Recent Climate Variability and Future Climate Change: What They Mean for United States' Farming[1]

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Climate variability continues to exert large year-to-year swings in U. S. crop yields and production in spite of impressive technology-driven gains in crop productivity over the 20th century (Figure 1). Recent persistent drought conditions in the western Corn Belt states have particularly affected wheat production. In 2002, the U. S. Risk Management Agency paid out more than $2 billion dollars in crop indemnities, with the greatest pay-outs to counties in the areas most affected by drought (Figure 2). The USDA estimates that season-ending U. S. wheat stocks this year will be down 94 million bushels from July, caused by a combination of the aforementioned drought conditions and increased foreign demand (also caused in part by drought-induced production shortfalls in Europe). The Worldwatch Institute suggests that such is an indication of increasing inadequacy of global food production. Yet, season-ending U. S. corn and soybean stocks are projected to be higher than last year.

Does this recent downturn in wheat production signal a trend toward greater climate-induced stress on U. S. agriculture? In the short-term, the answer is, not likely. In the long-term, the answer is, yes, maybe. It is difficult to discern long-term (decades or longer) changes in the frequency or intensity of droughts, heat waves or other extreme events in the climate record for the United States as a whole. Easterling et al (2000) suggest that there is evidence for the following long-term trends: a) an earlier start (~11 days) of the frost-free season and occurrence of fewer extreme cold days in the northeastern U. S.; b) an increase in one-day heavy precipitation (>1") events nationally (by approximately 2-12% across the Corn Belt); c) a pronounced increase in minimum daily temperatures nationally (but no trend in maximum temperatures); and d) an increase in the area of the U. S. experiencing extreme wetness (but no change in dryness).

What does the future climate hold for U. S. agriculture? Climate model simulations on the whole indicate that most mid-continental locations in the Northern Hemisphere (home to the world's major grain production regions) will warm more than the global average and will receive more precipitation than current. The trend toward more high-intensity rainfall events is expected to continue. However, droughts are likely to become more frequent in these regions, in spite of more rainfall, due to higher evapotranspiration. Critically, soils will eventually dry. Growing seasons likely will be extended, but the probability of destructive heat waves will rise.

What do these potential changes bode for the nation's crop production? Experiments persuasively demonstrate the positive effects of rising atmospheric CO_2 concentrations on photosynthesis of certain major crops such as soybeans and wheat and on the drought-

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tolerance of all crops. It appears that the CO_2 effect is slightly higher under moisture stress than under adequate moisture (Gitay et al, 2001). However, experiments are showing that the beneficial effects of CO_2 may decline as temperatures rise above crop photosynthetic optima. Moreover, these effects are not likely to fully offset the potential stresses of warmer temperatures and drier soils, especially as the warming progresses. An ensemble of crop simulation studies with explicit modeling of the interactive effects of temperature, precipitation and atmospheric CO_2 concentration was assembled in preparation for drafting Gitay et al (2001) of the IPCC-TAR (Figure 3). The ensemble indicates a nominal increase in mid-latitude (including U. S. Midwest) corn and wheat yields for up to 1º C local warming in wheat and 2° C for corn. Further warming causes yields for both crops to fall below current levels. At +4º C, corn yields are 15% below current levels and wheat yields are 25% below current. Hence, the higher rainfall and increased warmth is beneficial for a while, but eventually the soils dry out and yields rapidly fall.

A deficiency of studies such as those making up the above ensemble is that they presume that only the averages and not the variability of years around those averages will change; also, that farmers will take no steps to adapt to the climate change. Those deficiencies detract from realism of the simulations. New research (Southworth et al, 2000; Southworth et al, 2002) simulates eastern U. S. Corn Belt corn and soybean yield response to climate change with change in variability and with the inclusion of a logical agronomic strategy (change in maturity class) to adjust. Corn yields under increased variability and an overall growing season warming of 2.8 degrees and a slight increase in rainfall decreased by as much as 45% across the southern states of the Corn Belt (due to extreme high temperatures) while increasing by as much as 45% across the northern states (due to the absence of extreme high temperatures). Soybeans were less negatively affected by the climate changes, although the increased variability also brought slightly lower yields in the southern states of the region. Crop modeling results as such are highly uncertain because they are dependent on the skill of the climate change prediction, they ignore key processes such as changes in pests and diseases, and they do not explicitly consider the effects of flooding, hail, extreme wind, and other climatic extremes. Moreover, they do not represent all of the possible adaptation strategies that farmers are likely to try. However, they do paint a consistent picture of crop yields being lower than today even in an environment with higher rainfall than now.

