Exploring the Potential for Using ENSO Forecasts in the U.S. Corn Belt

Jennifer G. Phillips[*] Cynthia Rosenzweig[†]
Mark Cane[‡]

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[*] NASA Goddard Institute for Space Studies and Columbia University, New York
[†] NASA Goddard Institute for Space Studies and Columbia University, New York
[‡] Lamont Doherty Earth Observatory, Palisades, New York

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Jennifer G. Phillips and Cynthia Rosenzweig
NASA Goddard Institute for Space Studies and Columbia University
New York

Mark Cane
Lamont Doherty Earth Observatory
Palisades, New York

Introduction

Interannual climate variability poses the greatest risk that farmers face. Until recently, seasonal climate forecasts have been weak and therefore rarely observed by farmers in making management decisions. Farm management is generally based on long-term mean expectations of climate and crop responses to local edaphic conditions. Currently, significant progress is being made in the skill level of predictions of seasonal to interannual climate, primarily because of new understanding of the teleconnections between ocean circulation and atmospheric processes. The El Niño/Southern Oscillation (ENSO) refers to fluctuations in both sea-surface temperatures (SSTs) in the eastern equatorial Pacific and in sea-level pressures in the southern Pacific at a time scale of roughly 3 to 7 years. Using ocean circulation models, we are now able to forecast the SST anomaly up to a year in advance with an 80% level of accuracy (Latif et al., 1994). Thus, associated climate phenomena may be predicted with a high degree of skill using this tool.

Given the strong relationship between crop growth and climate, this predictability carries significant implications for improved efficiency of agricultural production (Adams et al., 1995; Sonka et al., 1986). In some regions, the teleconnection between climate and ENSO has been well established. In others, however, the relationship is only now being elucidated. Thus, the spatial extent of the potential for use of ENSO forecasts is not well defined. We are developing a methodology that uses analysis of historical climate and crop data as well as models of crop growth and farm management to explore the extent of ENSO impacts and implications for using forecasts in agricultural management.

Based on the few studies that have been done, there is indication of a significant link between ENSO and climate in the midwestern United States. Using reconstruction from white oak tree rings in Iowa going back to 1640, Cleveland and Duvick (1992) showed a strong correlation with the Southern Oscillation Index, one indicator of the ENSO phase. Handler (1984) used yield data from the major Corn Belt states going back to 1868 and a classification scheme ranking event intensity. He found a strong relationship, with El Niño years associated with positive maize yield anomalies and La Niña with negative anomalies. Our current work extends the analysis of the U.S. Corn Belt, with the objective of testing the potential for using long-range ENSO/climate forecasts to increase profit margins and decrease risk for maize farmers in the United States.

Findings in the U.S. Corn Belt

Based on aggregate U.S. maize yields from 1961 to 1991, we found a significant positive relationship (correlation coefficient, r = 0.45) between yield and NINO3 SSTs (Figure 1). The positive relationship indicates that during cold SST events, or La Niñas, maize yields in the United States are likely to be below normal, while El Niños are associated with higher-than-average maize yields, in agreement with Handler's 1986 results. Soybean yields are not significantly correlated with SSTs (Figure 1) at the 95% level of confidence, although there appears to be a weak yield trend with SSTs. When data for the 9 most important corn-producing states in the United States are analyzed individually, it becomes clear that the impact of ENSO is not spatially homogeneous across the Corn Belt (Table 1). Defining ENSO events as years in which the November-December-January mean SST falls 0.5 standard deviations above or below the long-term mean, all Corn Belt states suffer below-normal yields in La Niña years, but the decrease ranges from 72% of neutral year yields in South Dakota to 91% in Nebraska.

