Chapter 7

Agriculture

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Introduction

Agriculture is a significant component of the New York economy that includes large wholesale grower-shippers selling products nationally and internationally, a substantial dairy industry, and thousands of small farm operations selling direct retail and providing communities throughout the state with local, fresh produce. Farmers will be on the front lines of coping with climate change, but the direct impacts on crops, livestock, and pests, and the costs of farmer adaptation, will have cascading effects beyond the farm gate and throughout the state's economy. While climate change will create unprecedented challenges, there are likely to be new opportunities as well, such as emerging markets for new crop options that may come with a longer growing season and warmer temperatures. Taking advantage of any opportunities and minimizing the adverse consequences of climate change will require new decision tools for strategic adaptation. Adaptations will not be cost- or risk-free, and inequities in availability of capital or information for strategic adaptation may become an issue for some sectors of the agricultural economy.

7.1 Sector Description

Agriculture, as defined in the ClimAID report, includes livestock, dairy, and crop production, as well as the economically important flower cultivation, nursery, and turf industries. The timber, maple syrup, and fishing industries are not included here; they are covered in Chapter 6 ("Ecosystems") and/or Chapter 5 ("Coastal Zones").

7.1.1 Economic Value

The agriculture sector in New York State encompasses more than 34,000 farms that occupy about one-quarter of the state's land area (more than 7.5 million acres) and contribute $4.5 billion annually to the state's economy. **Table 7.1** summarizes some recent New York agriculture statistics (USDA, 2007). The annual value of dairy products alone approached $2.4 billion in 2007. Hay value (primarily realized through sale of milk and livestock) was $327 million, while New York ranked third nationally in grain silage production with a value of $262 million. The vegetable industry

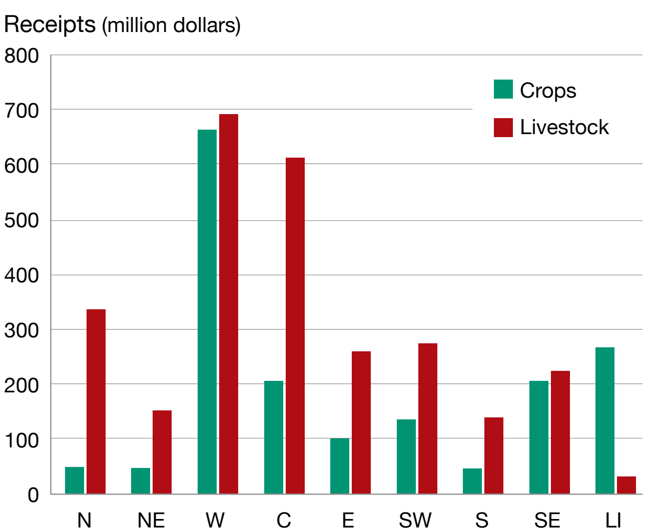
Commodity	2007 Value (1,000 dollars)	2007 Harvested Acres (1,000's)	National Rank
Dairy Products	$2,377,987	N/A	1 (cottage cheese) 3 (milk)
Poultry, eggs	122,643	N/A	26 (poultry) 22 (eggs)
Cattle, hogs, sheep	118,742	N/A	2 (calves) 6 (lambs sheep)
Other	107,927		
Total Livestock	2,727,299		
Apples (fresh)	198,467		
Apples (processed)	50,432		
Apples (Total)	286,000	42	2
Grapes (fresh)	3,600		
Grapes (juice)	25,200*		
Grapes (wine)	14,842		
Grapes (Total)	49,222	34	3
Tart cherries	4,369	1.7	4
Sweet cherries	3,518	0.7	8
Peaches	3,995	1.7	10
Pears	5,120	1.2	4
Strawberries	7,590	1.5	7
Blueberries	3,373	0.7	10
Red raspberries	5,723	0.45	N/A
Other fruits and nuts	4,440		
Total Fruit Crops	373,350	84.25	
Cabbage (fresh)	101,190	12.6	2
Cabbage (kraut)	4,460	2.6	N/A
Sweet corn (fresh)	72,600	27.5	4
Sweet corn (processed)	15,286	17.2*	N/A
Snap bean (fresh)	49,749	9.9	4
Snap bean (processed)	14,990	19.9*	N/A
Pumpkins (fresh)	22,694	6.4	4
Onions (fresh)	94,182	12.3	5
Peas (processed)	9,033	17.4*	N/A
Beets (processed)	1,824	2.4	N/A
Other	189,815		
Total Vegetable Crops	575,823	109.1	
Grain corn	300,355	550	22
Silage corn	262,548	495	3
Potatoes (Total)	64,372	18.3	11
Soybeans	75,212	203	24
Dry beans	8,557	16.5	12
Wheat	29,835	85	31 (winter wheat)
Oats	7,866	60	8
Hay (Total)	322,128	1,360	22
Total Field Crops	1,070,873**	27695	
Floriculture	199,028	N/A	6
Nursery	63,343*	N/A	N/A
Other greenhouse	125,000	N/A	N/A
Total Other	357,661		
Total Livestock & Crops	$4,454,294	(actual cash receipts)	

