Late-1990s Climate Shift Impact on Corn Yield in Iowa

Christopher J. Anderson  
*Iowa State University*, cjamess@iastate.edu

Bruce A. Babcock  
*Iowa State University*, babcock@iastate.edu

Yixing Peng  
*Iowa State University*, pyixing@iastate.edu

Philip W. Gassman  
*Iowa State University*, pwgassma@iastate.edu

Todd D. Campbell  
*Iowa State University*, tdc@iastate.edu

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THE NEXT advance in climate science will come out of experiments in forecasting shifts in climate regimes—an extended period of time in which weather conditions have consistent range, such as the Dust Bowl years or the Little Ice Age. A climate regime shift results in a new range of weather conditions for an extended period, so being able to predict a regime shift allows planners to anticipate an emerging weather risk profile that would be expected to persist for 20–30 years. One way a regime change occurs is when slowly varying ocean surface temperatures change from warm to cold. In the Corn Belt, summer rainfall is influenced over 20–30 year periods by two recurring ocean surface temperature patterns: the Pacific Decadal Oscillation (PDO) (Hu and Feng 2001) and the Atlantic Multidecadal Oscillation (AMO) (Hu et al. 2011). Together they have four phases of warm and cold conditions that result in four different spatial patterns for drought risk across the United States (McCabe et al. 2004). While climate scientists will focus on decadal forecast capability for broad temperature and rainfall patterns, the more immediate question for agriculture is, how have climate regime shifts affected yield?


We develop an empirical model that relates a logarithm of county-level corn yield to temperature, rainfall, and soil moisture. This means our model predicts the change of yield rather than yield itself. We use model predictors based on corn phenological stage development (Table 1) in order to examine interaction among weather extremes, such as 2011 when wet conditions in spring were followed by dry and hot conditions in summer. Model parameters are estimated by the method developed in Yu and Babcock (2011).

Data

Corn production and planted acres are obtained for all 99 Iowa counties from the US Department of Agriculture National Agricultural Statistics Service, and yield is constructed as corn production divided by planted acres. Daily temperature and rainfall data are obtained from values in a one-eighth degree grid dataset produced by an interpolation routine applied to daily measurements of more than 10,000 stations across the United States (Maurer et al. 2002). Temperature and rainfall are aggregated to county scale.

Soil moisture is not widely measured. We use EPIC model version 1102-64.
Table 1. Names and descriptions for predictor variables

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Variable Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Calendar year of yield report</td>
</tr>
<tr>
<td>May-Jun T</td>
<td>May through June average temperature (°C)</td>
</tr>
<tr>
<td>Jul-Aug T</td>
<td>July through August average temperature (°C)</td>
</tr>
<tr>
<td>May-Jun R</td>
<td>May through June average daily rainfall (mm)</td>
</tr>
<tr>
<td>Jul-Aug R</td>
<td>July through August average daily rainfall (mm)</td>
</tr>
<tr>
<td>May 1st SM</td>
<td>Simulated soil moisture on May 1st (mm)</td>
</tr>
<tr>
<td>July 1st SM</td>
<td>Simulated soil moisture on July 1st (mm)</td>
</tr>
</tbody>
</table>

Note: Bold indicates period mean values for 1980–1992 and 2000–2012 are statistically significant at 95 percent level. Italics indicates years with July–August T > 24.92 have mean values for 1980–1992 and 2000–2012 that are statistically significant at 95 percent level.

We point out some aspects of spring rainfall increase, because it presents complicated tradeoffs for machinery decisions, drainage, timeliness of planting, and resilience to summer drought. The change in spring rainfall is not unique to Iowa (Figure 1), but is a large pattern shift across the Corn Belt. In Iowa, yield loss from late planting occurs after May 10–14, such that expected yield loss at May 31 is 10 percent and 30 percent on June 15 (Farnham 2001). Negative correlation between average suitable fieldwork days from April 1 to May 15 and average April–May rainfall in Iowa during 1976–2010 is clear, and a linear regression predicts a reduction of 2.2 fieldwork days for every one inch increase in April–May rainfall. The increase of 1.3 inches in Iowa average April–May rainfall suggests a decrease of roughly three suitable fieldwork days.