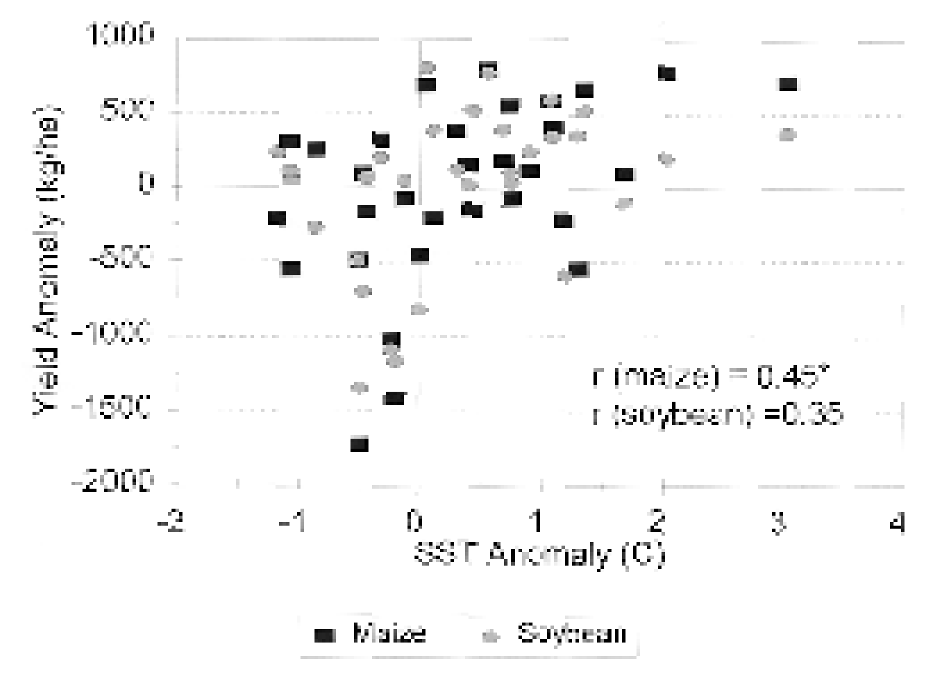

Figure 1. Sea surface temperature (SST) versus yield anomalies for U.S. maize and soybeans, 1961–91. Soybean anomalies were scaled up to be equivalent to maize in order to compare the relationships with SSTs. Asterisk (*) denotes significance at the 95% level of confidence. Source of yield data: World Agricultural Trends and Indicators, USDA/ERS.

State	Mean Yield (t/ha)			Change from Neutral Years	
	El Niño	La Niña	Neutral	El Niño	La Niña
Illinois	7.34	6.11	7.28	1.01	0.84
Indiana	6.94	5.92	7.05	0.98	0.84
Iowa	7.29	5.88	7.16	1.02	0.82
Minnesota	6.32	4.96	6.69	0.95	0.74
Missouri	5.85	4.75	5.62	1.04	0.85
Nebraska	7.05	6.34	6.97	1.01	0.91
Ohio	6.78	5.40	6.92	0.98	0.78
S. Dakota	4.13	3.06	4.22	0.98	0.72
Wisconsin	6.36	4.88	6.55	0.97	0.74

Table 1. Impacts of ENSO on maize yields—Corn Belt states (1972–88).

To investigate the extent of the heterogeneity in impacts on maize yields, we used a GIS system to map yield differences at the county level. Figure 2a shows the ratio of mean El Niño year yields to mean neutral year yields for counties in the top producing Corn Belt states. A slight yield advantage in El Niño years occurs for sections of Iowa, Missouri, Illinois, and Indiana, although generally the change in yield from neutral years is small. In La Niña years, however, the impact of ENSO is more strongly pronounced and somewhat more well defined spatially (Figure 2b). Almost all the counties shown, except for areas in South Dakota, Nebraska, and southern Missouri, experience yield levels in La Niña years that are 70% to 90% of yields in neutral years. A small region in southern Iowa and northern Missouri suffers even greater losses on average. Interestingly, there is a strip in the center of Iowa with the opposite trend, which shows no significant change in yield during La Niña years. This may be related to high water tables in this part of the state, which can damage crop roots in normal or wet years but may alleviate water stress in dry years.