* 2006 data (2007 not available).
** Field crop total includes estimated values of silage, hay, and seed corn that was not sold but was used directly for animal and dairy production.
Source: USDA National Agricultural Statistics Service: www.nass.usda.gov/ny

Table 7.1 2007 NY agriculture value, harvested acres, and ranking contributed $648 million and the fruit industry more than $368 million.

New York is the dominant agricultural state in the Northeast and typically ranks within the top five in the United States for production of apples, grapes, fresh-market sweet corn, snap beans, cabbage, milk, cottage cheese, and several other commodities. In addition to many large-scale wholesale operations, small farms throughout the state are vital to the economy of rural areas and fill an important market niche for fresh, high-quality, affordable local produce. About half of all New York farms have sales of less than $10,000 (www.nass.usda.gov/ny), while 18 percent have sales exceeding $100,000. This 18 percent accounts for about half of all land area occupied by farms (3.77 million acres).

The value of agriculture to the state goes beyond direct farm revenue statistics. For example, a recent analysis of the value of the New York grape and wine industry, which included multipliers such as regional tourism and supporting industries, estimated that the total economic impact of this industry was more than $6 billion in 2004 (MKF Research, 2005). Also, farm landscapes can be managed in a sustainable manner to provide important "ecosystem services" such as preservation of soil and water resources, habitat to enhance biodiversity, carbon sequestration to mitigate climate change, and a land-base resource for wind turbine development (Bennet and Balvanera, 2007).



Note: Abbreviations are for counties in geographic areas: e.g., N = Northern, NE = Northeastern, etc. C = Central, LI = Long Island.[1] Source: USDA National Agricultural Statistics Service: www.nass.usda.gov/ny

Figure 7.1 Total cash receipts for crops and livestock in 2007, by region

The economic value of the greenhouse/nursery industry is significant, with cash receipts exceeding $347 million in 2007. Data for turf were not available for 2007, but an analysis of that industry conducted in 2003 by the New York Agriculture Statistics Service found more than 3.4 million acres of turf in the state (82 percent in private residences); more than $5 billion was spent on maintenance expenses for all turf sectors combined. There were 8,148 "sod" acres devoted to the actual production of turf, employing 140 laborers with a payroll of $4.2 million and selling a total of 2,226 acres in 2003 at a value of $14.9 million.

Regional Variation of the New York Agriculture Economy

Agriculture is important throughout the state, including regions near urban centers such as Long Island adjacent to the New York City metropolitan area and the counties near Rochester, Buffalo, Syracuse, and Albany. Farming near these urban centers has unique challenges, including educating the public about farm operations, addressing human health concerns, and changing land values, tax structures, and land-use restrictions. Overall, only a very small fraction of New York State voters are either farmers or directly involved in the agriculture industry. Dairy farms are located throughout the state and are the dominant component of the agricultural economy of many counties in the northern, central, and southern regions (**Figure 7.1**). In some of these more rural regions, a large fraction of the total economy is affected by the fate of the dairy sector. Many dairy farms also produce hay and corn (for grain and silage) and maintain some pastureland to support their own livestock and to sell hay. A large fraction of the high-value fruit and vegetable crops are grown in western New York. Long Island and the Hudson Valley region are also important fruit and vegetable crop areas.

7.1.2 Non-climate Stressors

Numerous economic and other forces will shape the response of New York agriculture to climate change. Some major trends, like the ongoing consolidation of the dairy industry, have been included in the ClimAID analysis of climate change impacts. Others, such as changes in market conditions due to altered growing conditions elsewhere, are mentioned briefly but are too uncertain to build into current analyses.

