-0.55	-0.35	-0.17
	(0.45)	(0.33)	(0.80)
May Temperature	0.75 *	0.07	0.58
	(0.36)	(0.38)	(0.47)
June Temperature	0.45	-0.65	0.45
	(0.72)	(0.76)	(0.76)
July Temperature	-2.94 ***	-2.08 **	-3.23 ***
	(0.73)	(0.83)	(0.79)
August Temperature	-2.64 ***	-2.45 ***	-2.59 ***
	(0.54)	(0.65)	(0.62)
R^2	0.95	0.93	0.93
Standard Error (bu./acre)	8.30	9.26	9.45
Regression F-statistic	54.19 ***	38.47 ***	38.38 ***

Note: One, two, and three stars denote statistical significance at the 10%, 5%, and 1% levels, respectively. Parenthesis indicate standard error.

Table 7. Regression Model Estimates for Corn Yields in Illinois, 1960-2008

	Coefficient Estimates		
Independent Variable or Statistic	**District 70**	**District 80**	**District 90**
Constant	402.14 ***	345.15 ***	395.31 ***
	(86.03)	(90.76)	(92.55)
Annual Time Trend	1.78 ***	1.74 ***	1.82 ***
	(0.10)	(0.11)	(0.10)
Pre-season Precipitation	0.39	0.40	-0.05
	(0.34)	(0.30)	(0.30)
May Precipitation	-0.96	-0.74	-1.48 **
	(0.64)	(0.65)	(0.68)
June Precipitation	5.67 *	6.34 *	8.15 *
	(3.01)	(3.38)	(4.15)
June Precipitation^2	-0.67 **	-0.70 *	-1.00 **
	(0.32)	(0.35)	(0.45)
July Precipitation	11.71 ***	7.73 *	15.29 **
	(3.88)	(4.37)	(6.39)
July Precipitation^2	-0.67	-0.25	-1.22
	(0.40)	(0.49)	(0.77)
August Precipitation	2.58	9.04 *	2.83
	(4.37)	(4.62)	(3.19)
August Precipitation^2	-0.11	-0.87	-0.08
	(0.55)	(0.62)	(0.37)
May Temperature	0.29	0.71	0.20
	(0.40)	(0.49)	(0.46)
June Temperature	-0.50	-0.54	-0.83
	(0.77)	(0.82)	(0.82)
July Temperature	-2.37 ***	-2.59 ***	-1.80 **
	(0.74)	(0.80)	(0.80)
August Temperature	-2.59 ***	-2.17 ***	-2.79 ***
	(0.59)	(0.62)	(0.63)
R^2	0.93	0.92	0.93
Standard Error (bu./acre)	8.62	9.09	9.07
Regression F-statistic	38.45 ***	33.18 ***	34.82 ***

Note: One, two, and three stars denote statistical significance at the 10%, 5%, and 1% levels, respectively. Parenthesis indicate standard error.

Table 8. Regression Model Estimates for Soybean Yields in Illinois, 1960-2008

	Coefficient Estimates		
Independent Variable or Statistic	**District 10**	**District 20**	**District 30**
Constant	-1.61	-0.65	62.75 *
	(33.81)	(31.58)	(31.87)
Annual Time Trend	0.42 ***	0.43 ***	0.45 ***
	(0.04)	(0.04)	(0.03)
Pre-season Precipitation	0.17	0.15	-0.06
	(0.14)	(0.14)	(0.11)
May Precipitation	-0.28	-0.51	0.00
	(0.30)	(0.36)	(0.23)
June Precipitation	2.95 **	2.89 **	0.24
	(1.11)	(1.17)	(1.12)
June Precipitation^2	-0.26	-0.26 **	-0.02
	(0.10)	(0.12)	(0.11)
July Precipitation	-0.40 **	3.59 *	0.71
	(1.33)	(1.75)	(1.20)
July Precipitation^2	0.09	-0.36 *	-0.04
	(0.14)	(0.19)	(0.10)
August Precipitation	2.64 **	2.57 **	1.16
	(0.97)	(0.95)	(1.05)
August Precipitation^2	-0.18 **	-0.19 **	-0.07
	(0.09)	(0.08)	(0.10)
May Temperature	0.13	0.27 *	0.17
	(0.15)	(0.15)	(0.14)
June Temperature	0.51	0.08	0.35
	(0.31)	(0.28)	(0.24)
July Temperature	-0.15	0.07	-0.40
	(0.29)	(0.28)	(0.27)
August Temperature	-0.24	-0.30	-0.61 **
	(0.22)	(0.22)	(0.21)
R^2	0.84	0.85	0.86
Standard Error (bu./acre)	3.45	3.24	3.06
Regression F-statistic	14.52 ***	15.68 ***	16.90 ***

Note: One, two, and three stars denote statistical significance at the 10%, 5%, and 1% levels, respectively. Parenthesis indicate standard error.

