U.S. Agriculture and Climate Change: New Results

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Abstract

We examined the impacts on U.S. agriculture of transient climate change as simulated by 2 global general circulation models focusing on the decades of the 2030's and 2090's. We examined historical shifts in the location of crops and trends in the variability of U.S. average crop yields, finding that non-climatic forces have likely dominated the north and westward movement of crops and the trend toward declining yield variability. For the simulated future climates we considered impacts on crops, grazing and pasture, livestock, pesticide use, irrigation water supply and demand, and the sensitivity to international trade assumptions, finding that the aggregate of these effects were positive for the U.S. consumer but negative, due to declining crop prices, for producers. We examined the effects of potential changes in El Niño/Southern Oscillaton (ENSO) and impacts on yield variability of changes in mean climate conditions. Increased losses occurred with ENSO intensity and frequency increases that could not be completely offset even with perfect forecasts of the events. Effects on yield variability of changes in mean temperatures were mixed. We also considered case study interactions of climate, agriculture, and the environment focusing on climate effects on nutrient loading to the Chesapeake Bay and groundwater depletion of the Edward's Aquifer that provides water for municipalities and agriculture to the San Antonio, Texas area. While only case studies, these results suggest environmental targets such as pumping limits and changes in farm practices to limit nutrient run-off would need to be tightened if current environmental goals were to be achieved under the climate scenarios we examined.

There have been many studies of the potential impacts of climate change on U.S. agriculture but all have limitations (*1,2,3,4*). Past studies have used doubled-CO_2 equilibrium climate scenarios usually without aerosols rather than more realistic transient climate scenarios driven by gradually increased greenhouse gas forcing. Past studies also have not considered the impact of climate change on the use of agricultural pesticides, on the environment via climate-induced changes in agricultural resource use, or the impacts on the agriculture sector of changes in climate variability. The potential for the agricultural economy to adapt to climate change has also received much attention but research remains inconclusive because of the difficulty of providing complete tests of competing hypotheses (*5*,*6*). We have investigated these unresolved issues and report the results and methods more fully in (7).

Historical Changes in US Agriculture and Climate

We asked 2 questions about the past 100 years that have a bearing on climate and agriculture interactions. These were: (1) Has yield variability changed over the past century? (2) Has the production of major crops relocated geographically?

The evidence on yield variability is that, if anything, variability decreased or did not change although the 1950-1994 period for corn was an exception (Table 1). There were substantial geographic shifts in production of three major crops over the past 100 years (fig. 1). There is evidence that climate has changed over the past 100 years *(8,9,10,11,12)* but these changes are of insufficient magnitude or of the wrong direction to be responsible for most of the observed changes in yield variability and the location of production. The northward movement of corn production is most likely associated with changes in production technology, the introduction of corn hybrids, and economic factors rather than as a result of climate change (*13*). The 4º C decrease in temperature at the mean location of geographic corn production over the past 100 years, despite the warming trend for the US as a whole, indicates the importance of factors other than climate affecting the production migration. Soybean is highly sensitive to length of the crop photoperiod such that the geographic range of a particular variety is quite limited. The northern movement of soybean is partly or largely due to breeding new varieties adapted to longer summer days (*14*). In early years of the century the general expansion of agriculture westward into lands suitable for wheat in Oregon, Washington, and California contributed to the westward shift of mean production.

Concentration of production of corn in the central US partly at the expense of wheat grown there, thus increasing the production weight of western grown wheat, contributed to further shifts through the century.

The explanation for the change in variability is more complex but the fact that cropping was increasingly concentrated in areas better suited for production, the ability of farmers to adopt technologies to limit yield risk to climate factors such as irrigation, grain drying, and the effects of federal farm programs on production choices (*15*) are likely responsible for these changes. The dominant forces in changes in yield variability and location in production are likely due to changes other than the changes in climate over the past 100 years. Sorting out either the direction of effect of historic climate change or its magnitude requires more sophisticated empirical evaluation.