Modeling is not the only way to gain knowledge of the adaptability of agriculture to climate variability and change. Historical cases of socioeconomic or environmental change can be useful analogs of adaptation to climate change. Although historical may not have been caused by a change in climate, they are bear crucial similarities to climate: they were gradual and, in many cases, irreversible, or resulted in large shifts in geographic location of activities. The two cases below illustrate the potential for technology, human ingenuity, and institutional innovation to deal with changes analogous to climate change: translocation of crops to new environments and resource substitution in response to scarcity.

Case 1: The Translocation of Hard Red Winter Wheat

Most crop species have been successfully translocated thousands of miles from their regions of origin by resourceful farmers, thus exposing them to a climate change by virtue of changing geography. Translocation requires that plant material and cultural practices be adapted to climatic conditions that are often significantly different from those in regions of origin. The translocation of hard red winter wheat across the prairies of the American Great Plains is a case in point.

Hard red winter wheat consistently accounted for about half of all wheat produced annually in the United States in the 20th century (Briggle and Curtis, 1987). Rosenberg (1982) tracked the geographic distribution of winter wheat in the Great Plains from 1920 to 1980. We updated the distribution to the current time (Figure 4). Over the period 1920 to 1999 the northern boundary of the winter wheat zone migrated northward into a climate that was about 4.5°C cooler and 20% drier than the climate for the wheat zone in 1920. The southward expansion of winter wheat has not been as extensive as the northward one. However, average annual temperatures at the current southern boundary of the winter wheat production zone are more than 2°C higher than those of the 1920 southern boundary. Thus, winter wheat was adapted both to cooler and warmer climates in its century-long expansion.

What happened to encourage this expansion? Dalrymple (1988) demonstrated a steady increase in the diversity of winter wheat cultivars being planted by American farmers throughout the 20th century. Increasing diversity was a trait of success in adapting wheat cultivars to local environments. Selective breeding for cold-hardy varieties of winter wheat helped the expansion of wheat to the north. Savdie et al. (1991) found that direct, no-till seeding of winter wheat into stubble immediately after harvest of the previous crop (stubbling-in) and snow trapping reduced the risk of winterkill and permitted expansion of the crop northeastward to include most of western Canada's agricultural area. Breeding for disease resistance helped the expansion to the south. Cox et al. (1986) traced the historical genetic diversity of winter wheat and found that diversity is increasing; they argue that greater genetic diversity provides raw material for further genetic progress.

Case 2: Resource Substitution in Response to Scarcity: Dryland for Irrigated Agriculture

When climate variability disrupts the delivery of climate resources, such as in periods of drought, production costs may rise causing a decrease in farm revenues. Persistent disruption of climate resources induces farmers to substitute more reliable resources for riskier ones. Consider, for example, the experience of Great Plains farmers in coping with the highly variable precipitation of that region.

Irrigation water became a widely used substitute for inadequate or unreliable precipitation in the Great Plains since World War II. As long as irrigation water was abundant and cheap, it lowered production costs relative to revenues, giving Great Plains irrigators a large comparative advantage. However, increasing scarcity of irrigation water is like drought in rainfed regions. Glantz and Ausubel (1984) argued that declining irrigation groundwater can serve as a useful analogy to a gradual decrease in precipitation, focusing on the recent agricultural experience with the High Plains or Ogallala Aquifer of the Great Plains. The aquifer is a large geologic formation of porous sand that underlies approximately 225,000 square miles of the Great Plains (Wilhite, 1988). Recharge rates are very low and lateral movement within the aquifer is slow. Groundwater utilization, primarily for irrigation, rose steadily from 7 million acre-feet in 1950 to 21 million acre-feet in 1980 (Wilhite, 1988). These withdrawals caused the saturated thickness of the aquifer to decline by as much as 25-50% since the 1940s, especially in the southern Plains (High Plains Associates, 1982; Lehe, 1986). Lehe (1986) noted that groundwater declines in the aquifer caused irrigation pumping costs to rise because more fuel is required to pump water from lower depths.

