Potential Climate Change Impacts on New England Agriculture

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ABSTRACT

The New England area is an important contributor to the national supply of dairy products and food crops such as apples, grapes, potatoes, sweet corn, onions, cabbage, and maple syrup. In upstate New York alone the cash receipts from the sale of farm products approach $3 billion on an annual basis. The agriculture sector of the New England economy will be particularly sensitive to climate change, and there will be both winners and losers within the farming community. The social and political consequences of this will reach well beyond the farm gate because of the impact on supply and price of agricultural commodities, and the impact on local economies and land use.

Some crops, and the New England farmers producing them, will benefit from warmer temperatures, longer growing seasons, and the positive direct effect of increased atmospheric carbon dioxide on yield. In contrast, the competitive position of those farmers producing crops well-adapted to the existing climate could be weakened, or their enterprises may completely collapse, if their crops do not respond well to shifts in climate, and adaptation strategies fail. The dairy industry is likely to suffer adverse consequences from warmer summer temperatures because milk production by dairy cattle is very sensitive to heat stress.

Reaping the potential benefits while minimizing the potential negative consequences of climate change will require diversion of agricultural research dollars to climate change issues, shifts in crops and varieties grown, and increases in water, fertilizer, pesticides, and other farm inputs. In some cases, substantial capital investment by farmers, and taxpayer investment in regional infrastructure (e.g., development of water resources for irrigation) may be necessary just to maintain the status quo.

Assuming a best-case climate change scenario—a "benign" warming, with no major shifts in precipitation patterns or increase in catastrophic weather events—the agricultural industry in New England should be able to adapt, but the transition during the next century could be very stressful both economically and politically for the region.

INTRODUCTION

The economic value of agriculture in New England is often underestimated, even by many residents of the region who are not directly involved with this industry. In upstate New York alone the total farm cash receipts approach $3 billion on an annual basis. Many are surprised to learn that New York ranks within the top three in the nation for production of apples, grapes, sweet corn, snap beans, cabbage, milk, cottage cheese, and several other commodities. Maine has long had important potato, egg production, and other agriculture-related industries. The Vermont maple syrup industry is internationally recognized. The New England area as a whole provides a significant proportion of the total U.S. supply of dairy and maple syrup products. In addition, small family farms throughout New England are vital to the economy of rural areas, and they fill an important market niche for fresh, high quality, affordable local produce.

Key questions regarding New England agriculture and climate change are:

- Could the beneficial effects of increasing atmospheric carbon dioxide (CO_2) on plants (the so-called "CO_2 fertilization effect") counteract some of the negative effects of climate change?
- What types of adaptations and policies will be necessary to take advantage of the opportunities and minimize the negative impacts of climate change on New England agriculture?
- What will the cost of these adaptations and policies be?

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- Who will be the likely winners and losers within our region?
- What will be the likely impact of climate change on New England agriculture relative to other areas?
- Will climate change help or hinder our efforts to maintain an affordable food supply for the region, the nation, and for an increasing world population?

To date, there has been no comprehensive quantitative analysis of potential climate change impacts on New England agriculture. However, some findings from studies focused on impacts at the national and international scale are relevant here. Also, basic information on the regional agricultural economy, and information on crop and livestock responses to temperature and greenhouse gases, can be utilized in developing a qualitative assessment for the New England area. We will first review some fundamental aspects of what we know and don't know about how crops respond to temperature and increases in atmospheric carbon dioxide (CO_2).

TEMPERATURE EFFECTS ON CROPS

Most plant processes related to growth and yield are highly temperature dependent. We can identify an optimum temperature range for maximum yield for any one crop. Crop species are often classified as warm- or cool-season types. Most of the crops for which the New England area currently holds a strong competitive market position at the national level are cool-season species well adapted to our mild summers and cool spring and fall temperatures.

The optimum growth temperature frequently corresponds to the optimum temperature for photosynthesis , the process by which plants absorb CO_2 from the atmosphere and convert it to sugars used for energy and growth. Temperature also affects the rate of plant development. Higher temperatures speed annual crops through their developmental phases. This shortens the life cycle of determinate species like grain crops, which only set seed once and then stop producing. For a variety currently being grown in a climate near its optimum, a temperature increase of several degrees could reduce photosynthesis and shorten the growing period. Both of these effects will tend to reduce yields. Brief high temperature events at critical stages can severely reduce the quality of some cool season vegetable and fruit crops, and thereby reduce marketable yields even when total productivity is not affected.