Dynamic Market Demands, Competition, and Economies of Scale

New York farmers are affected by often rapidly changing consumer preferences and demands of supermarket buyers. Increasingly, farmers must consider global market forces and international competition as well as competition from neighboring states. Climate change will exacerbate these challenges. Farmers will have to adapt their own practices to climate change impacts and also will need to assess the effects (either beneficial or detrimental) of climate change on their competitors as well as their competitors' ability to adapt.

The dairy industry at both the state and national levels has been undergoing significant consolidation and other changes in recent years due, in part, to the fact that milk production per cow is increasing more rapidly than demand. Between 1998 and 2007, the average annual milk production per cow in New York rose by 2,624 pounds to a total of 19,859 pounds (www.nass.usda.gov/ny). During this same time interval, the dairy cow population in the state decreased by 16 percent, but the size of an average herd rose from 85 to 110 cows, and total milk production for the state was almost constant at around 12,500 million pounds per year. This continues a linear national trend since 1950 that has resulted in an almost 300-percent increase in milk production per cow, generally fewer cows per state across the country, and yet constant or increased total production (Blaney, 2002).

An analysis for New York (not accounting for possible climate change effects) projected that the state's competitive position will remain strong, but the number of dairy farms would decline from 7,900 in 2000 to 1,800 in 2020, and the average herd will have about 250 cows producing more than 25,000 pounds of milk per cow per year (LaDue et al., 2003). (Current statistics show this projection to be on track with 5,495 dairy farms in 2009 [NYSDAM, 2010]). At the time of that study (2003), large farms in New York were estimated to have an economic advantage, with a 50-cent profit margin per 100 pounds of milk over that of small farms. Although the price of milk has fallen considerably since then, the same economies of scale are likely to continue the trend toward larger farms. Some factors could potentially constrain the future size of herds, such as increased health risks to the animals and regulations for large operations (LaDue et al., 2003). Numerous ways in which climate change might interact with these trends are discussed in the sections on dairy vulnerability (7.3.5) and adaptation (7.4.1), and in Case Study D. Dairy Heat Stress.

Changes in some sectors of the horticulture industry (such as apple production) have included a shift in structure from primarily mid-sized farms to a bimodal distribution structure that includes large commodity-style and small diversified farms. This has been driven by the rise of local marketing that has occurred simultaneously with some producers entering global markets. The New York wine grape industry has experienced rapid growth in recent decades, despite winter cold limitations on growing some popular non-native European wine grapes. The industry has focused on more cold-hardy varieties such as Riesling and hybrid grapes. A warming climate will provide new opportunities and challenges for grape growers (see Sections 7.3.5 and 7.4.2, and in Case Study A. Frost Damage to Grapes.

Rising Energy Costs, Renewable Energy, and Emerging Carbon Markets

Like farmers elsewhere, New York farmers have been faced with highly volatile and rising energy costs and inputs that are sensitive to energy prices, such as nitrogen-based fertilizers. This makes business planning and maintaining profit margins difficult. New York energy prices are higher than in some states, affecting the competitive ability of New York farmers. It is quite difficult to predict future energy prices and the effect that future government policies might have on the price of carbon-based fuels. On the benefit side, incentives and low-cost loans for expanding the use of renewable-energy sources, and emerging carbon markets (e.g., receiving carbon "offset" payments for agriculture practices that sequester more soil carbon or reduce greenhouse gas emissions), could create important new economic opportunities for farmers and buffer them from the detrimental effects of rising energy costs. The use of farmland and marginal woodlot acreage for biomass "fuel" crops is likely to become increasingly important in coming years. A

Renewable Fuels Roadmap, intended to guide State policy on renewable fuels, was recently issued by the New York State Energy Research and Development Authority (NYSERDA, 2010).

Water Issues

New York has historically been characterized as a humid region with significant summer rainfall that, in most years, provides for acceptable productivity of rain-fed grain and forage crops. In the context of a changing climate, however, the state lacks an inventory of drought-vulnerable locations, clearly defined agricultural water rights, and regional infrastructure for water delivery to farmland in dry years.

An analysis of historical data for New York reveals that even with today's climate in an average year, summer rainfall does not completely meet seasonal crop water requirements; supplemental irrigation is required for maximum productivity (Wilks and Wolfe, 1998), particularly on sandy or compacted soils with low water-holding capacity. Only a small percentage of farm acreage is irrigated in the state, most of this occurring on the relatively high-value vegetable and fruit acreage that accounts for about 6.5 percent of total cultivated land area. However, even farmers producing high-value fruit and vegetable crops often lack sufficient irrigation capacity to meet water needs of their entire acreage during extended periods of summer drought. Such drought events are projected to increase in frequency (Hayhoe et al., 2007; and see Chapter 1, "Climate Risks," and Case Study C. Drought). The substantial rain-fed grain crop, corn silage, and hay acreage of the state (often providing low-cost feedstock for dairy and other livestock) would be particularly vulnerable to potential increases in summer drought frequency because the value of such crops is not likely to warrant investment in irrigation equipment.