Kromm and White (1986) cataloged potential adaptations to declining groundwater levels by farmers across the High Plains Aquifer and ranked the adaptations in terms of desirability for adoption. They found that the two leading adaptations preferred by water users were to increase irrigation efficiency and to practice conservation tillage. Lehe (1986) showed a dramatic increase in the use of low-pressure irrigation systems in the southern Plains states and a switch to low water intensity crops such as wheat as aquifer levels dropped. Nellis (1987) demonstrated a decline in the amount of irrigated acreage in southwestern Kansas of 5.5% between 1977 and 1983 accompanied by a switch to low water intensity crops. Some farms failed during the reversion, but those that survived emerged healthy and remain competitive, although their yield expectations were lowered.

The above case studies give some reason for optimism that American agriculture may be able to muddle through with adaptation provided that climate change is gradual, with no major surprises. However, any of the following could cause adaptation to be more difficult and costly than suggested by the case studies:

- Sudden acceleration in the pace of climate change, including abrupt change in climate variability
- Increase in multiple environmental stresses that may boost climate impacts on agricultural production, including encroachment by invasive species, change in pest ranges, and degradation of land and water
- Unanticipated expansion in the demand for food and fiber
- Loss of productivity due to rising costs of inputs such as fertilizer, energy, and pesticides
- Disruption of the continued increase in yields from technological improvements and innovations due to research and outreach
- Others?

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FIGURE 1

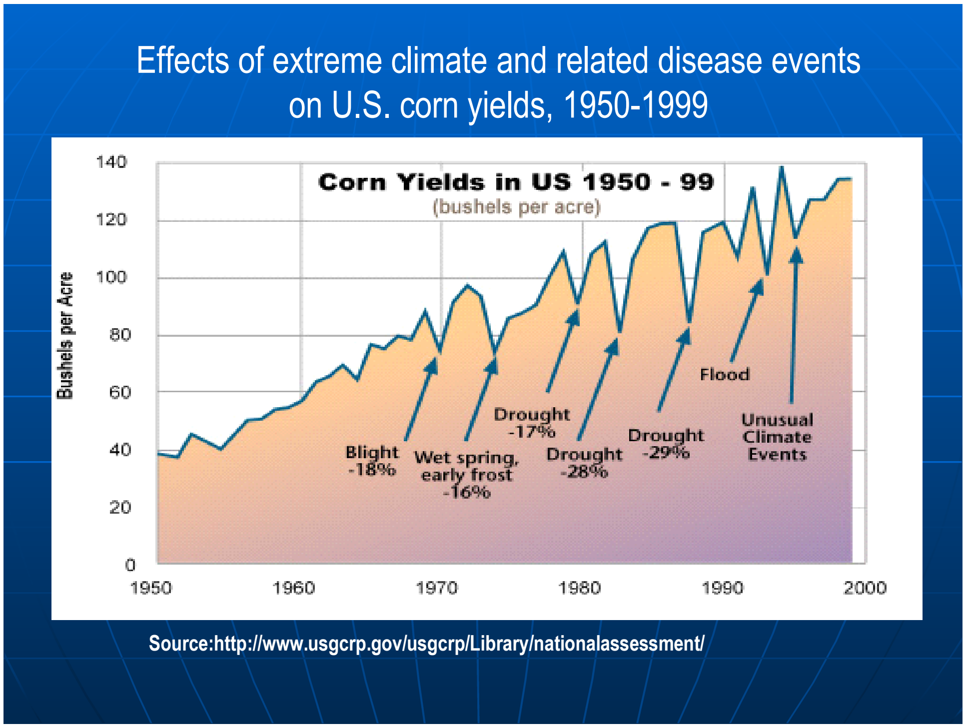

Effects of extreme climate and related disease events on U.S. corn yields, 1950-1999
Corn Yields in US 1950 - 99
(bushels per acre)
Bushels per Acre
140
120
100
80
60
40
20
0
1950
1960
1970
1980
1990
2000
Blight -18%
Wet spring, early frost -16%
Drought -17%
Drought -28%
Drought -29%
Flood
Unusual Climate Events
Source:http://www.usgcrp.gov/usgcrp/Library/nationalassessment/