The particular crop varieties currently being grown in major production areas are usually those best-adapted to the current climate. A significant increase in growing season temperatures will require shifts to new varieties that are more heat tolerant, do not mature too quickly, and have a higher temperature optimum for photosynthesis. Developing such varieties should be possible for many crop species, but there are limits to what can be accomplished through plant breeding and modern genetic engineering approaches. In many cases traditional crops will have to be abandoned for new crops better suited to the new environment. On the positive side, for farmers in cool regions such as New England, a "benign" warming (no major shifts in precipitation patterns and no increase in frequency of catastrophic weather events) will lengthen the growing season and should expand the list of crop species and varieties that can be grown successfully.

TEMPERATURE EFFECTS ON LIVESTOCK

Farm animals are directly affected by temperature and vary in their optimum temperature range. Dairy cattle perform best in cool climates (temperatures between 40 and 75 °F), and are particularly sensitive to heat stress (Bray and Bucklin 1996). High relative humidity (RH) exacerbates the negative effect from high temperatures. For example, at 80% RH heat stress in dairy cattle can begin at temperatures as low as 73 °F and stress becomes severe at 93 °F. Heat stress can have a carryover effect on milk production and reproduction for up to 150 days. Renovation or new construction of controlled environment facilities to house farm animals is costly and will not be a viable option for many New England dairy farmers. Climate change will also affect livestock production indirectly by its impact on the availability and price of animal feed, such as corn silage.

CARBON DIOXIDE (CO_2) EFFECTS ON PLANTS

The debate over whether CO_2 and other greenhouse gases are warming the planet continues, but few question the fact that atmospheric CO_2 is increasing exponentially and will likely double (to 700 parts per million (ppm)) within the next century. We can be relatively certain that agriculture in the future will be affected by the direct effects of

CO_2 on crops and weed species, whether or not we have a concomitant change in climate. Elevated CO_2 levels have a potential beneficial effect on the Earth's plant life because plants take up CO_2 via photosynthesis and use it to produce sugars and grow. The magnitude of this "CO_2 fertilization effect" varies with crop species and other environmental conditions such as temperature and availability of water and plant nutrients (see reviews: Wolfe 1994; Wolfe and Erickson 1993).

Most of our information regarding the yield response to CO_2 is based on experiments where plants were well supplied with water and nutrients, temperatures were near optimum, and pressure from weeds, disease and insect pests were nonexistent. Under such optimum conditions, a doubling of CO_2 (e.g., from 350 to 700 ppm) typically increases the yield of most crops by 20 - 35% (Kimball, 1983). While this describes the average, there are reports in the literature of lower yield responses in some slow-growing winter vegetables such as cabbage, and reports of higher yield responses in some fast-growing indeterminate species such as cotton and citrus.

Corn, an important crop in New England, is somewhat unique in that it shows very little growth stimulation with a doubling of CO_2 concentration even under optimum conditions. This is because it has a rather unique mechanism of photosynthesis. Some pasture grasses, weed species, and a small number of other crop plants (sorghum, millet, sugarcane) are similar to corn in their photosynthetic biochemistry, and so also do not benefit much from elevated CO_2.

It is possible that the beneficial effects from elevated CO_2 may compensate in some cases for negative yield responses to increasing temperatures. However, New England farmers in this situation could still be out-competed by farmers in more northern, cooler regions whose crops get the full benefit from higher CO_2 without the negative effects from high temperature stress.

Within the non-stress temperature range, the beneficial effects from elevated CO_2 tend to increase as temperatures increase. However, when temperatures become so high as to adversely affect flowering and pollination (e.g., >100 °F) the CO_2 benefits on yield become negligible.