The role of July 1 soil moisture and July–August rainfall in ameliorating high temperature yield effect is clear in our model predictions. The percent yield loss in Iowa under high July–August temperature drops from 26.25 percent to 10.89 percent if both soil moisture and rainfall are abundant in July–August. Weather during hot-dry summer years is statistically different during the two periods for all variables except May–June rainfall and May–June temperature (Table 1). Comparing 2000–2012 to 1980–1992, the average hot-dry summer growing season sees 2.5 inches more rainfall in spring—adding 0.66 inches to the July 1 soil moisture reservoir—and summer sees 1.5 inches more rainfall and temperatures one degree Fahrenheit cooler. The yield impact of different growing seasons for hot-dry summers is substantial. Our model predicts smaller yield losses from cooler July–August temperatures, more July–August rainfall, and more July 1 soil moisture of 12.6, 11.9 and 4.5 bu ac⁻¹. The effect of May–June rainfall is positive, because of the positive yield effect from July 1 soil moisture, despite its impact on planting delay. The net yield effect of all weather factors during hot-dry summers is a reduction of yield loss by 25.3 bu ac⁻¹.

Results
We evaluate weather changes between 1980–1992 and 2000–2012 by comparison of mean values of the predictors. We compute mean values for the entire thirteen year period and focus on volatility with means for only hot-dry summers within the periods. Period mean values are statistically different for all variables except July–August rainfall. The mean growing season conditions in 2000–2012 compared to 1980–1992 began with drier May 1 soil moisture and progressed to wetter and cooler May–June, wetter July 1 soil moisture, and a cooler July–August. Weather during these two regimes is different, but the yield effect of these factors is mixed, resulting in the model predicting a 2.33 bu ac⁻¹ net increase in state average yield. For reference, the model estimates a yield trend of 1.56 bu ac⁻¹, such that the yield effect of the 1990s regime shift is equivalent to 1.5 years of advancement in technology.

Final thoughts
The results show the power of knowing yield effects under climate regimes, and it suggests substantial value to forecasts of climate regime shifts if they prove to be skillful. Iowa agriculture can suggest priorities to this work. An immediate priority is clear from the historical sequence of PDO and AMO phases that suggest a combination could occur within the next decade that has higher drought risk. There is urgency for agriculture, then, to identify differences in weather seasonality under past climate regimes and translate this to yield effects. We can then evaluate whether the recent trend of wet springs is characteristic of past regimes, and what types of investments can be made when a regime shift occurs.

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disproportionately drawn from non-crop uses.

Land Use Change in Iowa

At the national level, corn and soybean acres planted and harvested have increased during the first decade of the twenty-first century (Wallender et al. 2011). The large majority of Iowa’s most productive land has long been under cultivation in a corn-soybean rotation. National Agricultural Statistics Service land use data depict little change in total corn and soybean acreage between 2001 and 2013 in Iowa and in the seven Loess Hills’ counties. Data also highlights a shift toward corn within corn-soybean rotations, especially in the seven Loess Hills counties.

A further change has been in acreage enrolled in CRP. Enrollment peaked at above 2 million acres in the mid-1990s before settling in the 1.5–2 million interval up until recent cutbacks in the national enrollment cap and higher commodity prices during 2007–2013. The seven Loess Hills’ counties CRP acreage trends are quite similar to those in the entire state; however, CRP acreage rose faster in the seven Loess Hills’ counties until the mid-1990s, and the seven county decline in post-2007 CRP acres has also outpaced Iowa. It is noteworthy that fallow cropland has apparently increased in the ILHE despite a decline in CRP acres for the seven counties.

Discussion

Satellite-data based assessments of land use changes in developed areas, grassland, and fallow cropland categories should be treated with caution (Kline et al. 2013), and so our emphasis has been on changes in row cropping. About half of the landform’s area is under tilled crops while significant amounts of previously cropped land are also under expiring CRP contracts. The advent of reduced till and glyphosate seed technologies has likely meant that the area’s difficult terrain is becoming less problematic for cultivation. Crop production has increased in profitability since 2000—according to Iowa State University’s annual rental rate survey, average cropland rental rates in the seven county region have increased from $119/acre in 2002 to $273/acre in 2014. We are therefore somewhat surprised to conclude that more land has not been converted to row-crop agriculture in the area.

References