Figure 2

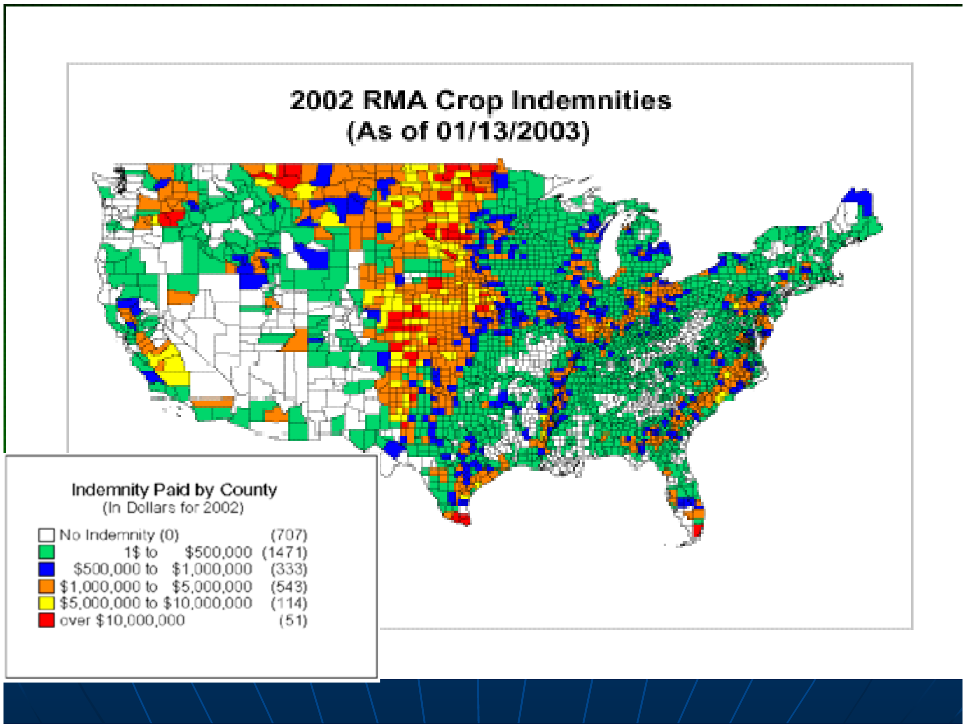
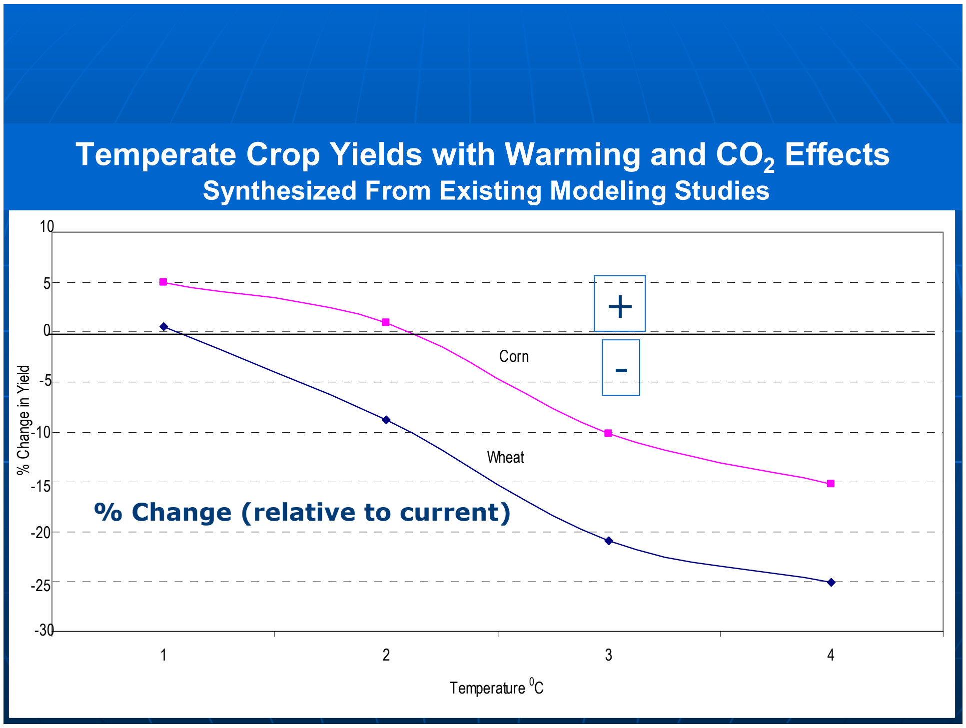
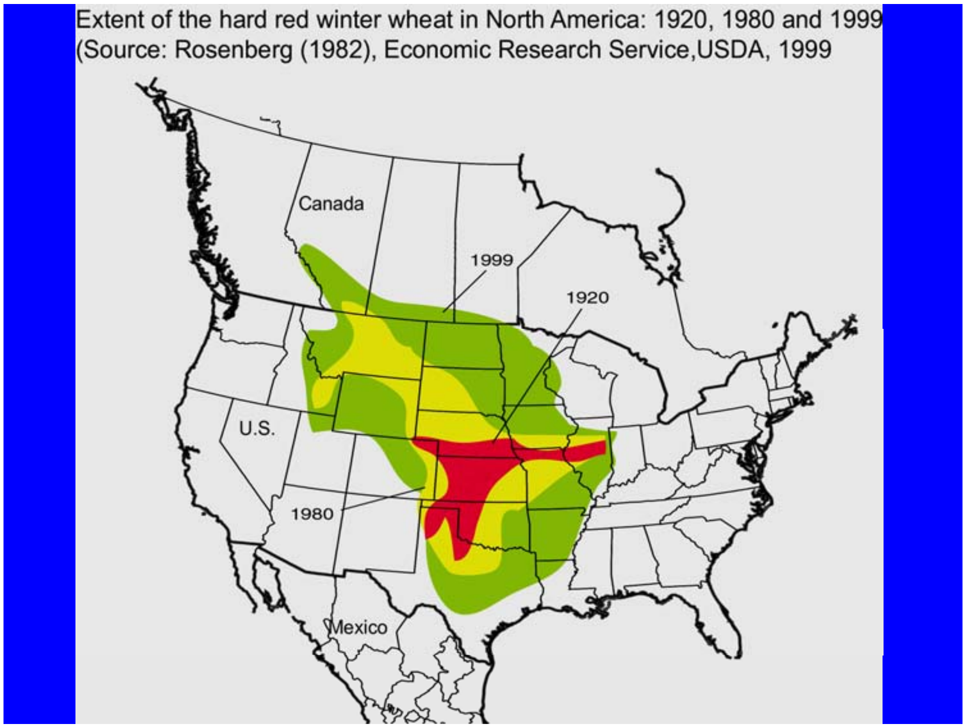

2002 RMA Crop Indemnities
(As of 01/13/2003)
Indemnity Paid by County
(In Dollars for 2002)
No Indemnity (0) (707)
1$ to $500,000 (1471)
$500,000 to $1,000,000 (333)
$1,000,000 to $5,000,000 (543)
$5,000,000 to $10,000,000 (114)
over $10,000,000 (51)

Figure 3



Temperate Crop Yields with Warming and CO_2 Effects
Synthesized From Existing Modeling Studies
10
5
0
-5
-10
-15
-20
-25
-30
% Change in Yield
+
-
Corn
Wheat
% Change (relative to current)
1
2
3
4
Temperature ^{0}C

Figure 4



Extent of the hard red winter wheat in North America: 1920, 1980 and 1999
(Source: Rosenberg (1982), Economic Research Service,USDA, 1999
Canada
1999
1920
U.S.
1980
Mexico