Plant response to CO_2 at low temperatures will have important implications for high latitude regions such as New England where, even with a global warming, plants will be subjected to suboptimal temperatures during early and late portions of the growing season. The specific low temperature threshold for realization of a positive CO_2 effect varies, but for most crops the beneficial effects on photosynthesis become minimal at temperatures below about 55 °F. A recent study (Boese et al., 1997) found that for some selected crop species, such as beans and cucumber, elevated CO_2 provides some protection from chilling injury at temperatures between 40 and 45 °F.

Obtaining maximum benefit from an increase in atmospheric CO_2 is likely to require an increase in chemical inputs by farmers. Weed species can benefit just as much as cash crops from the CO_2 fertilization effect, and therefore growers may need to use more herbicides to control weeds in the future. Warmer temperatures in high latitude areas such as New England may allow more insects to overwinter in these areas, leading to greater pest pressure in the spring and increased pesticide use. Plants grown at high CO_2 tend to use water and nitrogen fertilizer more efficiently on a per unit leaf area basis, but when the increase in plant size due to high CO_2 is greater than the increase in efficiency, more water and fertilizer may be necessary.

MODEL PROJECTIONS OF CLIMATE CHANGE IMPACT ON AGRICULTURE

Scientists have attempted to address the issue of climate change impact on agriculture by linking together climate, crop growth, and economic-food trade computer models. These multi-layered models are extremely complex and contain numerous assumptions about the physical, biological, and socioeconomic systems they attempt to simulate. Nevertheless, they represent the most comprehensive analyses we have at present. They can be useful to policymakers at both the regional and national level provided there is an educated appreciation for the level of uncertainty inherent in their projections.

A comparison of impacts on U.S. agriculture for selected regions, based on a simulation analysis by Adams et al. (1995), is shown in Table 1. They considered climate uncertainties by comparing results from three different general circulation models (GCMs), those from the NASA Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GDFL) and the UK Meteorological Office (UKMO). These GCMs vary in the severity and spatial distribution of their predicted changes in temperature and precipitation. The UKMO model predicts the greatest increases in temperature and, not surprisingly, the greatest effect on regional economic welfare.

The results in Table 1 indicate that the greatest negative effects on economic welfare tend to occur in southern, warm regions of the U.S. In general these negative effects are small relative to the base economy, but it should be noted that the yield forecasts used to create Table 1 are optimistic in that they assume a substantial CO_2 fertilization effect. The model is quite sensitive to this CO_2 effect assumption. For example, in simulations for the Northeast where no benefit from CO_2 was assumed, the negative impact from climate change more than doubled, with a percent change in economic welfare of -1.67, -2.91, and -14.86% for the GISS, GDFL, and UKMO models, respectively.

Table 1. Model projections of climate change effects on regional economic welfare (percent change from base) assuming current (1990) technology and positive CO_2 fertilization effects on yield. From Adams et al. (1995).

	Climate Model		
Geographic Region	GISS	GFDL-QFlux	UKMO
Mountain	+16.27	+1.18	+44.83
Northern Plains	+2.38	+10.32	+7.11
Pacific	+1.94	+1.57	-2.15
Lake States	+0.89	+3.23	-4.11
Northeast	-0.45	-0.35	-5.05
Southeast	-0.61	-0.70	-5.08
Appalachian	-0.69	-0.81	-5.21
Corn Belt	-0.90	-0.38	-3.50
Delta	-0.93	-0.44	-2.38
Southern Plains	-1.14	-0.63	-4.94

Although these computer projections can be a useful tool for policymakers, it is important that the results of such simulations not be take too literally. For example, the data for the Northeast region in Table 1 may not be particularly relevant to the situation for New England for several reasons. First, "Northeast" as defined by Adams et al. (1995) included Pennsylvania and New Jersey, as well as all of New York and the rest of New England. Second, the yield simulations are based entirely on crop models for wheat, maize (field corn), and soybeans. It is questionable whether these results have relevance for horticultural crops such as apples, grapes, potatoes, and cabbage that dominate the New England agricultural economy. The lack of reliable crop models for many important high value crops is a shortcoming of our current knowledge base. Finally, heat stress effects on milk production by dairy cattle, a very important consideration for the New England area, is not quantified in data in Table 1.

CAN FARMERS ADAPT TO CLIMATE CHANGE?

