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# Weather Effects on Expected Corn and Soybean Yields

**Paul C. Westcott**, [westcott@ers.usda.gov](mailto:westcott@ers.usda.gov)

**Michael Jewison**, [mjewison@oce.usda.gov](mailto:mjewison@oce.usda.gov)

## Abstract

Weather during the growing season is critical for corn and soybean yields. Adjusting for weather in an analysis of historical U.S. corn and soybean yields is important for determining underlying trends and future yield expectations. Models for U.S. corn and soybean yields provide estimates of the effects of weather on yields for those crops, allowing an analysis of those effects to be used to derive weather-adjusted trend yields. The corn model also includes planting progress by the middle of May. The estimated models indicate that the responses of corn and soybean yields are asymmetric for variations in precipitation in the summer—reductions in precipitation below its average result in larger declines in yields than the gains in yields resulting from increases in precipitation of equal magnitudes above its average. The yield models are used to track effects of high temperatures and drought on U.S. corn and soybean yields in 2012 and to provide estimates for expected 2013 yields. Further, the models provide a framework for assessing changes in expected yields due to planting progress and weather developments.

**Keywords:** Corn yields, soybean yields, weather, drought, temperature, precipitation, asymmetric yield response, post-drought yield drag

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## 2012 U.S. Drought Information

See additional discussion related to the 2012 U.S. drought, “U.S. Drought 2012: Farm and Food Impacts.”

<http://www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts.aspx>

## Introduction

Drought and high temperatures during the 2012 growing season affected many agricultural regions in the United States. For the third consecutive year, national average corn yields were below trend expectations due to weather. Similarly, weather pushed national average soybean yields below trend for the second year in a row. As a result, there is a renewed interest in the relationship between weather and yields for these crops. This report addresses this issue by developing U.S. corn- and soybean-yield models that account for weather and other factors.

This report reviews weather and yields for 2012 and develops national yield models for corn and soybeans, examining selected model properties. It also discusses the performance of the weather-related yield models through the 2012 growing season and implications for expected 2013 yields.

## Background—2012 Growing Season

The 2012 growing season got off to a good start. The U.S. Department of Agriculture’s (USDA) March 2012 *Prospective Plantings* report indicated a 4-percent increase in corn plantings and only a small reduction in soybean area. Weather was mild, facilitating early plantings of crops, and planting-progress data for corn indicated an advanced pace through much of the spring. As of the middle and end of April, corn plantings were ahead of a typical pace (fig. 1), a factor usually favorable for boosting yields.

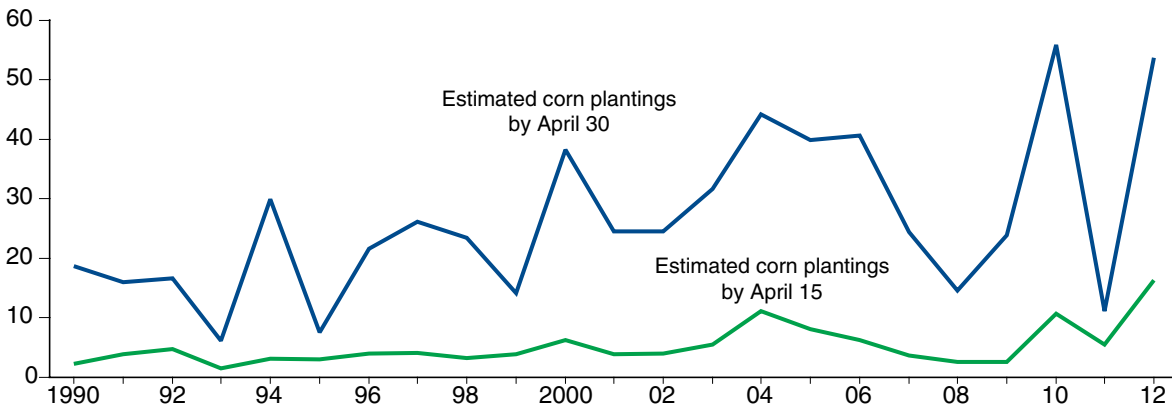
Additionally, the mild weather and advanced planting pace facilitated an increase in plantings of both corn and soybeans beyond the initial intentions, with corn acreage rising to 97.2 million acres and soybeans to 77.2 million acres (fig. 2).

Following this favorable start, however, growing season weather was very poor. June 2012 was very dry—precipitation totals in 4 of the top 10 corn-producing States that month ranked in the top 10 driest Junes since 1895 (table 1).<sup>1</sup> The 4 States with less than 2 inches of precipitation in June 2012 have had fewer than 10 such Junes since 1895.

Figure 1

### Early prospects for 2012 corn production were promising: Early plantings typically beneficial for yield prospects

Million acres



Note: U.S. total prospective corn plantings were multiplied by the 18-State (17-State in the 1990s) aggregate corn-planting progress as of April 15 and April 30.

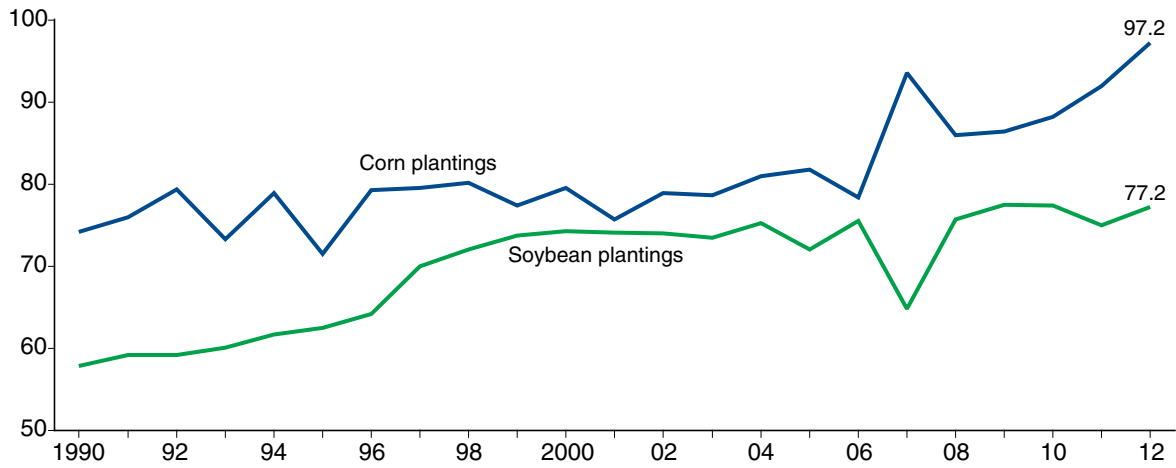
Source: USDA, Economic Research Service calculations derived from the USDA’s March 2012 *Prospective Plantings* report and USDA, National Agricultural Statistics Service’s *Quick Stats*.

<sup>1</sup>While the discussion in this section is presented mostly in the context of corn-producing States, those same States are also leading producers of soybeans.

Figure 2

**Early prospects for 2012 production were promising: Corn plantings largest since the 1930s; soybean plantings third highest on record**

Million acres



Source: USDA, National Agricultural Statistics Service's *Quick Stats*.

Table 1

**June 2012 was dry**

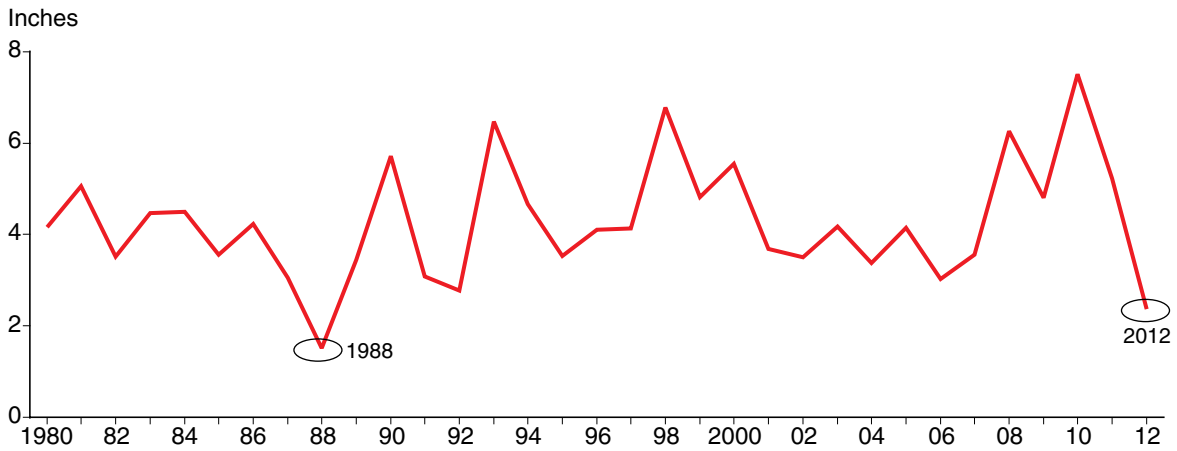
State	2011 corn production rank	June 2012 precipitation (inches)	Low ranking since 1895
Iowa	1	2.88	15
Illinois	2	1.80	8
Nebraska	3	1.62	4
Minnesota	4	4.41	73
Indiana	5	1.30	3
South Dakota	6	2.15	23
Wisconsin	7	3.23	38
Ohio	8	2.13	12
Kansas	9	2.17	11
Missouri	10	1.93	6

Source: U.S. Department of Commerce/National Oceanic and Atmospheric Administration, National Climatic Data Center.

Looking at an aggregation of eight primary corn-producing States (Iowa, Illinois, Indiana, Ohio, Missouri, Minnesota, South Dakota, and Nebraska), figure 3 shows the extreme dry weather of June 2012, similar to June 1988.

Figure 3

**June precipitation, 8-State weighted average: June 2012 was dry, much like June 1988**



Note: States included are Iowa, Illinois, Nebraska, Minnesota, Indiana, South Dakota, Ohio, and Missouri. The data were weighted by harvested corn acres.

Source: USDA, Economic Research Service calculations using data from U.S. Department of Commerce/National Oceanic and Atmospheric Administration's National Climatic Data Center and USDA, National Agricultural Statistics Service.

July 2012 was hot in the top 10 corn-producing States—average temperatures that month in each of those States ranked in the top 7 hottest Julys since 1895 (table 2). July 2012 was also dry in several key corn-producing States (table 3).

The top three corn-producing States had precipitation totals in July that ranked in the top four driest Julys since 1895. Figures 4 and 5 illustrate the hot and dry July 2012 across eight corn-producing States.

The results of this unfavorable weather were a sharp reduction of corn yields for the 2012 crop to 123.4 bushels per acre and a decrease of soybean yields to 39.6 bushels per acre (figs. 6-7).

Table 2

**July 2012 was hot in key corn-producing States**

State	2011 corn production rank	July 2012 temperature ranking since 1895
Iowa	1	3
Illinois	2	2
Nebraska	3	4 <sup>t</sup>
Minnesota	4	2 <sup>t</sup>
Indiana	5	3 <sup>t</sup>
South Dakota	6	2 <sup>t</sup>
Wisconsin	7	4 <sup>t</sup>
Ohio	8	2
Kansas	9	7
Missouri	10	4

Note: t = tie ranking.

Source: U.S. Department of Commerce/National Oceanic and Atmospheric Administration, National Climatic Data Center.