Simulated Climate Change Impacts on US Agriculture Production in 2030 and 2090

To consider the production impacts of climate change on agriculture we conducted crop modeling studies at 45 sites in the US for wheat, maize, soybean, potato, citrus, tomato, sorghum, rice, and hay under dryland and irrigated conditions for two transient climate scenarios (*16*) and an alternative crop modeling assessment using a different crop model (*17*). The sites were chosen using USDA national and state-level statistics to cover major producing regions. Climate scenarios were developed from transient runs of 2 general circulation models (GCMs): the Canadian Center Climate Model (CC) and the Hadley Centre Model (HC) (*18*). For the US as a whole, the Canadian model predicts a 2.1º C average temperature change by 2030 and a 5.8º C warming by 2095 with a four percent decline and 17 percent increase in precipitation, respectively. The Hadley Center scenario produces a 1.4º C (2030) and 3.3º C (2095) increase in temperature with precipitation increases of 6 and 23 percent. Crop models were run for twenty-year average climates centered around 2030 and 2090. The deviations in temperature and precipitation from control runs of these models were applied to actual 30-year weather records at each of the 45 sites. Yields were simulated for current varieties and planting schedules as well as for alternative varieties and planting schedules to consider the potential to adapt to the changed climatic conditions. The crop yield impacts used for the economic analysis were the difference between 30-year mean simulated yields under the historical weather and the historical weather adjusted by the GCM climate deviations. Atmospheric CO_2 concentrations used for the crop studies were 350 ppm for the baseline, 445 ppm for 2030, and 660 ppm for 2090 assuming that a proportion of the forcing used by the GCMS, consistent with the 1995 Intergovernmental Panel on Climate Change (IPPC) Business-as-Usual scenario, was from other greenhouse gases (*19)*.

Yield results and changes in water demand for irrigated crops from the crop models were used in an economic model to simulate national level changes in production, resource use, and economic impact on farmers and consumers. The simulated yield changes were also used as proxies for changes in yields of related but unmodeled crops (barley, oats, sugar cane, sugar beet, and cotton) in order to estimate national crop production for all crops included in the economic model. Water supply forecasts based on the climate scenarios were used to change water available for irrigation (7). Also included were a positive relationship between input use and yield and a generally negative relationship between livestock productivity and temperature based on previous work (*20*). New econometric work was conducted to find the specific relationship between climate and pesticide use for major crops, showing increased pesticide expenditures with rising temperatures and greater precipitation (*21*). Because it was not possible to develop a new set of global yield estimates, potential impacts of climate change on US agricultural trade were simulated in a sensitivity analysis that used previous estimates of production shifts globally (*22, 23*).

The net effect in terms of economic welfare (the sum of changes in consumers' and producers' surplus) of the combined changes in crop yields including adaptation and CO_2 fertilization effects, water supply, irrigation demand, pesticide expenditures, and livestock effects was generally positive. The increase in economic welfare was $.8 billion and $3.2 billion ($US 2000) for the 2030 and 2090, respectively, under the CC scenarios. The increase for the HC 2030 and 2090 scenarios was $7.8 and $12.2 billion, respectively. These gains were distributed unevenly among domestic consumers, foreign consumers and US producers. US producers generally suffered income losses due to lower commodity prices while consumers gained from these lower prices. There were substantial regional differences with some regions suffering production declines under some conditions (Fig. 2) even though the overall production effect was positive. The CC scenario was much warmer and much drier, particularly in the 2030 period and thus the less positive effects on crop production overall and negative effects in the Southern and Plains areas of the US. The HC scenario has more moderate warming and particularly large increases in precipitation. The overall results showed a decline in the number of irrigated acres and in water demand for irrigation of between 5 and 35 percent, largely because of the differential effects of climate change on productivity of irrigated versus non-irrigated crops and declines in the use of most resources. The overall productivity increases generally reduce demand for these resources. Thus, if the climate changes as represented in these scenarios, there is potential that reductions in agricultural demand could ease the growing competition for water from urban and environmental users and land for other uses such as preservation of natural systems. The primary result of the trade sensitivity scenarios was to shift the estimated gains away from producers and toward consumers (for cases where global production increased) and toward producers and away from consumers (for cases where global production decreased).

Adaptation in terms of shifting of varieties and planting dates was less important overall in our study than in many previous studies because, for the most part, yields for crops in many regions increased substantially even without adaptation measures and there was little room to increase yields further. The exception was in the South and Southeast where yield reductions were particularly severe in the CC scenario. But here, adaptation measures were unable to erase the yield losses. Economic adaptation such as changes in types of crops, irrigation, and input use are endogenously modeled within the economic model.

