BREVIA

Climate and Management Contributions to Recent Trends in U.S. Agricultural Yields

David B. Lobell* and Gregory P. Asner

Major increases in crop yields will be required to meet the future demand for food worldwide, yet changes in climate and diminishing returns from technological advances may limit the ability of many regions to achieve the necessary gains (*1*, *2*). Many researchers have predicted the effect of future climate changes on crop production using a combination of field studies and models (*3*), but there has been little evidence relating decadal-scale climate change to large-scale crop production. Here, we show that recent trends in temperature have increased the productivity of the two major U.S. crops and that accounting for climate significantly reduces the perceived gains due to management and other factors.

We studied the relation between climate variation and crop production by synthesizing data on temperature, precipitation, solar radiation, and county corn and soybean yields throughout the United States for the period 1982–98 (see note S1 in the supporting online material) (*4*). Two regions with distinct relations between de-trended crop yield and climate anomalies were observed: a large area centered in the Midwest where yields were favored by cooler, wetter years and a smaller region including the Northern Great Plains favored by hotter, drier years (Fig. 1, A and B). These findings suggest a strong but spatially explicit coupling between interannual climate and crop yield anomalies but do not indicate the relative importance of decadal-scale change in climatic factors over the 17-year period, during which management also changed.

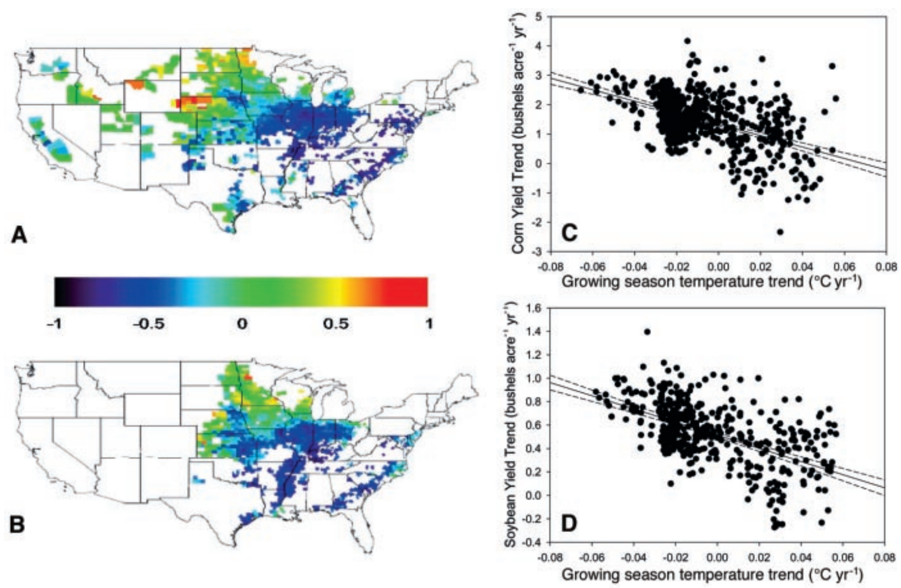

Fig. 1. Correlation between June to August average temperature anomalies and (**A**) corn and (**B**) soybean yield anomalies for 1982–98. Areas with significantly negative correlations (in blue) were selected to investigate the relative importance of climate and other factors in yield trends. (**C**) Regression statistics for corn and temperature trends are slope = −19.49 ± 1.37 bushels acre^{-1} °C^{-1}, offset = 1.34 ± .03 bushels acre^{-1} year^{-1}, r^2 = 0.25, n = 618, and $P < 0.01$. (**D**) For soybean, slope = −5.62 ± 0.39, offset = 0.51 ± .01, r^2 = 0.32, n = 444, and $P < 0.01$. Dashed lines are 95% confidence limits.

To assess the impact of low-frequency climate changes on yields, we selected a subset of counties that exhibited a significant negative correlation with growing season temperature (t test, $P < 0.10$), resulting in 618 and 444 counties for corn and soybean, respectively (see note S2) (*4*). We then applied a simple model to this representative subset of counties:

$$\Delta \text{Yield} = m + r_y \, \Delta \text{Climate} + \varepsilon \quad (1)$$

where ΔYield is the observed trend in yield; m is the average yield change due to management and other nonclimatic factors (e.g., increased CO_2); ΔClimate is the observed trend in temperature, precipitation, or radiation; r_y is the yield response to this trend; and ε is the residual error. Yield trends for both crops were significantly correlated with observed temperature trends (Fig. 1, C and D). Roughly 25% of corn and 32% of soybean trends can be explained by temperature ($P < 0.01$) over the 17-year period. Precipitation and solar radiation trends did not show significant relationships with crop yields ($P > 0.10$).

The majority of counties experienced negative trends in growing season temperature over the study period. Using the observed relationship between temperature and yield trends, we compute a climate-corrected average yield trend (m) of 1.34 bushels acre^{-1} year^{-1} for corn and 0.51 bushels acre^{-1} year^{-1} for soybean. These values are 78% and 80%, respectively, of the trends in total national production, indicating that yield gains due to nonclimatic factors are roughly 20% lower than previously assumed. As the United States is the largest producer of both corn and soybean in the world, predicted future global production of these crops based on historical trends may be overestimated (*5*).

We conclude that gradual temperature changes have had a measurable impact on crop yield trends. The slope of regression (r_y) indicates a roughly 17% relative decrease in both corn and soybean yield for each degree increase in growing season temperature. Previous modeling studies predict changes of similar magnitude for a 3° temperature increase, suggesting that the observed sensitivity is higher than previously expected (*6*). On the basis of this investigation, there is a clear and present need to synthesize crop yield and climate data from different areas, perhaps with more detailed information on management, to provide critically needed observational constraints to projections of both climate change and management impacts on future food production.

References and Notes

1. K. G. Cassman, *Proc. Natl. Acad. Sci. U.S.A.* **96**, 5952 (1999).
2. G. Conway, G. Toenniessen, *Nature* **402**, C55 (1999).
3. C. Rosenzweig, M. L. Parry, *Nature* **367**, 133 (1994).
4. Notes S1 and S2 are available on *Science* Online.
5. T. Dyson, *Proc. Natl. Acad. Sci. U.S.A.* **96**, 5929 (1999).
6. R. A. Brown, N. J. Rosenberg, *Agric. For. Meteorol.* **83**, 171 (1997).
7. This work was supported by a NSF Graduate Research Fellowship and NASA New Investigator Program grant NAG5-8709. The authors thank C. Field, J. Hicke, I. Ortiz-Monasterio, J. Foley, and an anonymous reviewer for helpful comments on the manuscript. This is CIW Department of Global Ecology publication 21.

Supporting Online Material
www.sciencemag.org/cgi/content/full/299/5609/1032/DC1
Notes S1 and S2

Department of Global Ecology, Carnegie Institution of Washington, Stanford, CA 94305, USA, and Department of Geological and Environmental Science, Stanford University, Stanford, CA 94305, USA.

*To whom correspondence should be addressed. E-mail: dlobell@globalecology.stanford.edu