Too much as well as too little rainfall is currently a recurrent problem for farmers in New York. The recent historical trend for increased frequency of high rainfall events (see Chapter 1, "Climate Risks") has adversely affected some vegetable growers in recent years by direct reductions in yields and also by delaying spring planting or other farm operations. Additionally, use of heavy farm equipment on wet soils is detrimental to soil structure and quality and further limits crop yield.

7.2 Climate Hazards

Below are aspects of climate change projected for New York that will be particularly relevant to the agriculture sector (see Chapter 1, "Climate Risks"). Several high-priority vulnerabilities and opportunities associated with these factors are discussed in more detail in section 7.3.

7.2.1 Temperature

Warmer summer temperatures and longer growing seasons may increase yields and expand market opportunities for some crops. Some insect pests, insect disease vectors, and disease-causing pathogens may also benefit in multiple ways, such as having more generations per season and, for leaf-feeding insects, an increase in food quantity or quality.

Increased frequency of summer heat stress will be damaging to the yield and quality of many crops and will adversely affect health and productivity of dairy cows and other livestock.

Warmer winters will affect the suitability of various perennial fruit crops and ornamentals for New York. The habitable range of some invasive plants, weeds, and insect and disease pests will have the potential to expand into New York, and warmer winters will increase survival and spring populations of some insects and other pests that currently marginally overwinter in the state.

7.2.2 Precipitation

Projections of future precipitation patterns are inherently less certain than projections of future temperature. ClimAID analyses for New York suggest total annual precipitation may increase somewhat, primarily in the winter months, but the magnitude of this change is quite uncertain. Of greater certainty are expected changes in qualitative aspects such as the fraction of precipitation coming as snow and the intensity of individual rainfall events (see Chapter 1, "Climate Risks").

Less snow cover insulation in winter will affect soil temperatures and depth of freezing, with complex effects on root biology, soil microbial activity, and nutrient retention (Rich, 2008), as well as winter survival of some insects, weed seeds, and pathogens.

Snow cover also will affect spring thaw dynamics, levels of spring flooding, regional hydrology, and water availability.

Increased frequency of late-summer droughts will adversely affect productivity and quality and will increase the need for irrigation (see Case Study D. Drought). Rain-fed crops, for which irrigation is not economically feasible, would be particularly vulnerable. Despite new challenges with water deficits, New York is not threatened with the severity of drought projected for many other agricultural regions in the United States and internationally.

Increased frequency of heavy rainfall events is already being observed with adverse consequences, such as direct crop flood damage, non-point source losses of nutrients and sediment via runoff and flood events, and costly delays in field access.

7.2.3 Sea Level Rise

Sea level rise will have few direct effects on agriculture in most parts of the state. Issues such as increased potential for saltwater intrusion into groundwater or coastal flooding in agricultural areas in Long Island and the Hudson Valley are discussed in Chapter 5, "Coastal Zones."

7.2.4 Other Climate Factors

There are some climate factors, such as increased frequency and clustering of extreme events, that could potentially have severe negative impacts on the agriculture industry, but our current level of certainty about these factors is low (see Chapter 1, "Climate Risks"). Although not a climate factor, the continued increase in atmospheric carbon dioxide has direct effects on plants separate from its influence on climate, as described briefly below with other factors of particular concern.

Most climate models project little change in climate variability per se, but there is not a high degree of certainty that this will be the case and, in fact, there is observational evidence of increased winter variability in recent years. More variable winter temperatures can adversely affect perennial plants and winter crops by making them more vulnerable to mid-winter freeze damage (due to de-hardening) or spring frost (due to premature leaf out and bud break). There is a need for new climate research and monitoring to determine whether such events are part of a long-term climate change trend, and there is a need for new extreme-event early warning systems for farmers.

Current climate models cannot project changes in cloud cover reliably, yet cloud cover changes can have profound effects on crop productivity and quality and on crop water demands.

While great strides have been made by climate modelers and computing power in improving the spatial resolution of climate projections, it will be important for farmers to have even higher resolution to encompass microclimate effects.