Agriculture-Climate-Environment Interactions

Potentially important in climate change are broader agriculture-climate-environment interactions. Beyond the aggregate water and land use results discussed above, we considered more detailed interactions. Our finding of increased expenditures on pesticides for major field crops was part of our aggregate results discussed above. This change in pesticide expenditure (for most states and crops an increase of 10 to 20% on corn, 5 to 15% on potatoes, 2 to 5% on cotton and soybean, –15 to +15% on wheat) only reduced the benefits of climate change by about $100 million because pesticide expenditures are only 3 to 5 percent of the total cost of production, although this varies by crop. We did not study the potential environmental implications of increased pesticide use but this is a concern that should be addressed in future studies.

We also examined the complex interactions of agriculture-climate-environment in the Edward's aquifer region around San Antonio Texas (*24*) and nitrogen run-off into the Chesapeake Bay (*25*). In both of these regional studies, we found increasing threats to the environment under the climate scenarios. The Edwards aquifer region, contrary to most of the rest of country, becomes drier in these scenarios and this increases urban and agricultural demand for water. Resultant increased pumping of groundwater from the aquifer combined with reduced rainfall would threaten surface spring flows supported by the aquifer that are habitat of protected endangered species. Our estimates are that the regional welfare loss was estimated to be between $2.2 -6.8 million per year due to climate change. If springflows are to be maintained at the currently protected level, pumping must be reduced by 10 to 20% below current legislated levels at an additional cost of $0.5 to 2 million per year.

The study in the Chesapeake Bay region showed that climate change could increase nitrogen loadings to the Bay by 25 to 50 percent, the greater figure for the HC scenario. Taking advantage of enhanced productivity potential, corn production in particular expanded and total nitrogen use is consequently increased. In the HC scenario substantial increases in rainfall led to greater erosion and run-off. We evaluated alternative practices that, if implemented, could reduce loadings on the order of 70 percent but at a farmer borne cost. These would require increased incentives for farmers to adopt such practices.

Future Climate and Crop Variability

One of the more difficult areas of study is future change in variability. This is difficult because there are many dimensions of variability (daily, seasonal, interannual) and response of crops to extreme conditions and extreme events. For example, whether a drought lasts 12 rather than 10 days and/or whether extreme temperatures occur during the very short period when crops are flowering can mean the difference between crop failure and minimal impact (26,*27*). The climate scenarios produced by general circulation models provide some information on changes in climate variability. Most climatologists however, doubt the reliability of these projections because of the coarse resolution of the models and because the forces that create climate variability result from processes that operate below the grid scale resolution of the GCMs. All of these issues mean that there are many research questions that could be asked and many ways to approach such studies.

We asked 2 questions: (1) Is there evidence that changes in the mean climate conditions as predicted by the 2 climate scenarios we investigated could change the variability of yields. (2) What would be the economic impact on the US if El Nino-Southern Oscillation (ENSO) intensity and frequency increased as projected by one recent study (28). Our analysis of changes in the variability of yield due to changes in mean climate conditions was based on a cross-sectional econometric analysis (29). The results are given in Table 2 and show fairly uniform decreases in corn and cotton yield variability with mixed results for other crops. Wheat yield variability tends to decrease under the HC climate and increase under the CC. Soybean yield variability shows a uniform increase with the HC. The principal reason for decreases in variability of yield was that the statistical results showed increases in precipitation to be variability-reducing and there were substantial increases in precipitation in these climate scenarios for most regions. The exception was for wheat growing regions, several of which had decreased precipitation, particularly in the CC scenario.

We found that, where farmers operate without information on ENSO event probability, an increased frequency of ENSO caused an average annual loss of $323 million (30). When both frequency and strength shifts were considered the loss increased to $1,008 million annual average, about 5 percent of typical U.S. agricultural producer net income. We also considered whether, with better information on the change in frequency, farmers could avoid these losses through changes in practices. Under current ENSO conditions the value of improved forecasts was estimated at $453 million average annually. This rose to $544 million under changed frequency of ENSO and to $556 million with changes frequency and intensity. The value of improved forecasts did not increase as much as did the losses, indicating that much of the increase could not be avoided through better forecasts of ENSO frequency and intensity. We caution that projections of the relationship between GHG-induced warming and ENSO are highly uncertain, with differing results as to whether intensity and frequency would increase or decrease.

Research and Policy Implications

We identified three broad areas requiring further research: (1) integrated modeling of the agricultural system, (2) research to improve resiliency of the agricultural system to change, and (3) several speicifc areas of climate-agriculture interactions that have not been extensively investigated.