Table 9. Regression Model Estimates for Soybean Yields in Illinois, 1960-2008

	Coefficient Estimates		
Independent Variable or Statistic	**District 40**	**District 50**	**District 60**
Constant	29.18	38.57	64.30 ***
	(31.08)	(30.75)	(20.32)
Annual Time Trend	0.44 ***	0.40 ***	0.40 ***
	(0.03)	(0.03)	(0.02)
Pre-season Precipitation	0.11	0.37 **	-0.01
	(0.13)	(0.14)	(0.08)
May Precipitation	-0.06	-0.65 **	-0.22
	(0.26)	(0.28)	(0.19)
June Precipitation	2.14 *	3.57 **	0.55
	(1.12)	(1.23)	(0.94)
June Precipitation^2	-0.25 *	-0.38 **	-0.04
	(0.12)	(0.13)	(0.09)
July Precipitation	2.07 **	3.61 ***	2.32 ***
	(0.82)	(1.13)	(0.71)
July Precipitation^2	-0.12	-0.30 **	-0.19 **
	(0.07)	(0.11)	(0.07)
August Precipitation	4.54 ***	0.72	4.31 ***
	(1.44)	(1.11)	(1.39)
August Precipitation^2	-0.43 **	0.00	-0.48 **
	(0.16)	(0.12)	(0.19)
May Temperature	0.06	0.02	0.00
	(0.13)	(0.13)	(0.11)
June Temperature	0.45 *	0.03	0.34 **
	(0.26)	(0.26)	(0.18)
July Temperature	-0.16	-0.05	-0.32
	(0.26)	(0.29)	(0.19)
August Temperature	-0.61 ***	-0.46 *	-0.68 ***
	(0.20)	(0.22)	(0.15)
R^2	0.88	0.87	0.91
Standard Error (bu./acre)	0.83	3.20	2.29
Regression F-statistic	19.11 ***	18.45 ***	25.90 ***

Note: One, two, and three stars denote statistical significance at the 10%, 5%, and 1% levels, respectively. Parenthesis indicate standard error.

Table 10. Regression Model Estimates for Soybean Yields in Illinois, 1960-2008

	Coefficient Estimates		
Independent Variable or Statistic	**District 70**	**District 80**	**District 90**
Constant	64.82 **	57.41 **	64.13 **
	(22.96)	(22.14)	(27.51)
Annual Time Trend	0.45 ***	0.33 ***	0.41 ***
	(0.03)	(0.03)	(0.03)
Pre-season Precipitation	0.08	0.10	-0.04
	(0.09)	(0.07)	(0.09)
May Precipitation	-0.34 *	-0.15	-0.24
	(0.17)	(0.16)	(0.20)
June Precipitation	2.23 **	1.82 **	1.60
	(0.80)	(0.82)	(1.23)
June Precipitation^2	-0.26 **	-0.18 **	-0.13
	(0.09)	(0.08)	(0.13)
July Precipitation	2.92 **	2.22 **	2.31
	(1.03)	(1.06)	(1.90)
July Precipitation^2	-0.20 *	-0.09	-0.15
	(0.11)	(0.12)	(0.23)
August Precipitation	1.50	3.16 **	2.69 **
	(1.17)	(1.13)	(0.95)
August Precipitation^2	-0.06	-0.26 *	-0.19 *
	(0.15)	(0.15)	(0.11)
May Temperature	0.02	0.06	-0.02
	(0.11)	(0.12)	(0.14)
June Temperature	-0.04	0.00	0.14
	(0.21)	(0.20)	(0.24)
July Temperature	-0.16	-0.21	-0.16
	(0.20)	(0.19)	(0.24)
August Temperature	-0.60 ***	-0.57 ***	-0.73 ***
	(0.16)	(0.15)	(0.19)
R^2	0.92	0.90	0.89
Standard Error (bu./acre)	2.30	2.22	2.70
Regression F-statistic	32.59 ***	23.46 ***	20.76 ***

Note: One, two, and three stars denote statistical significance at the 10%, 5%, and 1% levels, respectively. Parenthesis indicate standard error.