Higher atmospheric carbon dioxide levels can potentially increase growth and yield of many crops under optimal conditions. However, research has shown that many aggressive weed species benefit more than cash crops, and that weeds also become more resistant to herbicides at higher carbon dioxide concentrations (see Section 7.3.2).

7.3 Vulnerabilities and Opportunities

Warmer temperatures, a longer growing season, and increased atmospheric carbon dioxide could create opportunities for farmers with enough capital to take risks on expanding production of crops adapted to warmer temperatures (e.g., European red wine grapes, peaches, tomatoes, watermelon), assuming a market for new crops can be developed. However, many of the high-value crops that currently dominate the state's agriculture economy (e.g., apples, cabbage, potatoes), as well as the dairy industry, benefit from the state's historically relatively cool climate. Some crops may have yield or quality losses associated with increased frequency of late-summer drought, increased summer high temperatures, increased risk of freeze injury as a result of more variable winters, and increased pressure from weeds, insects, and disease. Dairy milk production per cow will decline in the region as temperatures and the frequency of summer heat stress increase, unless farmers adapt by increasing the cooling capacity of animal facilities. Below are some high-priority vulnerabilities for New York.

7.3.1 Increased Insect and Disease Pressure

Insects are cold-blooded organisms; the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. It has been estimated that with a 3.6°F temperature increase, insects might experience one to five additional lifecycles per season (Yamamura and Kiritani, 1998). Other researchers have found that moisture and carbon dioxide effects on insects may also be important considerations under global climate change conditions (Hamilton et al., 2005; Coviella and Trumble, 1999; Hunter, 2001).

More frequent intense precipitation events projected for climate change may negatively impact many insects such as onion thrips, known to be killed or removed from crops by heavy rains (Reiners and Petzoldt, 2009). As with temperature, precipitation changes can affect insect pest predators, parasites, and diseases, resulting in a complex dynamic. Fungal pathogens of insects are favored by high humidity; the populations of these fungi would increase under climate changes that lengthen periods of high humidity and be reduced by those that result in drier conditions.

Soybean insects have been observed in increased numbers and have caused increased damage under elevated carbon dioxide and elevated ground-level ozone concentrations (Dermody et al., 2008). Some invasive insect pests, including pests of important crops, are predicted to increase under future climate change scenarios (Ward and Masters, 2007).

As a result, it is likely that New York farmers will experience new challenges with insect management, as longer growing seasons increase the number of insect generations per year, warmer winters lead to larger spring populations of marginally overwintering species, and earlier springs lead to the earlier arrival of migratory insects. Numerous studies throughout the northern hemisphere have already documented changes in the spring arrival and/or geographic range of many insect and animal species due to climate change (Parmesan, 2006; Montaigne, 2004; Goho, 2004; Walther et al., 2002).

In New York, a network of pheromone traps to monitor corn earworm (*Helicoverpa zea*) throughout the central and western parts of the state has documented a trend for its earlier arrival over the past 10 years (with its early arrival date moving from mid-July to early June). This has required earlier initiation of insecticide sprays to control the pest and has increased costs to the growers (Abby Seaman, personal communication, January 2007).

Temperature also has potential impacts on plant diseases through both the host crop plant and the pathogen. Downy mildew of grapevine is predicted to occur earlier in the season, resulting in more severe infections (Salinari et al., 2007). Many mathematical models that have been useful for forecasting plant disease epidemics are based on increases in pathogen growth and infection within specified temperature ranges. Generally, fungi that cause plant disease grow best in moderate temperature ranges. Temperate climate zones that include seasons with cooler average temperatures are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction as the climate warms.

Increased carbon dioxide levels can affect both the host and the pathogen in multiple ways. Some of the observed carbon dioxide effects on diseases may counteract others. Researchers have shown that higher growth rates of leaves and stems observed for plants grown under high carbon dioxide concentrations may result in denser canopies with higher humidity that favor pathogens. Lower plant decomposition rates observed in high carbon dioxide conditions could increase the crop residues on which disease organisms can overwinter, resulting in higher inoculum levels of the disease organisms at the beginning of the growing season and earlier and faster disease epidemics. Higher carbon dioxide concentrations can also result in greater fungal spore production, affecting pathogen growth. However, increased carbon dioxide can also result in physiological changes to the host plant that can increase host resistance to pathogens (Coakley et al., 1999).