Integrated modeling of agricultural system. The main methodology for conducting agricultural impact models has been to run detailed crop models at a selected set of sites and to use the output of these site models as input to an economic model. Although this approach has provided great insights, future assessments will have to integrate these models to consider interactions and feedbacks, multiple environmental stresses (tropospheric ozone, acid deposition, and nitrogen deposition), transient climate scenarios, and global analysis. A fully integrated model will facilitate study of uncertainty where many (100’s) climate scenarios should be used. This will allow impact assessment to more fully evaluate the extent to which results are climate scenario dependent. The present approach, whereby crop modelers run models at specific sites, severely limits the number of sites and scenarios that can be considered feasibly.

The boundaries of the agricultural system in an integrated model also must be expanded so that more of the complex interactions can be represented. Changes in soils, multiple demands for water, more detailed analysis and modeling of pests, and the environmental consequences of agriculture and changes in climate are areas that should be incorporated into integrated modeling frameworks. Agricultural systems are highly interactive with economic management choices that are affected by climate change. Separate models and separate analyses cannot capture these interactions.

Resiliency and adaptation. Weather and climate is an integral part of agriculture, making it potentially misleading to identify a small set of responses as relevant to climate change. Thus, specific research on adaptation of agriculture to climate change at the time scale of decades to centuries should not be the centerpiece of an agricultural research strategy. Decision making in agriculture mostly involves time horizons of one to five years, and long-term climate predictions are not very helpful for this purpose. Instead, effort should be directed toward understanding successful farming strategies that address multiple changes and risks—including climate change and climate variability. Better monitoring and prediction of weather and further investigation into ways to make better use of short-term and intermediate-term (i.e., seasonal) weather changes would have benefits without climate change and those benefits are likely greater given the prospect of changing climate.

New areas of research. If the goal of integrated modeling of agricultural systems with broadened boundaries is to be achieved, a better understanding of some of the key interactions are needed. Experimentation and modeling of interactions of multiple environmental changes on crops (changing temperature, CO_2 levels, ozone, soil conditions, moisture, etc.) are needed. The environmental conditions interact in complex ways. Experimental evidence is needed under realistic field conditions, such as FACE experiments for CO_2 enrichment, that also consider multiple stressors. Much more work on agricultural pests and their response to climate change is needed. Economic analysis needs to better study the dynamics of adjustment to changing conditions. Climate-agriculture-environment interactions may be one of the more important vulnerabilities, but existing research is extremely limited. Effects on soil, water quality, and air quality should be included in a comprehensive study of interactions. Finally, the area of changing variability requires more attention. A fundamental principle in this regard is that agricultural modeling must be more closely integrated with climate modeling so that modelers can develop better techniques for assessing the impacts of climate variability. This work requires significant advances in climate predictions to better represent changes in variability, as well as assessment of and improvements in the performance of crop models under extreme conditions.

The ultimate question for US agriculture over the next several decades is, “Can agriculture become more resilient and adaptable given the many forces that will reshape the sector—of which climate change is only one?” US agriculture has, in fact, been very adaptable and resilient along many dimensions; to stay ahead in a competitive world, however, we can always ask: “Can it do still better?” The market and policy environment for agriculture will strongly affect

Over the past half-century, federal farm policy has aimed to boost farm and rural incomes, smooth out the ups and downs of commodity prices, insure farmers against the inevitable disasters of droughts and floods, feed the poor, improve productivity, protect natural resources, and come to the aid of the small farmer. There have been great successes: Since 1950, US agricultural productivity has doubled; real world food prices have fallen by two-thirds, so feeding the world is cheaper; and the average US farm household is now wealthier than the average nonfarm household. There also have been contradictory and costly policies such as supply control with production-based payments and “conservation” programs that idled land with only minimal environmental benefits.

We identified four broad policy considerations: (1) Agricultural research and development strategies (2) commodity policy and adjustment assistance (3) risk management, and (4) environment and natural resource management. Because the nature of climate change remains only poorly understood, it is possible only to offer general guidelines.

Agricultural research and development strategies. Successful adaptation to climate change will require successful R&D. Traditional public R&D is part of the research portfolio, but the engine of invention now is in private firms. More basic research remains the province of the public sector. It is critical to continue to foster linkages between basic and more applied research as there is not a bright line that separates these. An important element for the future will be to find ways encourage and direct the power of the private research engine to improve environmental performance. Science-based environmental targets implemented with market-based mechanisms can provide sound incentives for innovations that improve environmental performance. Designing market-based mechanisms to deal with nonpoint pollution has proved difficult; more attention is needed to assure that whatever mechanisms are chosen, they provide incentives for the private sector to develop and commercialize agricultural technologies and practices with improved environmental performance.