Table 3

**July 2012 was also dry in several key corn-producing States**

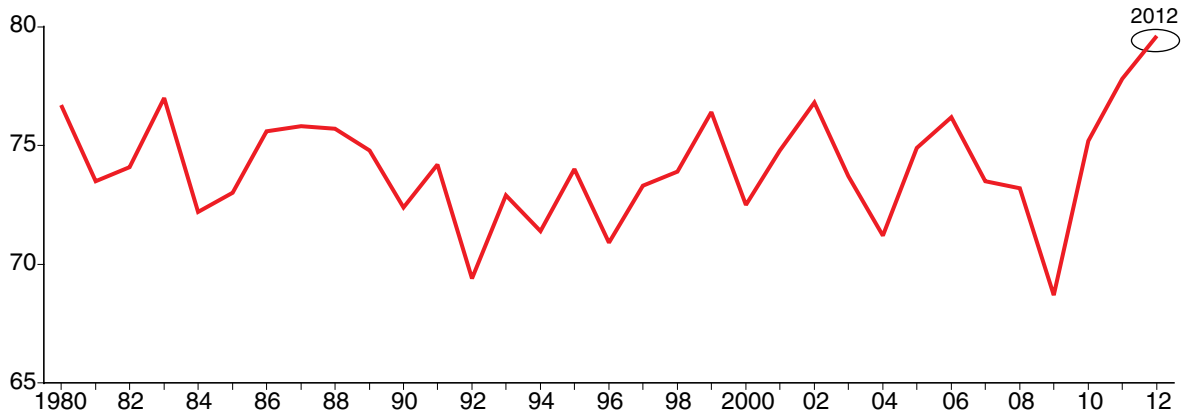
State	2011 corn production rank	July 2012 precipitation (inches)	Low ranking since 1895
Iowa	1	1.18	3
Illinois	2	1.48	4
Nebraska	3	1.06	3
Minnesota	4	3.34	57
Indiana	5	2.62	21
South Dakota	6	1.60	23
Wisconsin	7	3.28	42
Ohio	8	3.36	32
Kansas	9	1.36	13
Missouri	10	1.58	7

Source: U.S. Department of Commerce/National Oceanic and Atmospheric Administration, National Climatic Data Center.

Figure 4

### July average daily temperature, 8-State weighted average

Degrees, Fahrenheit



Note: States included are Iowa, Illinois, Nebraska, Minnesota, Indiana, South Dakota, Ohio, and Missouri. The data were weighted by harvested corn acres.

Source: USDA, Economic Research Service calculations using data from U.S. Department of Commerce/National Oceanic and Atmospheric Administration's National Climatic Data Center and USDA, National Agricultural Statistics Service.

Figure 5

### July precipitation, 8-State weighted average

Inches



Note: States included are Iowa, Illinois, Nebraska, Minnesota, Indiana, South Dakota, Ohio, and Missouri. The data were weighted by harvested corn acres.

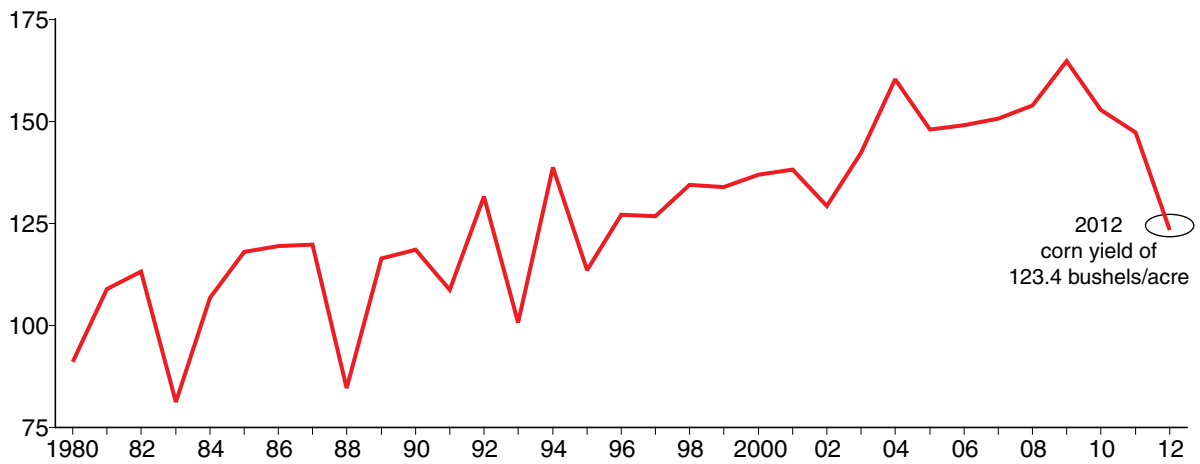
Source: USDA, Economic Research Service calculations using data from U.S. Department of Commerce/National Oceanic and Atmospheric Administration's National Climatic Data Center and USDA, National Agricultural Statistics Service.



Figure 6

**2012 U.S. corn yields sharply reduced; 2010 and 2011 also below expectations**

Corn yield, bushels per acre



Source: USDA, National Agricultural Statistics Service.

Figure 7

**2012 U.S. soybean yields also sharply reduced**

Soybean yield, bushels per acre



Source: USDA, National Agricultural Statistics Service.

## 2012 Market Impacts

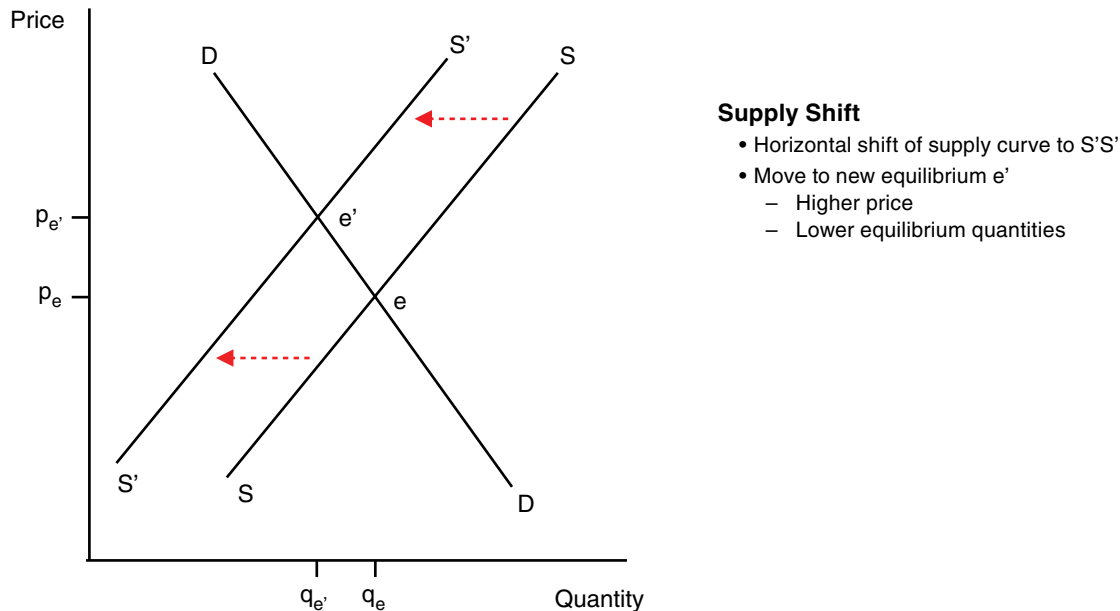
A general economic framework for assessing the market impacts of the reduced corn and soybean yields is in figure 8. Reduced yields shift the supply curve to the left, raising prices and reducing quantities demanded as the market equilibrium moves up the demand curve. The new equilibrium occurs with higher prices allocating reduced quantities among demands. Thus, knowing corn and soybean yields is important for determining market equilibrium prices and the way changes in supplies affect utilization of the crops.

Although not a perfect measure of the impacts of the reduced yields of 2012 (since other factors also changed), a comparison of the corn and soybean supply and demand balances for 2012/13, as projected by USDA in the May 2012 and January 2013 *World Agricultural Supply and Demand Estimates* (WASDE) reports, provides general indications of the market impacts (since the reduction in yields was the major changing factor). The projections in May 2012 and January 2013 are shown in tables 4 and 5, as is the change between the two projections. The last column of each table indicates how the reduction in supply was allocated across various demands.<sup>2</sup>

Reflecting lower yields, projected corn prices went up \$2.80 per bushel. Ending stocks fell the most, with feed and residual use and exports also declining sharply. Much of the reduction in feed and residual use reflects the residual component of this category, which tends to be partly related to corn production. Soybean prices were \$1.25 per bushel higher in the January 2013 projections than in the May 2012 projections. A much larger percentage of the adjustments in the soybean sector occurs for exports. Higher soybean-meal prices (up \$95 per ton) and higher corn prices raise livestock sector feed costs.

Figure 8

### Reduced production shifts supply curve to the left



Source: USDA, Economic Research Service.

<sup>2</sup>Comparisons are based on *World Agricultural Supply and Demand Estimates* in January 2013 since that is the month when final 2012 yield estimates from the National Agricultural Statistics Service are provided in the annual *Crop Production—2012 Summary* report. Changes in the supply and demand estimates from May 2012 to January 2013 largely resulted from reductions in 2012 yields—the focus of this market-impact discussion.

Table 4

**Corn sector impacts, 2012/13 marketing year: Higher prices and lower use**

Item	May 2012 forecast	Jan. 2013 forecast	Change	Percent of supply change
Planted acres (million acres)	95.9	97.2	1.3	
Harvested acres (million acres)	89.1	87.4	-1.7	
Yields: Bushels per harvested acre	166.0	123.4	-42.6	
Supply and use (million bushels):				
Beginning stocks	851	989	138	
Production	14,790	10,780	-4,010	
Imports	15	100	85	
Supply	15,656	11,869	-3,787	100
Feed & residual	5,450	4,450	-1,000	26
Ethanol and by-products	5,000	4,500	-500	13
Other food, seed, & industrial	1,425	1,367	-58	2
Domestic use	11,875	10,317	-1,558	
Exports	1,900	950	-950	25
Total use	13,775	11,267	-2,508	
Ending stocks	1,881	602	-1,279	34
Farm price (dollars per bushel)	4.60	7.40	2.80	

Note: Marketing year beginning September 1 for corn.

Source: USDA, Economic Research Service using USDA's *World Agricultural Supply and Demand Estimates*, May 2012 and January 2013.

Table 5

**Soybean sector impacts, 2012/13 marketing year: Exports adjust relatively more**

Item	May 2012 forecast	Jan. 2013 forecast	Change	Percent of supply change
Planted acres (million acres)	73.9	77.2	3.3	
Harvested acres (million acres)	73.0	76.1	3.1	
Yields: Bushels per harvested acre	43.9	39.6	-4.3	
Supply and use (million bushels):				
Beginning stocks, September 1	210	169	-41	
Production	3,205	3,015	-190	
Imports	15	20	5	
Total supply	3,430	3,204	-226	100
Crush	1,655	1,605	-50	22
Seed and residual	125	119	-6	3
Exports	1,505	1,345	-160	71
Total disposition	3,285	3,070	-215	
Ending stocks	145	135	-10	4
Prices:				
Soybeans, farm (\$ per bushel)	13.00	14.25	1.25	
Soybean oil (dollars per lb)	0.545	0.510	-0.035	
Soybean meal (dollars per ton)	350	445	95	

Note: Marketing year beginning September 1 for soybeans.

Source: USDA, Economic Research Service using USDA's *World Agricultural Supply and Demand Estimates*, May 2012 and January 2013.