An increase in the frequency of heavy rainfall events projected for New York will tend to favor some leaf and root pathogens (Coakley et al., 1999; Garrett et al., 2006) and, depending on the timing, wash off chemical sprays. However, short- to medium-term droughts will tend to decrease the duration of leaf wetness, thereby reducing some of the ways in which pathogens attack leaves. Although the specific impacts of climate change on plant diseases are difficult to predict given current knowledge, it is possible to make several generalizations for farmers in the Northeast:

- Increased winter temperatures are likely to result in more pathogens surviving the winter and earlier infestation of plants in spring.
- Increased temperatures will likely result in northward expansion of the range of some diseases.
- More frequent heavy rainfall events will tend to favor some types of pathogens over others.

Two pathogens important in the northeastern United States, Stewart's Wilt and late blight, illustrate some of these effects. Stewart's Wilt (*Erwinia stewartii*), a bacterial disease that generally has sporadic importance in sweet corn in the Northeast, is vectored (carried) by the corn flea beetle (*Chaetocnema pulicaria*). Survival of the vector through winter is considered key to the severity of Stewart's Wilt infections the following year. A recent analysis projected increased severity of the flea beetle and Stewart's Wilt in the Northeast throughout this century, based on climate change projections for the region and a disease-severity forecast model based on winter temperatures (Wolfe et al., 2008).

Late blight infects potatoes and tomatoes in the Northeast. It can be a devastating disease for both crops and farmers, with complete crop loss a possibility if control measures are not employed. Infection is triggered by high moisture conditions within a fairly specific temperature range. Annually, 5 to 20 fungicide applications from as early as June through August are used in the northeastern United States to control potato late blight. This represents a significant expense to farmers and an important environmental risk. Predictive models for potato and tomato late blight show that the fungus infects and reproduces most successfully during periods of high moisture that occur when temperatures are between 45°F and 80°F. Earlier onset of warm temperatures could result in an earlier threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control. Work in Finland, which is considered to be in a similar late blight risk zone to the northeastern United States, has predicted that for each 1.8°F increase in temperature late blight would occur four to seven days earlier and the susceptibility period of the plants would extend by 10 to 20 days (Kaukoranta, 1996). This would likely translate into an additional one to four fungicide applications for northeastern United States tomato and potato farmers—increasing both costs to farmers and environmental risks (see Case Study B. Potato Late Blight).

7.3.2 Increased Weed Pressure

Many weeds have a stronger growth response to increasing carbon dioxide concentrations than most cash crops, particularly "invasive" weeds with the C_3 photosynthetic pathway, and with rapid and expansive growth patterns, including large allocation of biomass below ground to roots, stolons, and/or storage organs (Ziska and George, 2004; Ziska, 2003). Recent research also suggests that glyphosate (e.g., Roundup), the most widely used herbicide in the United States, loses its efficacy on weeds grown at the increased carbon dioxide levels likely to occur in the coming decades (Ziska et al., 1999). While there are many weed species that have the C_4 photosynthetic pathway and therefore show a smaller response to increased atmospheric carbon dioxide concentrations relative to C_3 crops, in most agronomic situations, crops compete with a mix of both C_3 and C_4 weeds. In addition, the worst weeds for a given crop are often similar in growth habit or photosynthetic pathway. To date, all weed/crop competition studies where the photosynthetic pathway is the same for both species favor weed growth over crop growth as carbon dioxide is increased (Ziska and Runion, 2006).

The habitable zone of many weed species is largely determined by temperature, and weed scientists have long recognized the potential for northward expansion of weed species' ranges as the climate changes (Patterson et al., 1999; McDonald et al., 2009). Kudzu (*Pueraria lobata*, var. montana), an aggressive invasive weed that currently infests more than 2 million acres in the southeastern United States, has a habitable range determined in part by the minimum winter temperature boundary of -4°F (Sasek and Strain, 1990). A recent study used high-resolution climate model projections for the northeastern United States and documented the potential for northward expansion of this invasive weed into New York within the next few decades (Wolfe et al., 2008). While temperature is not the only factor that could constrain the spread of kudzu and other invasive weeds, a more comprehensive assessment of potential weed species migration into New York seems warranted.