Commodity policy and adjustment assistance. The lesson from the last 50 years of agricultural policy is that use of broad-based commodity policy to fight rural poverty is an extremely blunt instrument. These payments often end up disproportionately in the hands of the wealthiest farmers. A goal could be to target income assistance far more carefully to disadvantaged people in rural areas—many of whom are not actually farmers on any significant scale. Tying aid to the business of farming also tends merely to inflate the value of assets (mainly land) tied to farming. Ultimately, the next generation of farmers pays a higher price for the land and faces a higher cost structure than if the payments had not been in place. This situation sets the stage for another income crisis when inevitable commodity price variability leads to a downturn in prices. The 1996 farm legislation eliminated most of these elements recognizing the basic dilemma the programs have faced and replacing them with payments that ultimately were to be phased out after seven years. Stress in the farm sector as a result of low prices for many commodities over the past few years has put pressure on legislators to revive elements of the previous farm programs.

Risk management. Climate variability and its potential increase necessarily focus attention on risk-management strategies. Contract production, vertical integration, forward markets, private savings, household employment decisions, and weather derivatives are market responses to risk. These strategies are likely to evolve further, and farmers who are not adept at using them will have to become so. Farmers can adopt technological solutions to risk—such as irrigation as insurance against weather damage or shorter maturing varieties against frost—but only if market conditions justify the investment. Crop insurance is another response, for which the federal government now takes some responsibility. Federal crop insurance contains a devilish public policy dilemma. One aspect of insurance is what is known in economics as "moral hazard." The existence of insurance reduces the incentive to undertake technological solutions to risks. A second aspect of insurance is that under a pure insurance program, the enrollee pays insurance premiums each year but over several years should expect to get back in loss payments no more than he or she paid. If the farmer can expect more, the insurance program also is a subsidy program. This situation may involve cross-subsidization among enrollees; the subsidizers then tend to drop out, however, or—where federally managed—the entire program can run a deficit with tax dollar support. There is a risk, then, that the desire to create a federal insurance program that enrolls a large proportion of farmers will end up as largely a subsidy program. If climate change causes a drift toward more frequent disasters in an area, the premiums for farmers in the area would have to be adjusted upward to maintain the program as a pure insurance program. Failure to adjust premiums ultimately could mean that insurance is paying out almost every year. A federal program would have difficulty, however, raising premiums substantially on areas that have suffered repeated disaster years. Ultimately, crop insurance or a broader form of producer insurance cannot offer much protection if an area is drifting toward reduced viability.

Environment and natural resource management. Environmental and resource policies need to be realistic, tough, and market-based and adapt as conditions change and put the ultimate objectives of the programs at risk. These situations can be "win-win." In the climate scenarios we examined increased yields and lower prices led to a reduction in resource use. In the past, acreage-reduction programs took vast tracts of land out of production to boost prices. In the same way, environmentally targeted programs that reduce production—through land retirement or through other types of constraints on production practices—can offset climate-induced productivity increases, raise commodity prices, and restore income levels. These programs also can be beneficial for the United States overall if the programs are targeted to generate substantial and real environmental gains. If—as projected in our analysis—use of water and land resources declines because of climate change, reallocating resources to environmental and conservation goals may be more feasible. Keep in mind, however, that we project reduced resource use compared with a reference. If far greater demand for resources occurs for other reasons (e.g., demand growth abroad), we will not see these reductions compared to current levels. Thus, again, climate change is just one of the factors that needs to be considered.

Conclusions

We investigated the impacts of climate change and the direct yield-enhancing effects of rising concentrations of atmospheric CO_2 on U.S. agriculture using two recent GCM-derived scenarios. . We found that overall climate change would be beneficial to crop productivity, although there are strong regional differences with possible declines in production in the Southern US. The benefits increased in 2090 compared with 2030 for both climate scenarios even though temperature increases were quite high by 2090 in the CC case. These results show the danger of attempting to summarize the impacts of climate change as a simple function of global mean temperature or to characterize losses from climate change as increasing over time. Further work should investigate the results from a broader set of climate models with varying rates of change in forcing to better understand the uncertainty that exists in such forecasts.