## Incorporating Weather into Yield Models

Trend analysis is a useful initial framework for examining crop yields. Long-term trends in crop yields reflect improvements in yield-enhancing technology (such as new hybrids), as well as improvements in production practices (such as better nutrient management and precision planting) that in turn support greater per-acre plant populations. Despite these long-term improvements, weather-related yield reductions for corn and soybeans have resulted in below-trend outcomes in the United States for the past 2-3 years. Thus, assessing the effects of weather on recent yields is important for determining underlying trend yields for these crops, as well as developing yield expectations for 2013.<sup>3</sup>

### Corn-Yield Model

A model for national corn yields was estimated for 1988-2012, thereby including both the 1988 and 2012 droughts. In addition to a trend variable, explanatory variables used in the model are mid-May planting progress, July weather (precipitation and average temperature), and a June precipitation-shortfall measure in selected years. These variables help explain previous yield variations and deviations from the trend.

Corn plantings by mid-May are important for yield potential because that allows more stages of crop development to occur earlier, before the most severe heat of the summer. Earlier development of the crop is also generally associated with less plant stress from moisture shortages. Much of the corn crop develops in July, so weather in that month is included in the model. Finally, while weather in June is important for development of the corn crop (and June typically has lower temperatures and more rain than July), effects of June weather are typically small relative to July weather effects. However, extreme weather deviations from normal in June can have larger impacts, as seen in 2012 and in 1988. To represent that effect, the model uses a measure of the precipitation shortfall from average in years when June precipitation is in the lowest 10-percent tail of its statistical distribution (assumed to a normal distribution). The mid-May planting-progress variable is based on weekly data from USDA's National Agricultural Statistics Service (NASS) and is prorated to May 15 from adjacent weeks' results for years that the statistic was not reported for that specific date. The weather data is from the National Oceanic and Atmospheric Administration.

The planting progress and weather data used is for eight key corn-producing States (Iowa, Illinois, Indiana, Ohio, Missouri, Minnesota, South Dakota, and Nebraska). These 8 States typically rank in the top 10 corn-producing States, and accounted for an average of 76 percent of U.S. corn production over the estimation period. An aggregate measure for the eight States for each of those variables is constructed using harvested corn acres to weight State-specific observations.

The effects of mid-May planting progress and July temperatures on corn yield are each linear in the model—each unit of change for those variables has a constant effect on yield. Similarly, the June precipitation-shortfall variable is linear for the years it is nonzero. However, the effect of July precipitation is nonlinear in the model to reflect the asymmetric response of corn yields to different amounts of precipitation above and below its average. That is, reductions in corn yields when rainfall is below average are larger than gains in corn yields when rainfall is above average. The model

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<sup>3</sup>The analysis does not cover how numerous non-weather factors contribute to long-term yield trends. Those factors are captured in the trend variable used in each specification. The focus here is on the way weather factors influence actual yield outcomes relative to those trends.

uses a squared term for July precipitation to represent that asymmetric effect. The estimated regression equation (table 6) explains over 96 percent of the variation in national corn yields during the estimation period (more than 91 percent of the variation around the equation's trend).

Model-predicted values with the actual yields are in figure 9, depicting good model performance over the estimation period. The underlying weather-adjusted trend corn yield is in figure 10. This trend estimate is calculated using sample averages for July weather, 80-percent mid-May planting progress (the most recent 10-year average), and no June weather adjustment (implicitly assuming June weather is not extremely dry). Additionally, an adjustment is made to derive this trend to reflect part of the asymmetric response of corn yields to July precipitation variations around its average.

Table 6  
**U.S. corn-yield equation**

Item	Intercept	Trend	Mid-May planting progress	July temperature	July precipitation	July precipitation squared	June precipitation shortfall*
Coefficient	228.5	1.952	0.289	-2.283	13.793	-1.522	-9.537
Standard error of coefficient		0.129	0.056	0.443	4.730	0.473	1.667
t-statistic		15.1	5.2	-5.2	2.9	-3.2	-5.7
R-squared		0.964					
Standard error		4.2					
Estimation period		1988-2012					

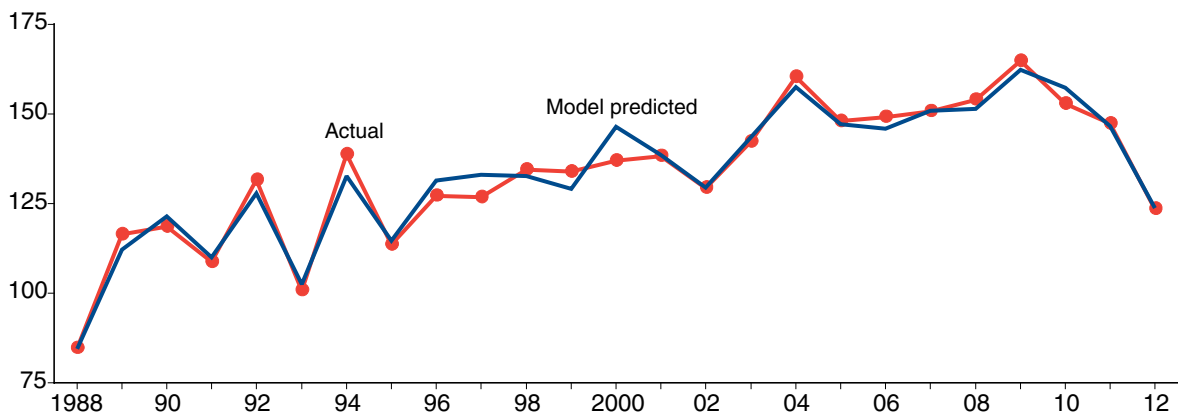
Note: All 8-State aggregates are weighted by harvested corn acres. The 8 States are Iowa, Illinois, Nebraska, Minnesota, Indiana, South Dakota, Ohio, and Missouri, which ranked 1st-6th, 8th, and 10th (respectively) in the United States for 2011 corn production, and accounted for 76 percent of the national total.

\*June precipitation shortfall equals average precipitation minus actual precipitation, when the actual is in the lowest 10-percent tail of its statistical distribution.

Source: USDA, Economic Research Service.

Figure 9  
**U.S. corn-yield model results**

Corn yield, bushels per acre

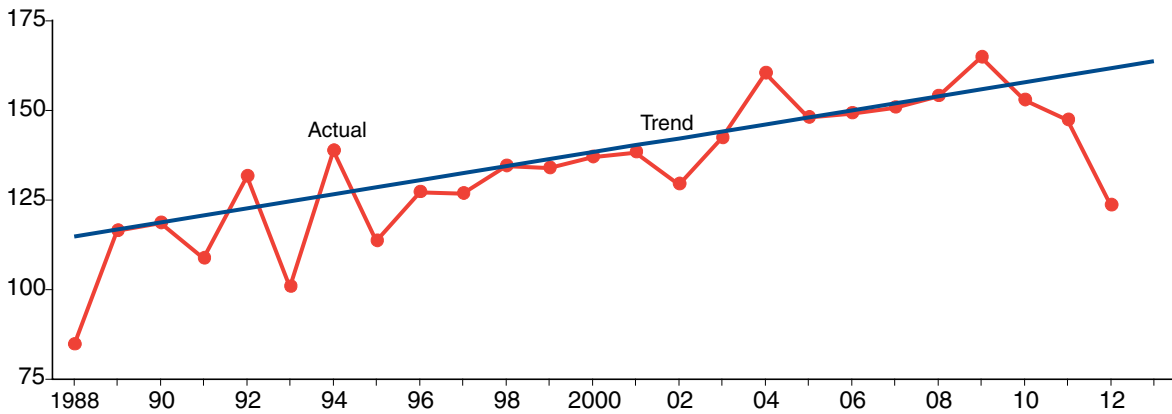


Source: USDA, National Agricultural Statistics Service (for actual data).

Figure 10

### U.S. corn-yield model results: Implied weather-adjusted trend

Corn yield, bushels per acre



Note: Trend evaluated at 10-year average for mid-May planting progress and sample means for July weather variables; trend then adjusted for asymmetric yield response to July precipitation. Assumes June weather is not extremely dry.

Source: USDA, National Agricultural Statistics Service (for actual data).

### Soybean-Yield Model

A similar approach was used to develop a weather-adjusted trend yield model for soybeans, estimated over the same 25-year period (1988-2012) as for corn. The soybean equation, however, does not include a planting-progress variable and uses an average of July and August weather variables (rather than just July weather). Those differences reflect a wider window for soybean reproduction than for corn. Nonetheless, a similar variable for June precipitation shortfall is included to reflect the potential importance of extreme weather situations in that month (such as in 2012 and 1988). The weather variables included are weighted averages for seven States (Iowa, Illinois, Indiana, Ohio, Missouri, Minnesota, and Nebraska), using harvested soybean acres to weight State-specific observations. These are currently the top seven soybean-producing States, accounting for about 70 percent of U.S. soybean production over the estimation period.

Similar to the model for corn, the effects of July-August temperatures and the June precipitation-shortfall variable are linear in the soybean-yield model, and the July-August precipitation effect is nonlinear. The estimated regression equation (table 7) explains 80 percent of the variation in national soybean yields over the estimation period, explaining 50 percent of the variation around the equation's trend. Overall, the model's weather variables have lower statistical significance in explaining soybean yields than in the corn-yield model, likely reflecting the longer reproductive period for soybeans, which makes the timing of favorable weather less critical than that for corn.

Model-predicted values and actual yields for soybeans are in figure 11, and figure 12 shows the implied underlying weather-adjusted trend soybean yield. This trend estimate is calculated using sample averages for July-August weather and assumes no June weather adjustment. Similar to the corn weather-adjusted yield, an adjustment is made in calculating this soybean trend to account for part of the asymmetric yield response to July-August precipitation variations around its average.

A notable outlier in both figures 11 and 12 is the below-trend soybean yield outcome in 2003, which was not captured by the model's weather variables. Much of the reduction in soybean yields that

year resulted from damage caused by soybean aphids. Adding a dummy variable for 2003 to the model shown in table 7 to account for that effect improves the model's explanatory power from 80 percent to almost 88 percent. The coefficient on the dummy variable is -6.0, with a t-statistic of 3.4. The other coefficients in this adjusted model are similar to those shown in table 7 and all have improved t-statistics.

Table 7  
**U.S. soybean-yield equation**

Item	Intercept	Trend	July-August temperature	July-August average monthly precipitation	July-August average monthly precipitation squared	June precipitation shortfall*
Coefficient	60.1	0.447	-0.514	5.083	-0.619	-1.279
Standard error of coefficient		0.061	0.237	4.447	0.512	0.723
t-statistic		7.3	-2.2	1.1	-1.2	-1.8
R-squared		0.800				
Standard error		2.1				
Estimation period		1988-2012				

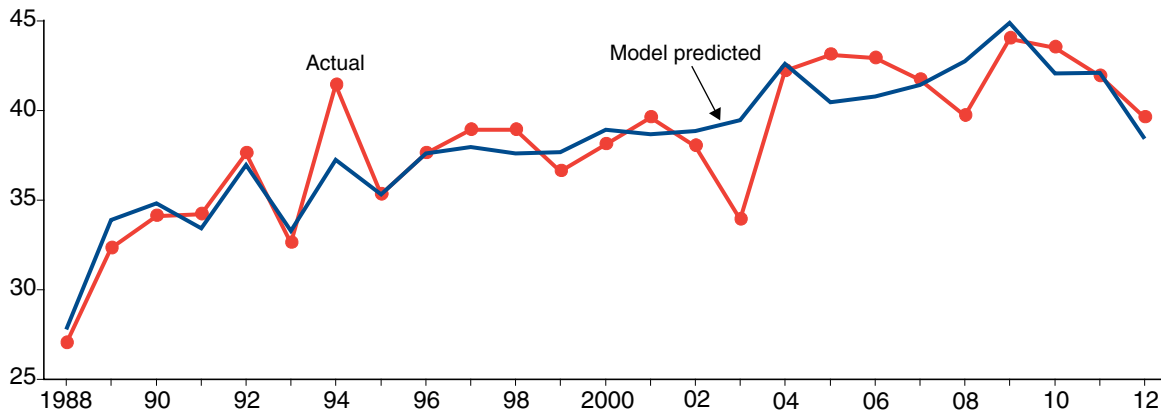
Note: All 7-State aggregates are weighted by harvested soybean acres. The 7 States are Iowa, Illinois, Minnesota, Nebraska, Indiana, Ohio, and Missouri, which ranked 1st-7th (respectively) in terms of 2011 soybean production and accounted for 67 percent of the total in the United States.