7.3.3 Too Little Water

Yield and quality losses due to increased frequency of late-summer drought could have a major impact on some sectors of the New York agriculture economy. This would most severely affect rain-fed agriculture, which in New York State includes most of the corn grain and silage acreage used as feedstock for dairy, as well as other grain crops (e.g., wheat) and hay. While many producers of high-value fruit and vegetable crops have some irrigation equipment, few have adequate capacity to meet water requirements of all of their acreage during severe summer droughts. Presumably, farmers will adapt by increasing irrigation capacity and use, but this may put demands on water resources and may eventually require development of new water supplies, storage and delivery systems within and between watersheds, and water policies to determine water rights during periods of low supply (see also Case Study C. Drought).

7.3.4 Too Much Water

The recent historical trend for increased frequency of high rainfall events (more than 2 inches in 48 hours) is projected to continue (Chapter 1, "Climate Risks;" Chapter 4, "Water Resources"). This can have negative economic consequences such as direct crop flood damage; delayed spring planting, reducing high-value early season production of vegetable crops; lack of access to the field during other critical periods; soil compaction because of tractor use on wet soils; increased crop foliar and root disease; increased soil erosion losses; and increased runoff of chemicals or manures into waterways or crop-growing areas, with negative implications for human health.

7.3.5 Issues of Concern for Key Industries

Here we focus on dairy (see also Case Study D. Dairy Heat Stress) because this is the major component of the New York agricultural economy. Farmers in this industry will be particularly vulnerable to new stresses associated with climate change because many are already operating close to the edge economically. Apples and grapes have also been selected for focus, below (and see Case Study A. Frost Damage to Grapes), because these are representative of our high-value horticultural industry, and distinctions between apples and grapes illustrate how even similar crop species can differ in their vulnerabilities (and opportunities) associated with climate change.

New Challenges for the Dairy and Livestock Industries

All livestock are affected by rising temperatures, but dairy cows are of special concern both because of their economic importance in New York State and their relatively low thresholds for temperature stress.

Heat Stress and Productivity

A number of environmental factors such as temperature, humidity, and sunlight can all contribute to the degree of heat stress experienced by livestock. The response of dairy cattle to heat stress includes lower feed intake, lower milk production, decreased calving, and an increased risk for other health disorders. Even relatively moderate warm temperatures (e.g., greater than 80°F) combined with moderate humidity (e.g., greater than 50 percent relative humidity) reduce milk productivity of dairy cows and have a long-term economic impact by reducing calving rates (Klinedinst et al., 1993).

Scientists have developed a "thermal heat index" (THI), which is based on temperature and humidity data and indicates the potential for heat stress in many livestock (Klenedinst et al., 1993):

$$\text{THI} = \text{Temp}(°\text{C, dry bulb}) + 0.36(\text{Temp}(°\text{C, dew point})) + 41.2.$$

Threshold THI values, above which reduced animal performance is predicted to cause production losses, have previously been ranked at approximately 70 to 72 for dairy cows, 72 to 75 for beef cows (*B. taurus*), 72 to 74 for pigs (*Sus domestica*), and 70 to 78 for chickens (*Gallus domestica*) (St. Pierre et al., 2003). A study in 2003 used THI calculations to estimate historical economic losses due to heat stress for dairy and other livestock industries in New York at $24.9 million per year (St. Pierre et al., 2003). Field observations in the unusually warm summer of 2005 in New York found a milk production decline of 5 to 15 pounds per cow per day at many dairy operations (an 8 to 20 percent decrease in normal production) (Larry Chase, personal communication, January 2007). Heat stress in dairy cattle can be exacerbated by the number of consecutive high-temperature days and the ability of the cows to cool off at night.

The recent Northeast Climate Assessment used a THI threshold of 72 to model dairy cow performance associated with climate model projections for the region and concluded that adverse economic impacts on the dairy industry will be substantial by mid-century unless growers adapt by making capital investments to increase cooling capacity of dairy barns (Wolfe et al., 2008). This study may have underestimated the economic consequences of climate warming, however, based on recent research that suggests that the THI threshold for decline in milk production should be 68 rather than 72 for the high-producing dairy cows (producing more than 77 pounds of milk per day) common in many of the state's dairy herds today (Zimbelman et al., 2009; Berman, 2005).

An additional factor regarding heat stress on cows is that if stressful conditions occur for even a few days during critical periods, the impacts may persist for many months. Early-lactation cows are most susceptible to the effects of heat stress, and the impact could persist for the complete lactation. If peak milk production is decreased by only 2 pounds per day, as might be seen under mild heat stress, 400 to 500 pounds of milk could be lost for the lactation period. This would amount to a $48 to $60 loss per cow at the current milk price of $12 per 100 pounds of milk. However, if more severely stressed, early-lactation cows may experience decreases of 5 to 15 pounds of peak milk production per day.