The risks from climate change to agriculture will more likely occur at regional levels, depend on changes in precipitation or changes in variability of climate, or stem from more complex climate-agriculture-environment interactions. In particular we found increased risks due to ENSO, to nitrogen loadings in the Chesapeake Bay, and to ecosystems dependent on the Edward's aquifer in Texas. The need to protect such environmental assets would require changes in agricultural practices that would, in turn, increase production costs. Much more study is needed here with a more complete assessment of environmental effects of climate change. On the positive side we found that for the U.S. as whole, water demand from agriculture would decrease under these scenarios, lessening competition with growing urban demand. We still remain highly uncertain about how climate will change. Our study is one of the first to examine the new, more realistic transient climate scenarios in some detail. Research on multiple environmental stresses and using these results to develop sound models that can simulate the complex biophysical interactions with farm management and farm policy is needed. Specific research areas include research on agriculture-environment links, on climate-pest interactions, and on the effects of climate variability. A vigorous public and private research and development enterprise and attention to environment and conservation policy will help respond to potential climate threats. Commodity policy as it has traditionally been designed and Federal risk management strategies will need to balance the well-meaning desire to aid farmers and regions that may be threatened by a changing climate with the recognition that such aid can often discourage the adaptation and change that will be needed. While climate prediction is highly uncertain, it seems likely that in some regions agriculture may well become non-viable even if many areas benefit.

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Table Titles and Captions.

Table 1. There has been either no significant trend or a trend of declining yield variability for corn, soybean, and wheat over the time period 1870-1994 The exception is a significant increase in yield variability in corn for the 1950-1994 period. Yield variation is measured by V = absolute value of $(X_t - X_{trend})/X_{trend}$, where X_t is crop yield in year t in tons per hectare and X_{trend} is the 9-year moving average of yield in tons per hectare centered on year t, using annual crop yield data from 1866 to 1998. The trend in yield variation is the estimate of coefficient β from the linear regression model $V = \alpha + \beta t$. * Significant at the 10% level; ** Significant at the 5% level. Computed by the authors. Source of data: U.S. Department of Agriculture.

Table 2. Simulated yield variability for 2090 climates show decreases for several states and crops owing largely to the effects of greater precipitation, although the relative effect of changes in precipitation and climate vary among crops and regionally differing changes in climate. The primary exception is wheat grown in regions subject to reductions in precipitation in one climate scenario.

Figure Titles and Captions:

Figure 1. Substantial shifts have occurred in the geographic center of corn, wheat and soybean production since circa 1900. The geographic center was calculated as the mean location using county level data for the entire US (map shows only that portion of the US that contains the geographic center of production), weighting counties by their production. The northward movement of soybean and corn production meant that mean temperature at the center of production was 4º C lower in 1990 inclusive of the trend of warming for the US since 1900 estimated at .6°C (*12).* Wheat production shifted mainly to the west.

Figure 2. Regional production changes under 2090 climate simulations show more positive effects in northern and western regions, with declining use of resources to meet agriculture production needs.
Panel a. Production changes under the Canadian Center Climate simulation show more negative effects in southern and plains regions.
Panel b. Production changes under the Hadley Center Climate simulation are positive across the entire US with the largest increases in the lake states, mountain, pacific, and corn belt regions
Panel c. Resource use declines under both the Canadian and Hadley Center climate scenarios. Irrigated land and water use declines the most with smaller declines in total cropland, pasture, and animal unit months (AUMs) of grazing.

Table 1:

Commodity	Area harvested in 1997	Area irrigated in 1997	Variation in crop yield from trend (Estimates are in percent with the standard error of the estimates in parentheses)					
	(000 ha)	(%)	1870-1994		1900-1994		1950-1994	
			Mean variation	Trend in variation	Mean variation	Trend in variation	Mean variation	Trend in variation
Corn	28,258	15.2	7.77 (0.58)	-1.271E-2 (1.620E-2)	7.24 (0.68)	1.553E-2 (2.480E-2)	6.97 (0.89)	2.357E-1 ** (5.938E-3)
Wheat	23,820	6.8	6.28 (0.45)	-2.834E-2 ** (1.230E-2)	5.86 (0.51)	-3.122E-2 * (1.81E-2)	4.92 (0.63)	-5.662E-4 (4.719E-2)
Potato	549	79.0	5.75 (0.52)	-8.159E-2 ** (1.237E-2)	4.40 (0.46)	-7.608E-2 ** (1.457E-2)	2.42 (0.30)	-4.076E-3 (2.211E-2)

Table 2.