\*June precipitation shortfall equals average precipitation minus actual precipitation, when the actual is in the lowest 10-percent tail of its statistical distribution.

Source: USDA, Economic Research Service.

Figure 11  
**U.S. soybean-yield model results**

Soybean yield, bushels per acre

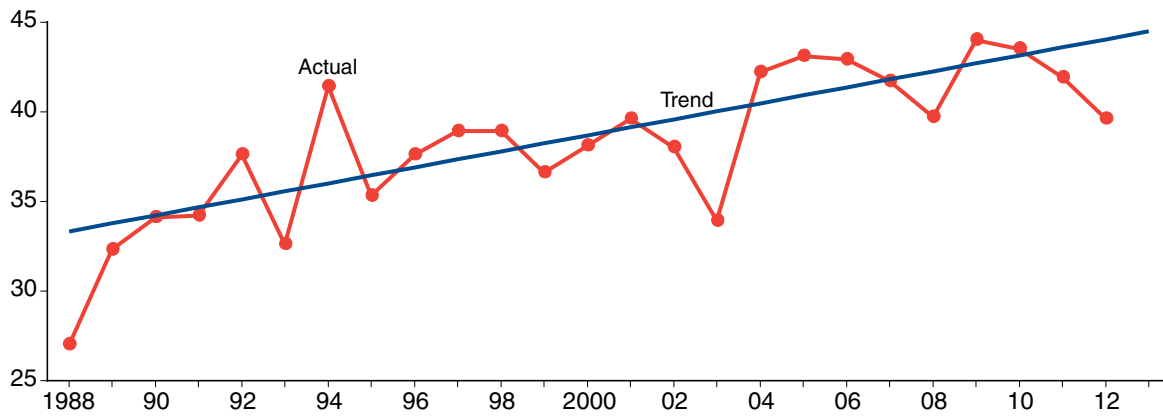


Source: USDA, National Agricultural Statistics Service (for actual data).

Figure 12

**U.S. soybean-yield model results: Implied weather-adjusted trend**

Soybean yield, bushels per acre



Note: Trend evaluated at sample means for average July-August weather variables, adjusted for asymmetric yield response to average July-August precipitation. Assumes June weather is not extremely dry.

Source: USDA, National Agricultural Statistics Service (for actual data).



## General Model Properties

The estimated models can be used to illustrate yield responses to various growing season conditions. The effects of planting progress and weather variables on corn yields are discussed, followed by weather-variable effects on soybean yields.

### Corn-Yield Asymmetric Response to July Precipitation Variation

The yield response to July precipitation, when other explanatory variables in the model are held constant, is depicted in figure 13. The weighted average of July precipitation in the eight selected corn-producing States is 3.87 inches. The quadratic form of this precipitation variable in the model results in an asymmetric yield response to variations in July precipitation above and below its mean. Reductions in July precipitation below its average result in larger declines in corn yields than the gains in corn yields resulting from increases in July precipitation of equal magnitudes above its average.

### Implications of Asymmetric Yield Response for Expected Corn Yields

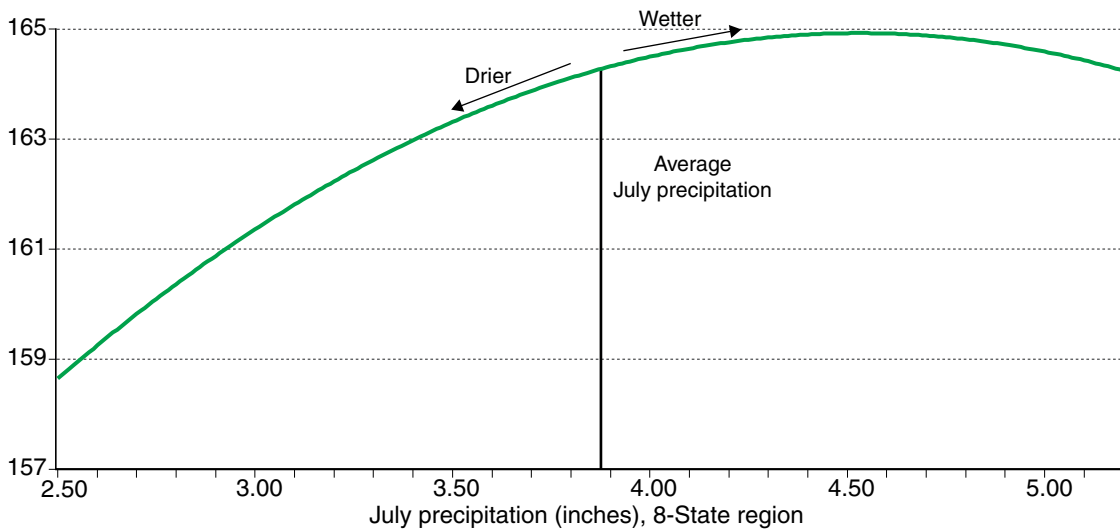
Expected yields can be derived using the corn-yield model with all explanatory variables assumed at their sample averages. However, an alternative is to adjust the expected yield to reflect some of the asymmetric yield response to July precipitation.

That type of asymmetric yield-response adjustment (fig. 14) covers corn-yield estimates for alternative levels of July precipitation within one standard deviation above and below its average.

Figure 13

#### Corn-yield model properties: Asymmetric yield response to July precipitation

Corn yield, bushels per acre

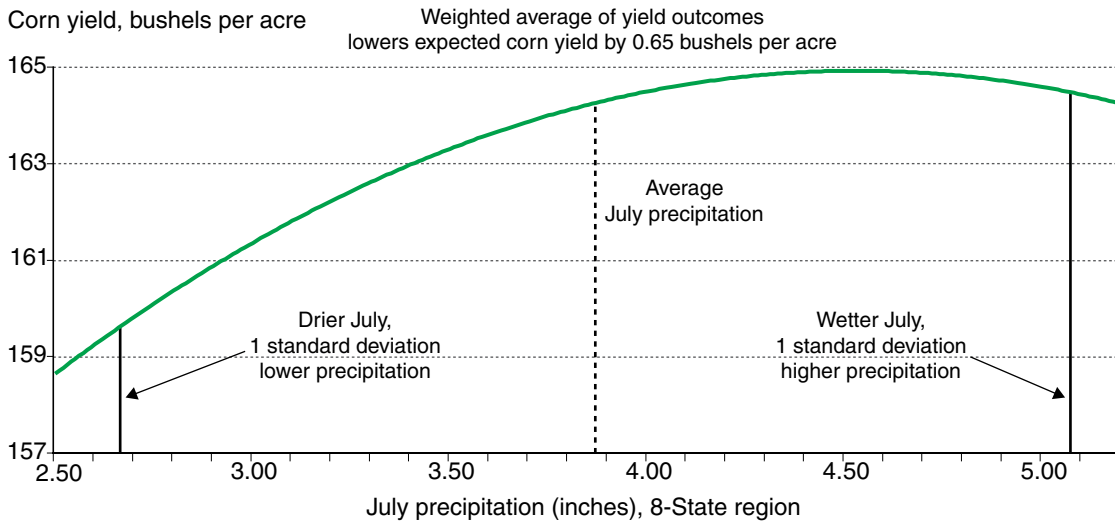


Note: Based on sample-period average for July temperatures and 80 percent mid-May planting progress in the 8-State region.

Source: USDA, Economic Research Service.

Figure 14

**Corn-yield model properties: Asymmetric yield response to July precipitation**



Note: Based on sample-period average for July temperatures and 80 percent mid-May planting progress in the 8-State region.

Source: USDA, Economic Research Service.

Compared to an expected yield evaluated at the average for July precipitation, a weighted average of corn-yield estimates for alternative levels of July precipitation within that range results in a 0.65-bushels-per-acre lower mean expected corn yield. For that adjustment, July precipitation is assumed to have a statistically normal distribution in the weighting of the alternative corn-yield estimates. Under those assumptions, the cutoff used (of one standard deviation) accounts for yield effects of 68 percent of the statistical distribution of July precipitation, leaving about 16 percent in the higher and lower tails of the distribution not covered.<sup>4</sup>

**Corn-Yield Response to Planting Progress**

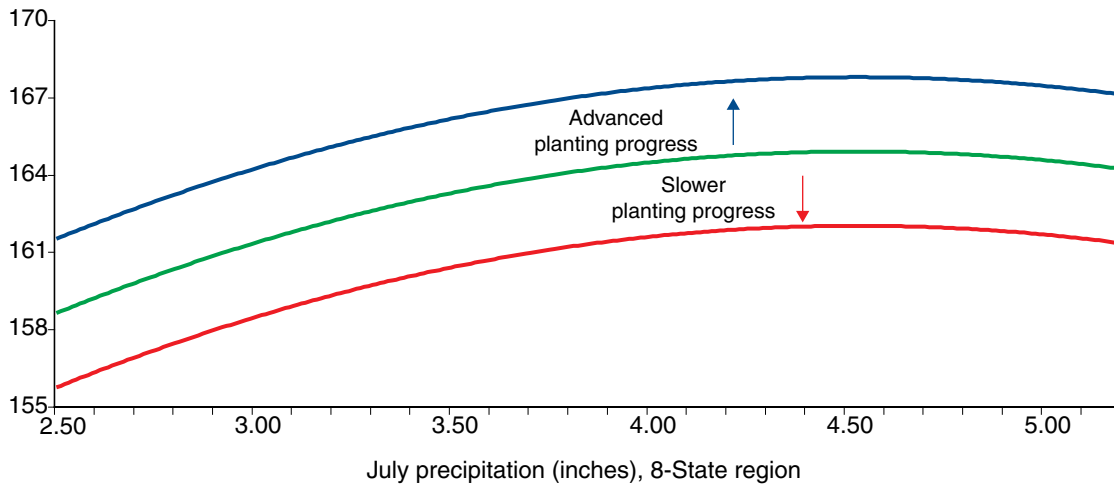
As depicted in the corn-yield model, earlier plantings of the corn crop tend to be beneficial to yields because that typically helps the crop avoid stress from moisture shortages and heat for more of its development. This effect on corn yields is illustrated in figure 15 for 10-percent higher and 10-percent lower mid-May planting progress relative to a base case. The middle curve in figure 15 is the same expected corn-yield result for different levels of July precipitation from figures 13 and 14. Advanced planting progress, as measured in the corn-yield model by the percent of the corn crop planted by mid-May, shifts the expected corn-yield curve upward. With a coefficient of 0.289 for that term in the corn-yield model, 10-percent more of the corn crop planted by mid-May raises the expected corn yield by 2.89 bushels per acre, as shown in figure 15. Similarly, 10-percent less of the crop planted by the middle of May reduces the model’s per-acre yield expectations by 2.89 bushels.

<sup>4</sup>Different adjustments to expected corn yields result for alternative ranges of the statistical distribution covered of July precipitation. For example, expanding the coverage of the distribution to 80 percent, thus leaving only 10 percent in each tail of the distribution not included, results in an additional 0.3 bushels-per-acre reduction in expected corn yields.