Using historical maize yields detrended to current levels, with current farm-level costs and prices received, this analysis was extended to farm-level profits and risks (Table 2). Between 1950 and 1992, farmers from 7 of the top 9 Corn Belt states suffered losses in 22% of years overall. Breaking those years into ENSO phases, only 14% of El Niño years were associated with losses, while 33% of La Niña years were associated with losses. These figures vary from state to state, but the trend is always the same, indicating that ENSO forecasts may help farmers avoid financial losses in La Niña years.

To explore management options available to Corn Belt farmers given an ENSO forecast with sufficient lead time, biophysical crop simulation models are being used (Hammer et al., 1987). For representative Corn Belt sites, climate data can be divided into ENSO phases and used to drive simulations

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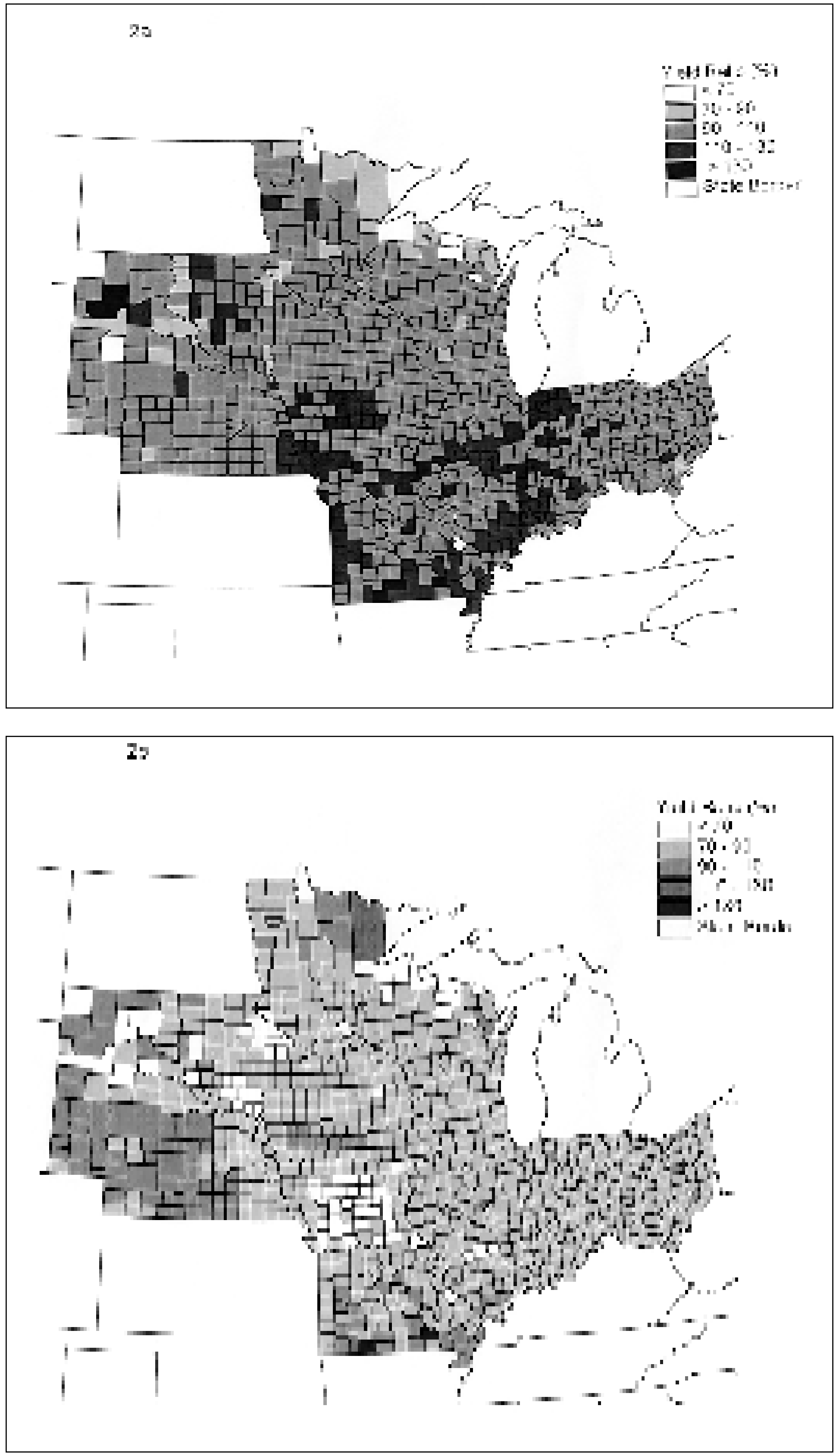