	Canadian Center Climate Change Scenario					Hadley Center Climate Change Scenario				
	Corn	Soyb.	Cott	Wht	Sorg	Corn	Soyb.	Cott	Wht	Sorg
CA			-12.84					-11.81		
CO				34.43					-10.60	
GA			-10.35					-6.92		
IL	-25.71	21.28				-24.73	18.90			
IN	-8.73	8.06				-26.31	20.30			
IA	-36.89	33.14				-26.83	20.90			
KS				-14.39	-0.75				-18.16	3.38
LA			-13.03					-7.97		
MN		4.01					10.60			
MT				32.86					-6.36	
MS			-13.92					-7.73		
NE	15.30	-4.74		48.22	-16.15	-15.05	11.65		-5.57	-1.72
OK				16.34	-9.27				-17.07	2.83
SD	-21.75			-6.94		-24.37			-19.10	
TX			-13.21	27.86	-10.83			-8.05	2.26	-3.10

Figure 1.

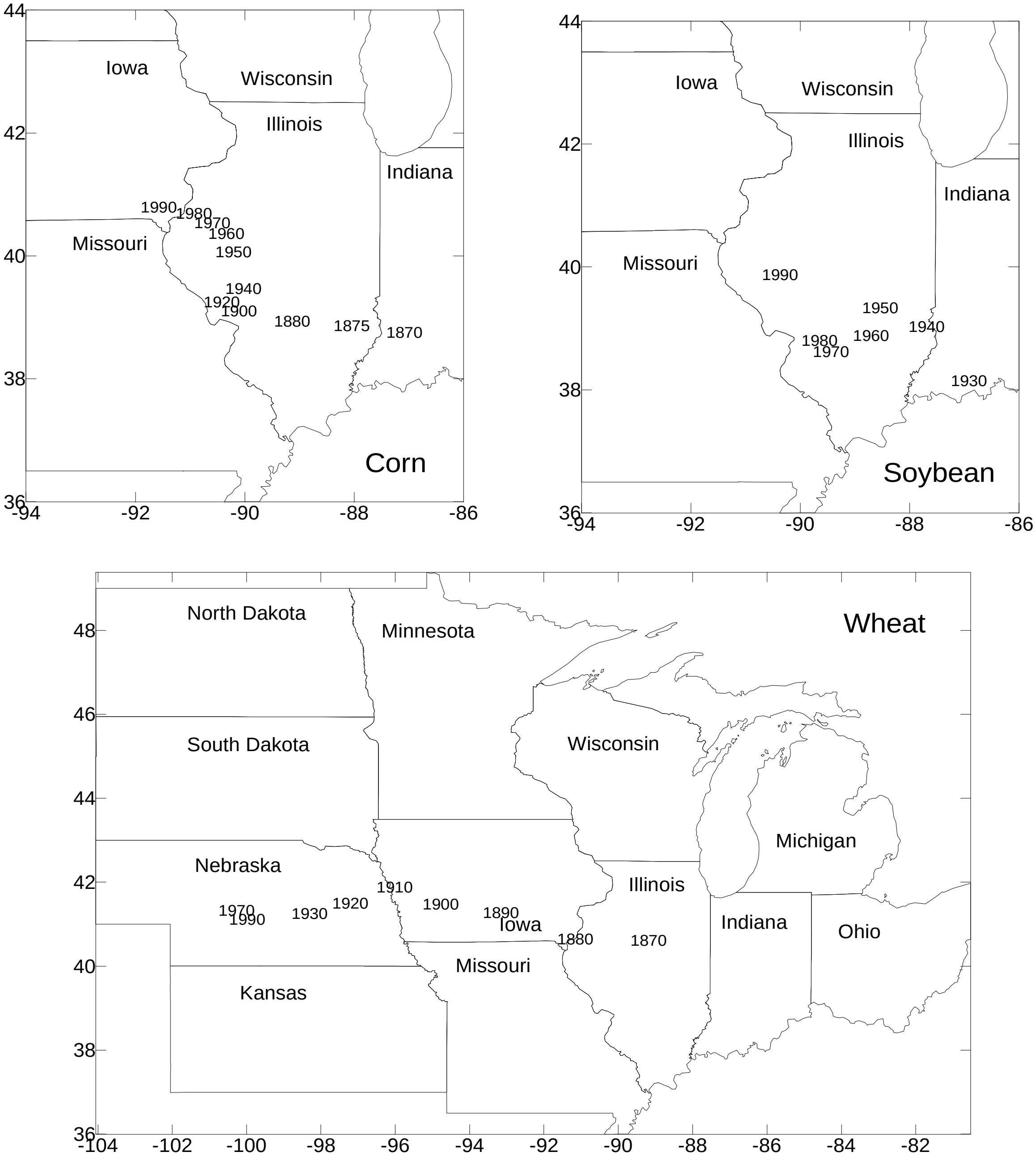
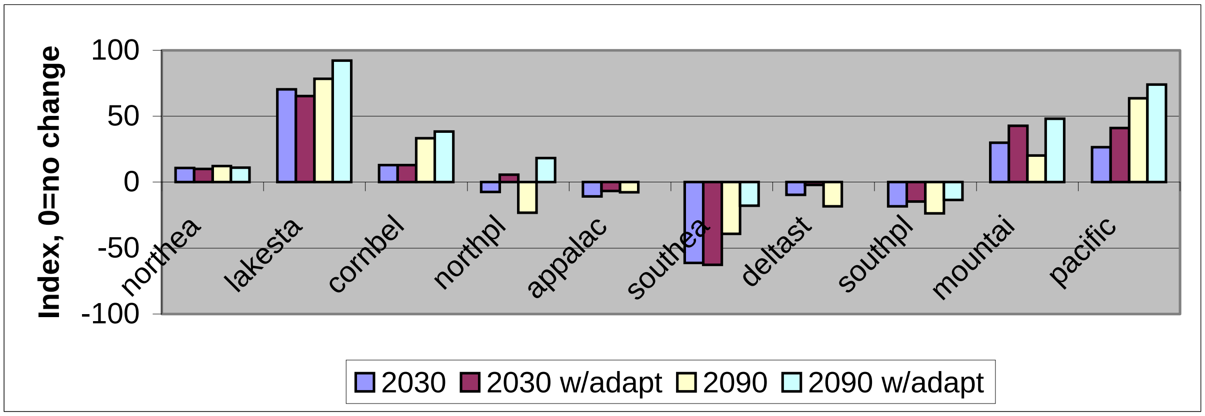
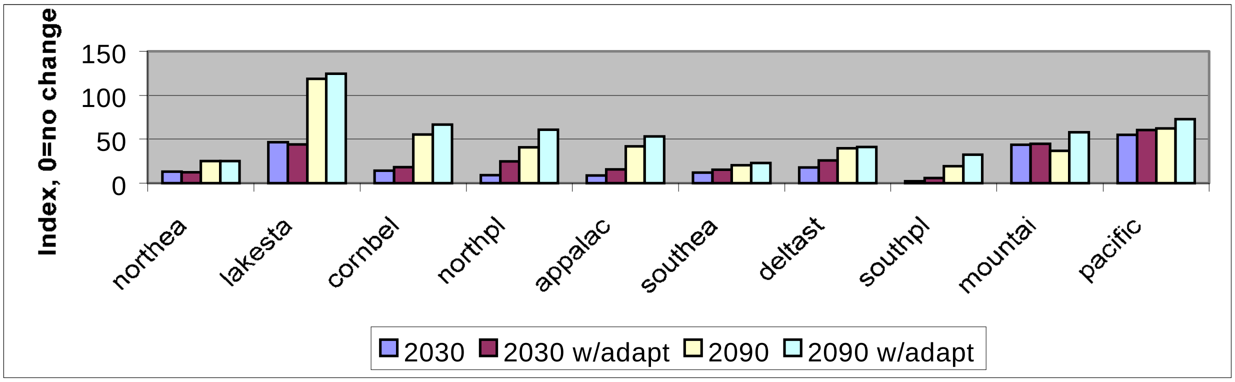

Corn
Iowa
Wisconsin
Illinois
Indiana
Missouri
1990
1980
1970
1960
1950
1940
1920
1900
1880
1875
1870
44
42
40
38
36
-94
-92
-90
-88
-86
Soybean
Iowa
Wisconsin
Illinois
Indiana
Missouri
1990
1950
1940
1980
1960
1970
1930
44
42
40
38
36
-94
-92
-90
-88
-86
Wheat
North Dakota
Minnesota
South Dakota
Wisconsin
Michigan
Nebraska
Illinois
Iowa
Indiana
Ohio
Missouri
Kansas
1910
1920
1930
1970
1990
1900
1890
1880
1870
48
46
44
42
40
38
36
-104
-102
-100
-98
-96
-94
-92
-90
-88
-86
-84
-82

Figure 2.

Panel a.



Panel b.



Panel c.