Figure 15

### Corn-yield model properties: Yield response to mid-May planting progress

Corn yield, bushels per acre



Note: Based on sample-period average for July temperatures in the 8-State region. Middle curve assumes 80 percent mid-May planting progress in the 8-State region.

Source: USDA, Economic Research Service.

### Corn-Yield Response to Dry Weather in June

The corn-yield model includes an adjustment to account for effects of June precipitation when exceptionally dry in that month. This adjustment represents the effects of the extremely dry Junes of 1988 and 2012, when monthly precipitation amounts were in the lower 10-percent tail of the statistical distribution. The effects on corn-yield expectations are in figure 16, should there be another such year. The higher curve is the same expected corn-yield result for different levels of July precipitation that was in figures 13 and 14. The lower curve in figure 16 shows the reduction in corn yield for June precipitation of 2.33 inches, 2 inches below the 4.33-inch average for the eight selected corn-producing States. A minimum of a 1.82-inch shortfall in June precipitation from its average is needed to trigger this variable in the model. The precipitation shortfall was 1.96 inches in June 2012 and 2.82 inches in June 1988. With the coefficient in the model for this term of -9.537, the 2-inch June precipitation shortfall shown in figure 16 reduces corn yields by 19.1 bushels per acre.

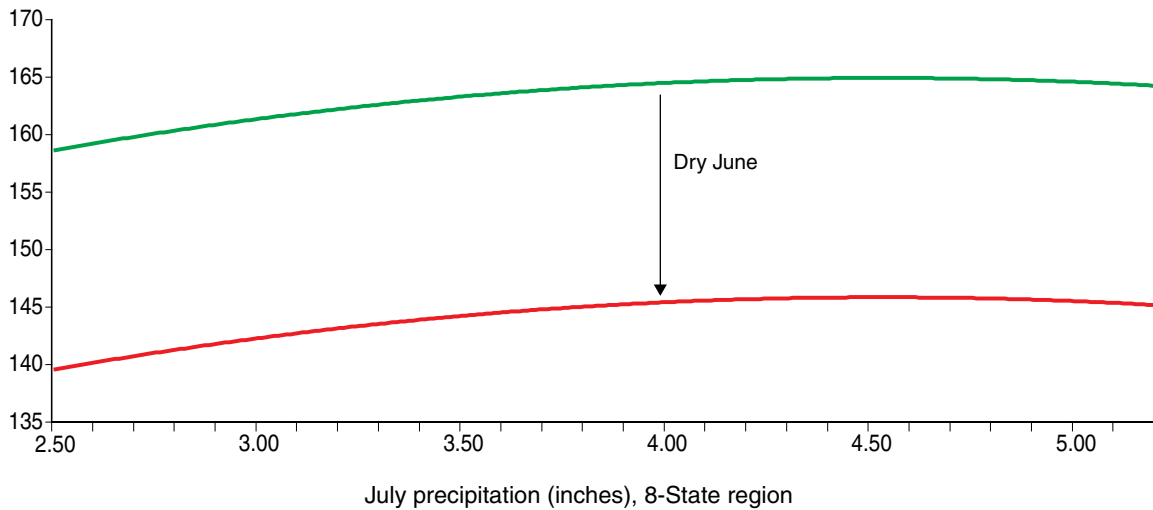
### Corn-Yield Response to July Temperatures

Finally, the corn-yield model includes temperatures in July, typically the most critical month for the development of the U.S. corn crop. The effects of hotter and cooler temperatures are shown in figure 17. The middle curve represents corn-yield expectations for different amounts of July precipitation and the sample mean for the average temperature in July. If the average July temperature for the eight selected corn-producing States is cooler, corn-yield expectations are raised, while hotter temperatures lower expected corn yields. With the coefficient in the model for the July temperature variable of -2.28, the scenarios of 1-degree cooler and 1-degree hotter shown in the figure raise and lower expected corn yields by 2.28 bushels per acre.

Figure 16

### Corn-yield model properties: Yield response to very dry June

Corn yield, bushels per acre



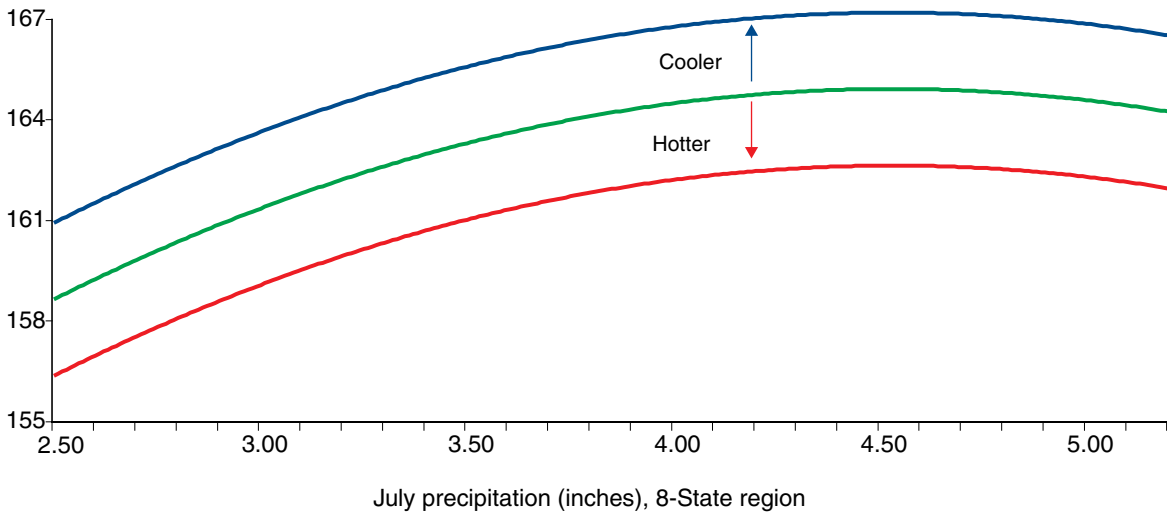
Note: Based on sample-period average for July temperatures and 80 percent mid-May planting progress in the 8-State region.

Source: USDA, Economic Research Service.

Figure 17

### Corn-yield model properties: Yield response to July temperature

Corn yield, bushels per acre



Note: Based on 80 percent mid-May planting progress in the 8-State region. Middle curve assumes sample-period average for July temperatures in the 8-State region.

Source: USDA, Economic Research Service.

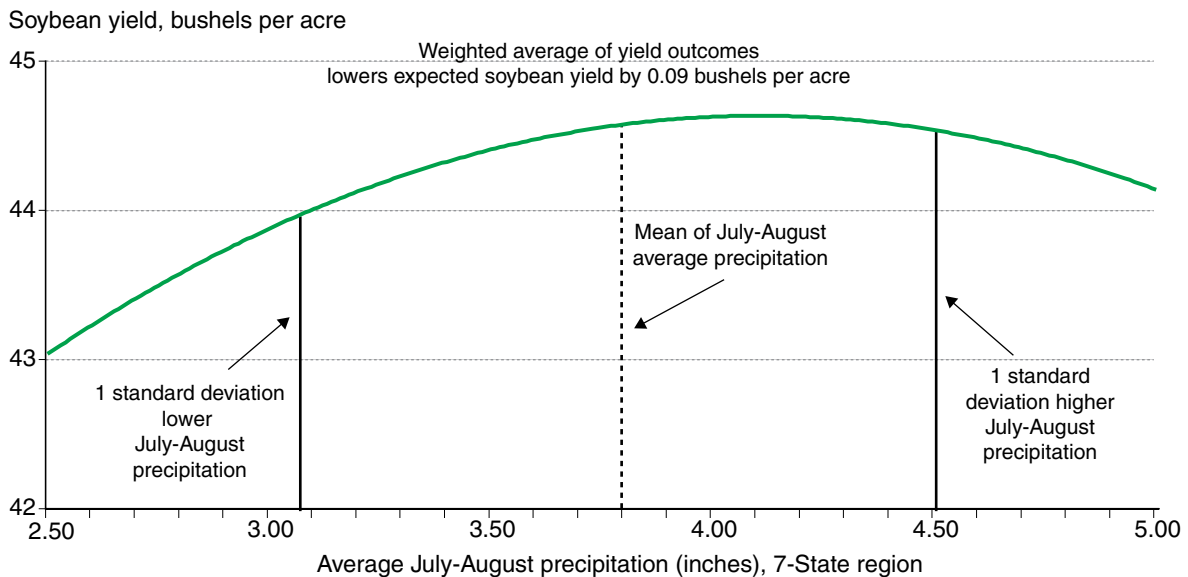
## Soybean-Yield Asymmetric Response to July-August Precipitation Variation

Similar relationships to those shown for corn can be illustrated for soybean-yield responses to weather variables. The asymmetric response of soybean yields to variations in precipitation in July and August is illustrated in figure 18. Yield reductions due to lower July-August precipitation are larger than yield gains due to higher precipitation.

Adjusting model implications to reflect this asymmetric yield response lowers expected yields. A weighted average of soybean-yield estimates for alternative levels of July-August precipitation within one standard deviation of its average, as illustrated in figure 18, results in a 0.09-bushels-per-acre lower mean expected soybean yield compared to an expected yield evaluated at the mean for average July-August precipitation. Average July-August precipitation is assumed to have a statistically normal distribution in the weighting of alternative soybean yields. Thus, similar to the adjustment for corn, under these assumptions, the lower expectation accounts for yield effects of 68 percent of the statistical distribution of July-August precipitation.<sup>5</sup> The soybean-yield adjustment is relatively smaller than the similar adjustment for corn, suggesting less soybean-yield variability due to weather than for corn.

Figure 18

### Soybean-yield model properties: Asymmetric yield response to July-August precipitation



Note: Based on sample-period mean for average July-August temperatures in the 7-State region.

Source: USDA, Economic Research Service.

<sup>5</sup>Expanding the coverage of the July-August precipitation distribution used in this adjustment to 80 percent reduces the expected soybean-yield estimate by an additional 0.05 bushels per acre.

## Soybean-Yield Response to Dry Weather in June

The soybean-yield model includes an adjustment to account for effects of June precipitation when conditions are exceptionally dry in that month, such as the extremely dry Junes of 1988 and 2012. The effects on soybean-yield expectations (should there be another such year) are in figure 19. The higher curve is the same expected soybean-yield result for different levels of July-August precipitation from figure 18. The lower curve shows soybean yields if June precipitation is 2 inches below the 4.41-inch average for the seven selected soybean-producing States. A minimum of a 1.91-inch shortfall in June precipitation is needed to trigger this variable in the model. The shortfall was 2.01 inches in June 2012 and 3.05 in June 1988. With the coefficient in the model for this term of -1.279, soybean yields are reduced by 2.56 bushels per acre (for the 2-inch shortfall shown in figure 19).