Figure 2. Ratio of average yield for ENSO years to average yield for neutral years between 1972 and 1992 at the county level; (a) El Niño/neutral, (b) La Niña/neutral. Source of yield data: Crops County Data, USDA.

State	Risk over all years	Risk in years classified as: El Niño	Neutral	La Niña
Illinois	16	07	07	36
Indiana	35	14	40	50
Iowa	09	0	07	21
Minnesota	16	14	14	21
Nebraska	58*	50	53	71
Ohio	09	07	0	21
Wisconsin	09	07	07	14
Average	22%	14%	18%	33%

Notes: Based on statewide average yields, 1950–92, detrended to 1992 levels. Cost per ha from USDA Bulletin No. 891, CORN—*State-level Production Costs, Characteristics, and Input Use*, 1991. Includes total economic (fixed and variable cash) costs by state. Price received based on year-averaged maize prices, 1981–86, in USDA Bulletin No. 757: *State-level Grain Statistics,* 1946–86.

*Unusually high risk calculated for Nebraska is for rainfed maize only.

Table 2. Percent of years with a financial loss per ha of maize (1950–92).

with parameters that reflect the individual soils, cultivars, and farm management practices common to each location. The primary management choices available to Corn Belt farmers are (1) whether to plant corn or soybeans, (2) which cultivars to plant, and (3) nitrogen fertilizer level for maize (soybeans are nitrogen-fixing plants and require very little N-fertilizer). Soybean appears to be less sensitive to the dry weather associated with La Niñas in the Midwest. Preliminary economic analysis for Illinois, the top soybean-producing state in the United States, indicates that profit levels per unit land for soybean remain quite stable across ENSO phases. By running yield simulations, and calculating farm-level profits associated with each management choice over the array of climate scenarios, optimal behavior for each ENSO phase can be determined (Anderson et al., 1994). "Optimal behavior" may refer either to profit-maximizing schemes or to risk minimization in terms of yield stability.

Conclusions and Continuing Efforts

Historical data from the U.S. Corn Belt indicate that maize yields resulting from management choices made in the absence of a long-range forecast are clearly vulnerable to the climate anomalies associated with ENSO. Reliable ENSO forecasts before the planting season would influence crop choice, level of fertilizer, and land allocation decisions for individual farmers. At the local level, helping farmers make decisions intended to improve yields given a particular ENSO forecast requires investigation on a site-by-site basis. The decision of how much land to devote to corn versus soybeans, or which cultivar to choose, is dependent on local variables such as soil type in a farmer's fields and the severity of the expected climate anomaly at that particular location, as well as regional variables such as prices of inputs and expected prices for the crop. Aggregate impacts affect not only prices but also food availability at the national and even global scale. It is the process of scaling regional climate information down to the local level, then extrapolating simulated yield and farm management implications back up to the regional scale that we are currently focusing on. This requires that in developing a methodology, we include both a regional analysis of climate and yields using GIS, remote sensing, and traditional statistical tools, and a site-based investigation using crop simulation models and long-term climate records. Ultimately, farmer adoption of forecast information will be the test of this approach.

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