The U.S. and many other developed nations have a strong agricultural research base, abundant natural resources for flexibility in cropping patterns, and capital available to pay for adaptations and buffer negative economic effects during transition. For this reason many are optimistic that farmers in regions such as New England will be able to take advantage of opportunities and minimize negative effects associated with climate change.

Adapting to climate change will be costly, however. Costs at the farm level will include such things as increased use of water, fertilizer and pesticides to maximize beneficial effects of higher CO_2, and investment in new farm equipment and storage facilities as shifts are made to new crop varieties and new crops. (Imagine the costs, for example, for an apple grower to change varieties, or for a dairy farmer to switch to tomato production). Costs at the regional and national level will include substantial diversion of agricultural research dollars to climate change issues, and major infrastructure investments, such as construction of new dams and reservoirs to meet increased crop water requirements. Environmental costs associated with agricultural expansion into some regions could include increased soil erosion, increased risk of ground and surface water pollution, depletion of water resources, and loss of wildlife habitat.

Developed as well as developing nations must be prepared to deal with the citizens in those regions negatively impacted by climate change. Regardless of capital availability, agricultural economies in some areas will collapse due to factors such as excessively high temperatures, severe pest pressure, lack of locally adapted varieties, or poor markets for adapted crops. As climatic zones shift, there will be some cases where those zones with the best climate for crops will not have good soils or available water.

It would be wise to begin examining national policies for their ability to handle these climate change issues. The Council for Agricultural Science and Technology report on preparing the U.S. for climate change (CAST, 1992) emphasized the need for climate change-related agricultural research, and suggested modifying existing policies to encourage more flexible land use, more prudent use of water resources, and freer trade.

CONCLUDING REMARKS

The three major uncertainties regarding impacts of climate change on agriculture are: (1) the magnitude of regional changes in temperature and precipitation; (2) the magnitude of the beneficial effects of higher CO_2 on crop yields; and (3) the ability of farmers to adapt to climate change. If we lean toward the optimistic in our assumptions regarding all three of these uncertainties (e.g., a "benign warming", significant yield increases with a CO_2 doubling for most crops, and considerable capacity for adaptation by farmers), the New England agriculture industry should be able to survive a climate change, and may even benefit relative to some other regions of the U.S.. However, even with an optimistic set of assumptions, we can be relatively certain that the transition will be very stressful both economically and politically for the region. While some components of the agriculture industry will benefit, others will lose. Some farm families may go completely out of business when adaptation strategies fail. There could also be environmental costs associated with adaptation such as expansion of agriculture into fragile ecosystems, the need to develop new water resources, and increased use of chemical inputs by farmers.

Adapting to climate change with minimal economic, social, and political upheaval will require a coordinated effort at regional, national, and international levels to deal with the many serious consequences of climate change on agriculture.

REFERENCES

Adams, RM, RA Fleming, C-C Chang, B.A. McCarl and C Rosenzweig. 1995. A reassessment of the economic effects of global climate change on U.S. agriculture. Climatic Change 30:147-167.

Boese, SR, DW Wolfe and J Melkonian. 1997. Elevated CO_2 mitigates chilling-induced water stress and photosynthetic reduction during chilling. Plant, Cell and Environ. 20:625-632.

Bray, DR and R Bucklin. 1996. Recommendations for Cooling Systems for Dairy Cattle. Univ. of Florida Coop. Ext. Fact Sheet DS-29.

Council for Agricultural Science and Technology (CAST). 1992. Preparing U.S. Agriculture for Global Climate Change. Task Force Report No. 119. CAST, Ames, Iowa. 96 pp.

Kimball, BA. 1983. Carbon dioxide and crop yield: An assemblage and analysis of 430 prior observations. Agron. J. 75:779-787.

Wolfe, DW 1994. Physiological and growth responses to atmospheric carbon dioxide. In: Handbook of Plant and Crop Physiology. M Pessarakli (ed.) Marcel Dekker, Inc., New York. pp. 223-242.

Wolfe, DW and JD Erickson. 1993. Carbon dioxide effects on plants: uncertainties and implications for modeling crop response to climate change. In: Agricultural Dimensions of Global Climate Change., HM Kaiser and TE Drennen (eds.). St. Lucie Press, Delray Beach, FL, pp. 153-178.