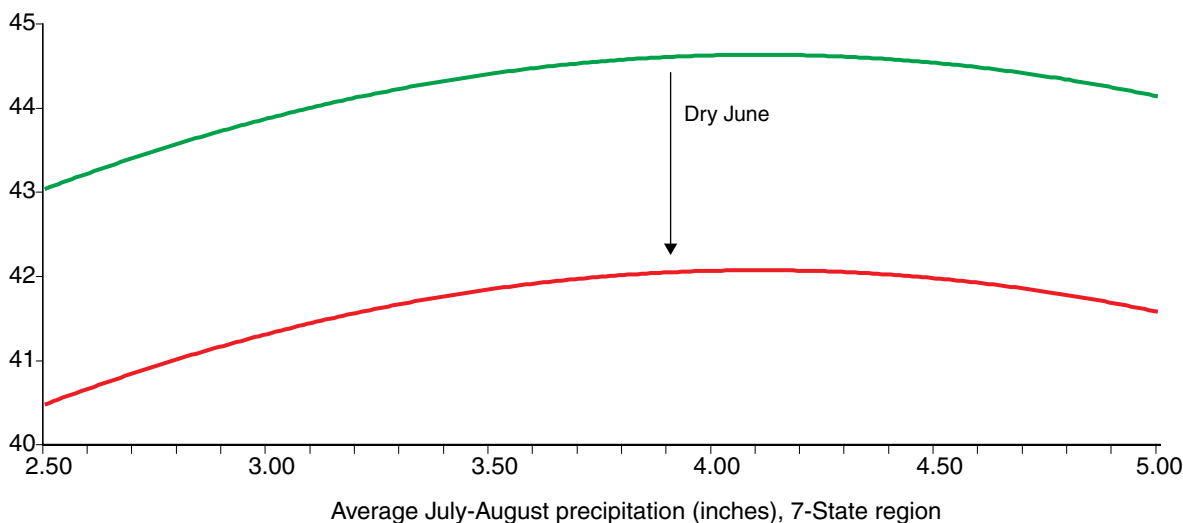
## Soybean-Yield Response to July-August Temperature

Average temperature in July-August for the seven selected soybean-producing States is included as an explanatory variable in the soybean-yield model. The effects of hotter and cooler temperatures on soybean yields are in figure 20. The middle curve again represents soybean-yield expectations for different amounts of July-August precipitation and the sample mean for the average temperature in July-August. If the average temperature is cooler, yield expectations are raised, while hotter temperatures lower expected soybean yields. With the coefficient in the model for the temperature variable of -0.514, the 1-degree cooler and 1-degree hotter scenarios shown in the figure raise and lower expected yields by 0.5 bushels per acre.

Figure 19

### Soybean-yield model properties: Yield response to very dry June

Soybean yield, bushels per acre



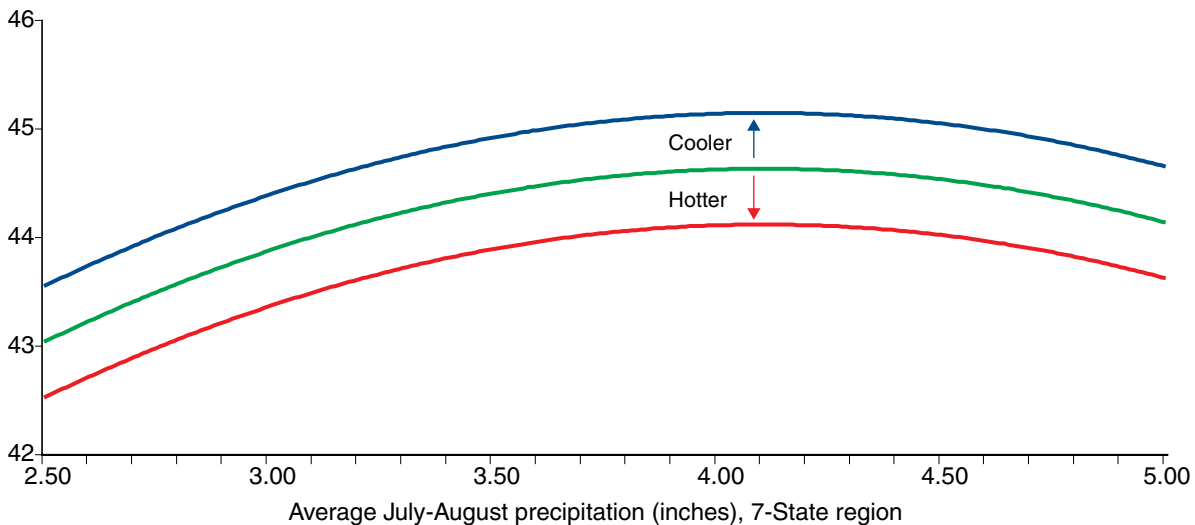
Note: Based on sample-period mean for average July-August temperatures in the 7-State region.

Source: USDA, Economic Research Service.

Figure 20

### Soybean-yield model properties: Yield response to July-August temperature

Soybean yield, bushels per acre



Note: Middle curve assumes sample-period mean for average July-August temperatures in the 7-State region.

Source: USDA, Economic Research Service.

## How Weather Affected 2012 Yields

The yield models for corn and soybeans can be used to show how weather in 2012 affected yield outcomes.

### 2012 Corn-Yield Developments

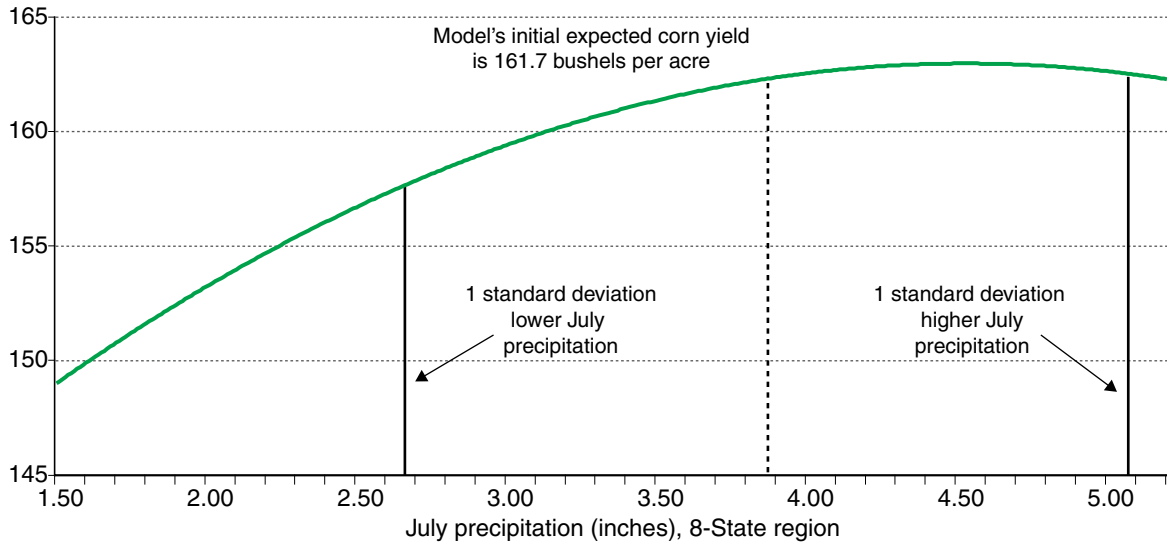
- The **initial expectation** for 2012 corn yields with this model is 161.7 bushels per acre, accounting for the asymmetric yield response to July precipitation within one standard deviation of the mean (fig. 21). This model estimate is somewhat lower than the implication of a 1990-2010 simple trend for corn yields, which was the basis of USDA's February 2012 projection of 164.0 bushels per acre at last year's Agricultural Outlook Forum.
- **Advanced planting progress** in the spring of 2012 raised early-season corn yield expectations. With 92 percent of the corn crop planted by May 15 in the eight selected corn-producing States, yield expectations based on the corn-yield model increased to 165.1 bushels per acre (fig. 22). This model estimate is somewhat lower than the adjusted corn-yield projection of 166.0 bushels per acre in USDA's May 2012 WASDE report.
- **Dry June** weather lowered the model's expected 2012 corn yield by 18.7 bushels per acre to 146.4 (fig. 23), based on a 1.96-inch shortfall in precipitation from the 4.33-inch average for that month. This yield estimate compares with USDA's July 2012 WASDE corn-yield projection of 146.0 bushels per acre.
- **Hot and dry weather in July** further lowered expected corn yields for 2012, reducing the model's yield estimate by 22.7 bushels per acre to 123.7 (fig. 24). That compares with the latest USDA estimate of 123.4 bushels per acre from the January 2013 *Crop Production—2012 Summary* report. The reduction due to July weather breaks into two parts in figure 24. First is the reduction in yield due to high temperatures (79.6 degrees Fahrenheit or 5.7 degrees above the average), which shifts the yield curve down 13 bushels per acre. The second part of the yield reduction reflects low July precipitation of 1.84 inches or 2.03 inches below average. This effect is represented by a downward movement along the lowered yield curve in figure 24 and accounts for a net reduction of 9.7 bushels per acre.



Figure 21

### Corn-yield model: 2012 developments—initial expectation

Corn yield, bushels per acre



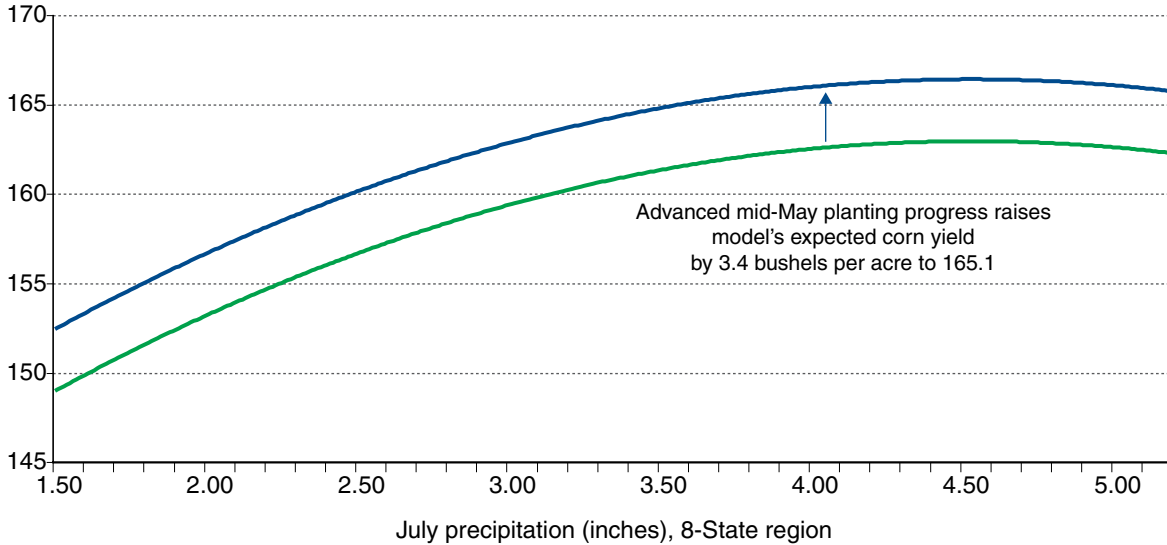
Note: Based on sample-period average for July temperatures and 80 percent mid-May planting progress in the 8-State region.

Source: USDA, Economic Research Service.

Figure 22

### Corn-yield model: 2012 developments—planting progress

Corn yield, bushels per acre



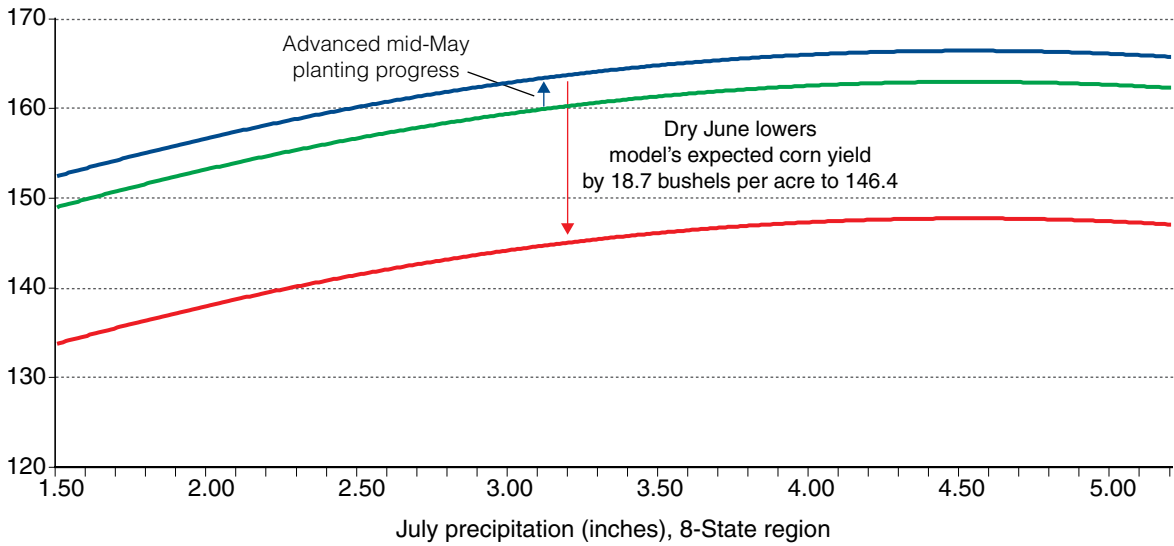
Note: Based on sample-period average for July temperatures in the 8-State region. Mid-May planting progress of 92 percent in 2012 for the 8-State region, compared with a 10-year average of 80 percent.

Source: USDA, Economic Research Service.

Figure 23

### Corn-yield model: 2012 developments—dry June

Corn yield, bushels per acre

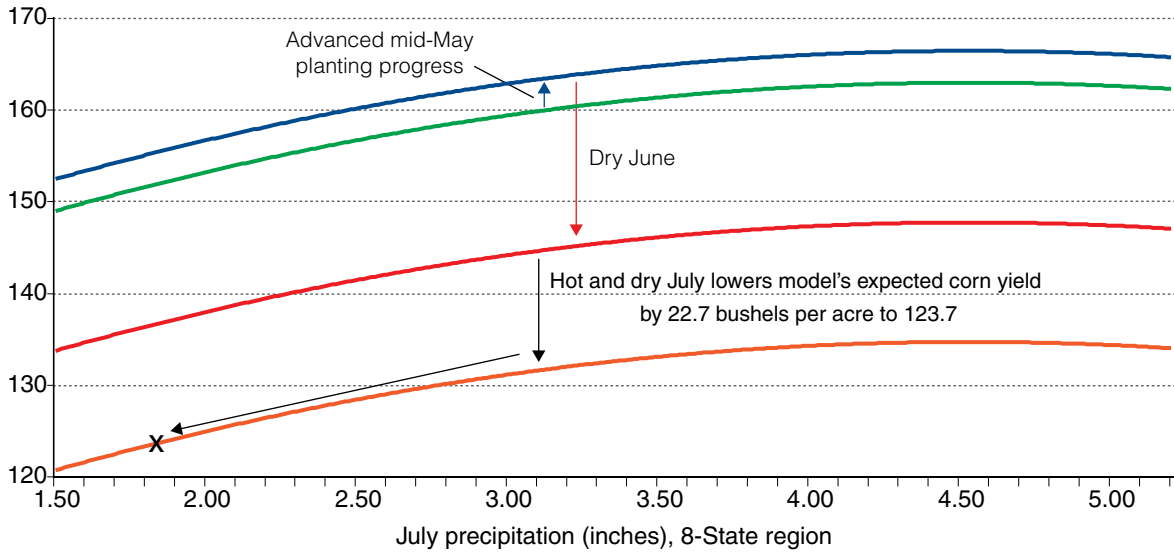


Note: Based on sample-period average for July temperatures in the 8-State region.  
Source: USDA, Economic Research Service.

Figure 24

### Corn-yield model: 2012 developments—hot and dry July

Corn yield, bushels per acre



Note: Hot July weather lowered the yield curve; dry July moved yields down along the lowered curve.  
Source: USDA, Economic Research Service.

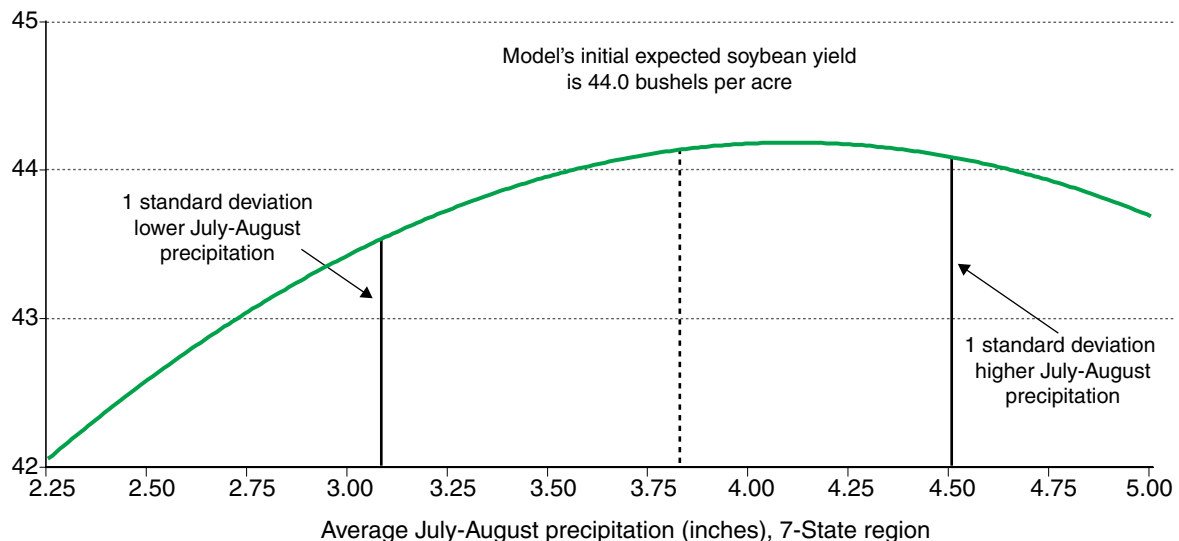
## 2012 Soybean-Yield Developments

- The **initial expectation** for 2012 yields with the soybean model is 44.0 bushels per acre, accounting for the asymmetric response of yields to variation in July-August average monthly precipitation within one standard deviation of the mean (fig. 25). That model estimate is close to USDA’s soybean-yield projection of 43.9 bushels per acre from the February 2012 Agricultural Outlook Forum and the May 2012 WASDE report.
- **Dry June** weather lowered the expected yield for soybeans in 2012, reducing the model’s yield estimate by 2.5 bushels per acre to 41.5 (fig. 26). That compares with USDA’s July 2012 WASDE soybean-yield projection of 40.5 bushels per acre.
- **Hot and dry weather in July and August** further lowered the model’s expected 2012 soybean-yield estimate by 3.1 bushels per acre, down to 38.4 (fig. 27). That compares with the latest USDA estimate of 39.6 bushels from the January 2013 *Crop Production—2012 Summary* report. The July-August weather effects reflect two parts in figure 27. The yield curve shifts down by 1.4 bushels per acre because of the effects of high temperatures. A further net reduction in the model’s soybean yield of 1.7 bushels per acre reflects low July-August precipitation (shown by moving down along the lowered yield curve in figure 27).

Figure 25

### Soybean-yield model: 2012 developments—initial expectation

Soybean yield, bushels per acre



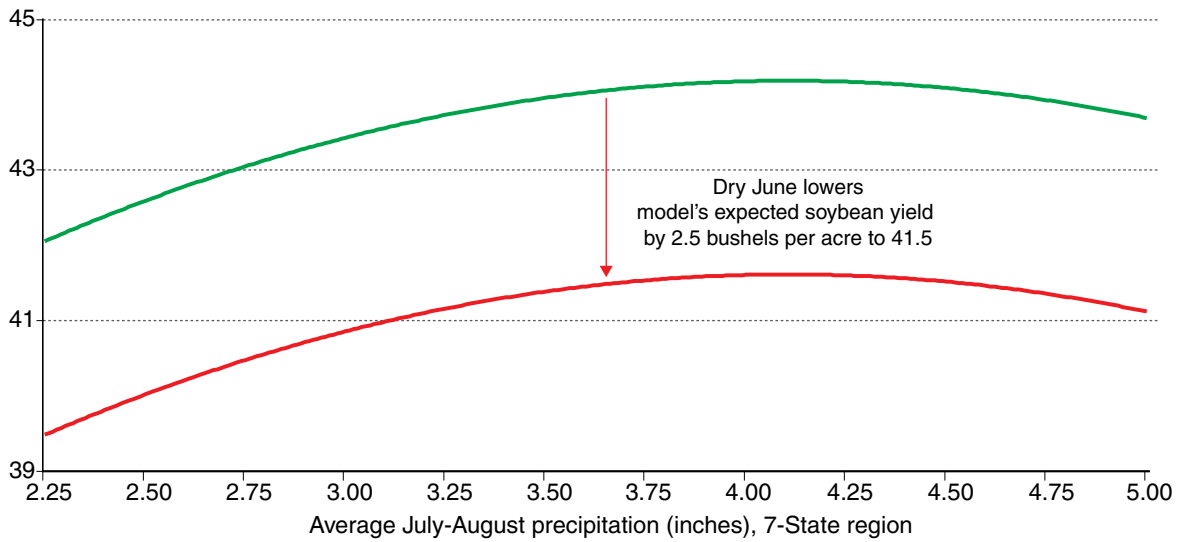
Note: Based on sample-period mean for average July-August temperatures in the 7-State region.

Source: USDA, Economic Research Service.

Figure 26

### Soybean-yield model: 2012 developments—dry June

Soybean yield, bushels per acre



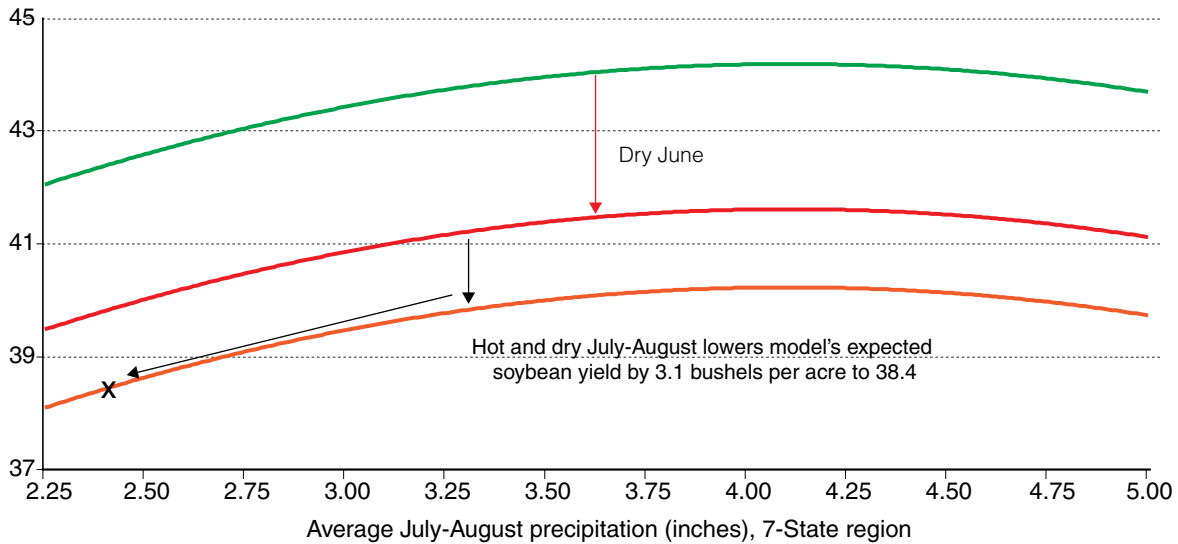
Note: Based on sample-period mean for average July-August temperatures in the 7-State region.

Source: USDA, Economic Research Service.

Figure 27

### Soybean-yield model: 2012 developments—hot and dry July-August

Soybean yield, bushels per acre



Note: Hot July-August weather lowered the yield curve; dry July-August moved yields down along the lowered curve.

Source: USDA, Economic Research Service.

## Pre-season Expected Yields for 2013 and Beyond

The yield models can be used to provide forecasts of expected yields for corn and soybeans for the 2013 season and projections of yields for later years.

### Implications for 2013 Corn Yields

Assuming that corn-planting progress by May 15, 2013 was at the average (80 percent) over the past 10 years, that June weather is not extremely dry, and that average weather occurs in July, the corn model suggests a 2013 yield of 164.3 bushels an acre. However, to reflect the asymmetric response of corn yields to different amounts of rainfall in July, the weighted average of corn-yield estimates for alternative levels of July precipitation within one standard deviation of its average lowers the corn-yield model's expected yield to 163.6 bushels per acre (fig. 28). This estimate was USDA's pre-season projection at the February 2013 Agricultural Outlook Forum.

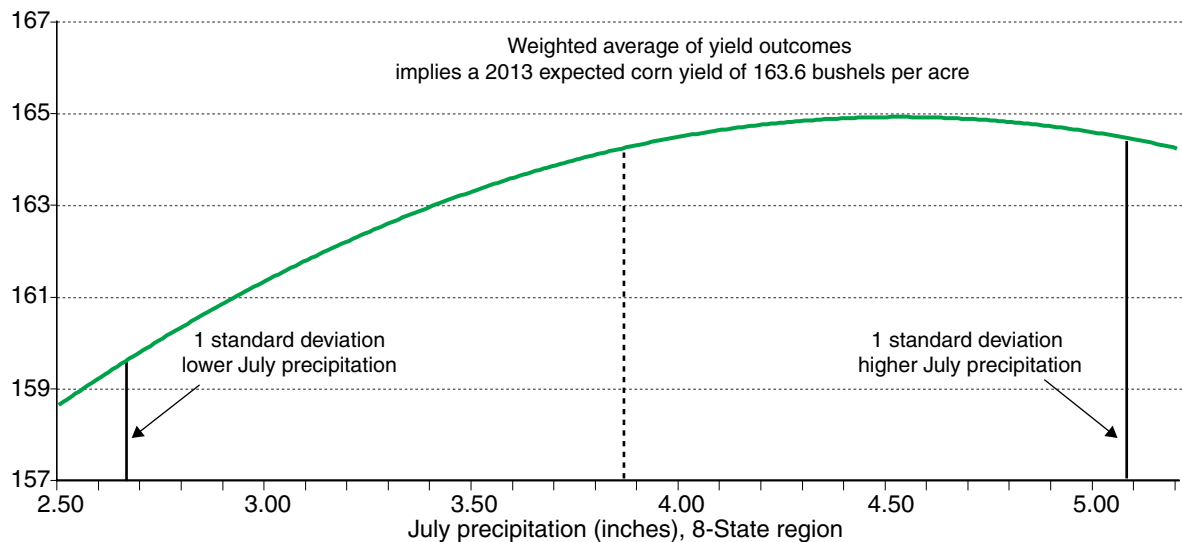
### Implications for 2013 Soybean Yields

Similarly, with average July-August weather and June weather that is not extremely dry, the soybean model suggests a 2013 yield of 44.6 bushels an acre. The weighted average of soybean-yield estimates for alternative levels of July-August precipitation within one standard deviation of its average results in a lower mean expected soybean yield for 2013 of 44.5 bushels per acre (fig. 29).

Figure 28

#### Corn-yield model: 2013 initial yield expectation

Corn yield, bushels per acre



Note: Based on sample-period average for July temperatures and 80 percent mid-May planting progress in the 8-State region.

Source: USDA, Economic Research Service.

## Adjustments for Developments during the 2013 Growing Season

As the 2013 season develops, the expected corn- and soybean-yield forecasts from the models can be updated and revised to reflect actual developments. This year's delayed plantings reduce the corn model's expected yield estimate from the initial pre-season yield. With 46 percent of the corn crop planted by May 15 across the eight major corn-producing States covered in the model, early-season U.S. average corn-yield expectations are lowered by 9.8 bushels per acre. This impact reflects the slower plantings pace and the coefficient of 0.289 on the mid-May term in the estimated corn-yield model. With this underlying relationship, lower planting progress this year decreases the model's expected 2013 corn yield from 163.6 bushels per acre to 153.8.

Additional updates of the corn and soybean models' 2013 yield expectations can be made as data for July and August weather become available. Additionally, the models provide a framework for assessing reductions in expected yields if June 2013 weather had been extremely dry, such as in 2012 and 1988.

USDA's first survey-based estimates of corn and soybean yields for 2013 will be released by NASS in the August *Crop Production* report.

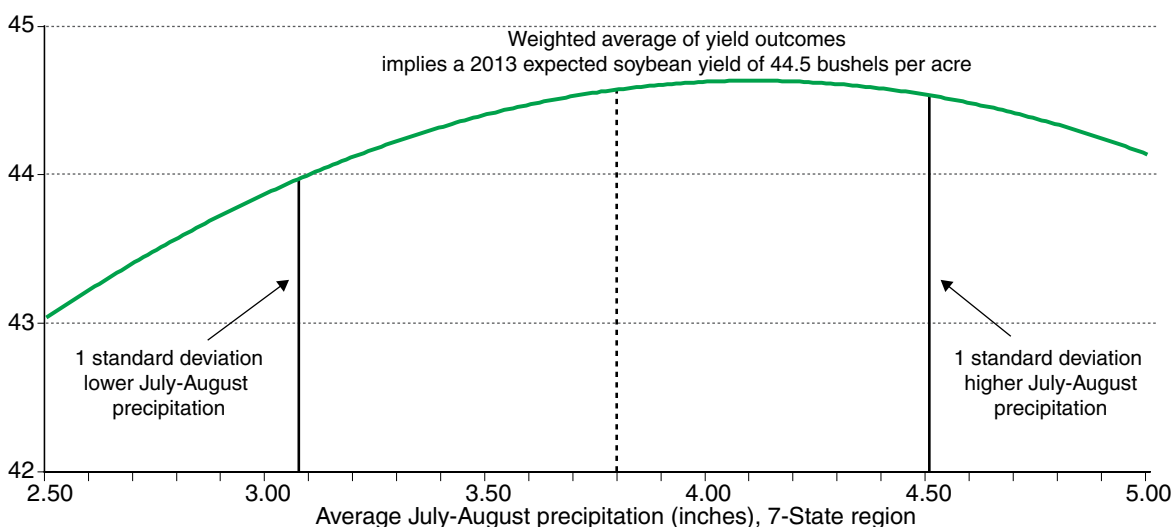
## Longer Term Implications for Corn and Soybean Yields

The 2013 adjusted yields from the models can also be used as starting points for corn- and soybean-yield projections for years beyond 2013. Although delayed plantings this spring lowered the expected corn yield from the pre-season mean expectation of 163.6 bushels per acre, that earlier 2013 estimate would remain the anchoring value for longer term projections and would be increased in each subsequent year by the 1.95-bushel trend coefficient in the corn-yield model. The adjusted 2013 soybean-yield estimate of 44.5 bushels per acre would be increased in each following year by the soybean-yield model's trend coefficient of 0.45.

Figure 29

### Soybean-yield model: 2013 initial yield expectation

Soybean yield, bushels per acre



Note: Based on sample-period mean for average July-August temperatures in the 7-State region.

Source: USDA, Economic Research Service.

## Post-Drought Yield Drag

Following the drought in 2012, an issue leading into the 2013 season was whether there would be any carryover effects on yields from the previous year's weather. This was of particular concern because of potential implications of lingering drought conditions during the winter months indicated by various drought measures.

The Palmer Modified Drought Index (PMDI) is a measure of long-term drought that reflects both current and past weather. Table 8 shows the January and April 2013 PMDI for the top 10 corn-producing States. Eight of the States shown had PMDI in January that were negative, indicating some degree of drought. Among these States, drought was most pronounced in the Plains States and the western Corn Belt. Extreme drought was indicated in Nebraska; severe drought in Iowa, Kansas, Minnesota, and South Dakota; and moderate drought in Missouri. Although the April 2013 PMDI indicated markedly improved conditions in each of the 10 States shown in table 8, drought continued in Nebraska, Kansas, and South Dakota.

To assess potential implications for the 2013 growing season if more-widespread drought conditions had continued, this report's corn- and soybean-yield models were augmented by different variables involving the PMDI. Alternatives examined included the January PMDI, the May PMDI, and each of those indexes only in years when the index value was extremely low (when the index value was in the lowest 10-percent tail of its statistical distribution). None of these alternatives gave a statistically significant result.

Similarly, cumulative precipitation over the months prior to plantings provides a measure of soil moisture recharge. Both the corn- and soybean-yield models were augmented by precipitation totals for the preceding October through March and the preceding October through May to assess the potential impact of this factor. Again, none of these alternatives gave a statistically significant result.

Table 8

### Palmer Modified Drought Index (PMDI): January and April 2013

State	2011 corn production rank	January 2013 PMDI	April 2013 PMDI
Iowa	1	-4.00	1.53
Illinois	2	-0.49	2.49
Nebraska	3	-5.41	-3.80
Minnesota	4	-3.24	1.17
Indiana	5	0.59	1.71
South Dakota	6	-3.83	-2.15
Wisconsin	7	-0.96	2.63
Ohio	8	2.01	0.87
Kansas	9	-3.89	-2.40
Missouri	10	-2.79	2.13

Note: PMDI of -4.00 or below indicates extreme drought; -3.00 to -3.99, severe drought; -2.00 to -2.99, moderate drought; -1.00 to -1.99, mild drought; -0.50 to -0.99, incipient drought.

Source: U.S. Department of Commerce/National Oceanic and Atmospheric Administration, National Climatic Data Center.

## Concluding Comments

Weather during the growing season is critical for corn- and soybean-yield development. Adjusting for weather in the analysis of historical U.S. corn and soybean yields is important for determining underlying trends and future yield expectations.

The corn- and soybean-yield models developed here have a similar general structure with differences in the explanatory variables used related to the timing and length of the reproductive periods of the crops. The corn model includes mid-May planting progress and July weather variables. The soybean model includes July-August weather variables. Both models include a variable for weather in June when it is extremely dry.

Yield responses in both models are asymmetric for variations in summer precipitation. Yield reductions for below-average rainfall are larger than yield increases for above-average rainfall of equal magnitudes. This asymmetric property has implications for formulating mean expected yields for the upcoming crops.

The corn model's pre-season mean expected yield for 2013 is 163.6 bushels per acre. Information regarding the plantings pace of the 2013 corn crop by May 15 suggests a downward revision of the model's initial estimate to 153.8 bushels per acre. The mean expected 2013 yield based on the soybean model is 44.5 bushels per acre. Updates to these estimates can be made as weather data for the summer months become available.

The potential for a post-drought drag on yields in the following year was examined using various measures, including the PMDI and cumulative monthly precipitation leading up to plantings. None provided a statistically significant effect when added to the corn- and soybean-yield models. While such measures are important to monitor, the overall results point to the dominance of summer weather in the determination of corn and soybean yields.



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