The New York dairy industry will be more affected by heat stress in the future than in the past, not only because of the warming trend, but also because today's high milk-producing cows are more sensitive to heat stress in terms of milk productivity (Fox and Tylutki, 1998). Dairy producers will benefit from working closely with their farm advisors and extension personnel to develop heat stress abatement practices and strategies for their specific situation (see Adaptations, Section 7.4.1, and Case Study D).

Feed Availability and Prices

Climate change could also indirectly affect livestock and dairy industries by altering the availability and price of crops used for animal feed. Yields of hay, grain, corn, and silage will be affected by multiple factors associated with climate change. Yields may increase and prices may go down due to opportunities to grow longer-growing-season varieties. On the other hand, yields may decline and prices may increase due to crop losses associated with the increased frequency of crop heat stress, late-summer drought, and heavy precipitation events projected for New York. Increased use of corn biomass as a renewable energy source could potentially reduce availability of corn grain and/or silage for feedstock, also increasing prices. However, a recent report commissioned by NYSERDA addresses many of these renewable fuels issues with initial recommendations for how to develop biomass fuel resources in a sustainable manner and with a minimum of adverse indirect effects (NYSERDA, 2010).

The combined uncertainties regarding climate change impacts on feedstock, future biofuel markets, and other factors make it difficult to predict the potential effects of climate change on the dairy industry. Monitoring these factors will be important for effective adaptive management.

Opportunities and Challenges for Perennial Fruit Crops

Perennial fruit crops are particularly vulnerable to climate change because they are exposed to and affected by the climate year round. Over the past 30 to 40 years, spring bloom dates for apples and grapes in New York have occurred several days earlier compared to the historical record, indicating that climate change effects are already in evidence (Wolfe et al., 2005). Changes in winter temperatures as well as summer temperatures affect the physiology, development, productivity, and fruit quality of perennial fruit crops (Howell, 2000; Gu et al., 2001).

Perennial fruit crops and the industries that produce them have several unique characteristics that affect their responses to climate change. For example, both previous season growth and over-wintering conditions can affect flowering potential the following spring. Thus, climate stresses in one season may have effects for two or more years. Since fruit crops are grown for quality as well as quantity, processes such as coloration, flavor, and appearance are valued, and these are very sensitive to environmental stresses (e.g., drought, heat spells).

Apples
Among the perennial fruit crops grown in New York, apples may be particularly vulnerable to climate change

and a high priority because of their economic value and the state's historical national leadership in productivity and quality (**Table 7.1**). The growth and potential productivity of apple trees should increase with increased atmospheric carbon dioxide and the longer, warmer growing seasons (Lakso et al., 2001) that are projected for New York. However, increased frequency of summer heat stress periods and droughts are likely to reduce fruit quality, especially if the capacity for irrigation is inadequate (Lakso, 1994).

Several analyses have indicated that apples tend to have reduced fruit set and yields in summers following warmer winter conditions (Jackson and Hamer, 1980; Jackson et al., 1983; Lakso, 1987), or due to heat during critical fruit set periods (Kondo and Takahashi, 1987; Greene, 2002). In some recent years with variable winter temperatures, apples have had increased spring frost damage because they leafed out and bloomed earlier in the spring. Hail damage has also been unusually severe in some recent years, although it is not clear if this is associated with any long-term climate trend.

Although climate warming will provide some opportunities to grow longer-season varieties (Fuji, Granny Smith), it may also mean that some of the state's cool-season signature varieties (McIntosh and Empire) may no longer be commercially viable due to poorer fruit quality in warmer climates, as seen today in the climates of the mid-Atlantic and Southeast, where McIntosh and Empire have performed poorly. One study projected possible negative effects on yields of some apple varieties by the end of century, as a result of warmer winters and inadequate winter-chill hours for optimum spring bloom and fruiting (Wolfe et al., 2008).

Overall, for apples, there is likely to be a reasonable balance of beneficial and detrimental impacts from climate change, assuming farmers adapt with new varieties or other strategies as any negative effects become apparent (see Section 7.4.2).

Grapes

For grapes, particularly the non-native *Vitis vinifera* red wine grape varieties for which the historical New York climate is at the cold margin of production, the net effects of a longer growing season and warmer winters are likely to be beneficial over the long term in terms of yield and wine quality. Late-summer drought, however, could limit yields or require greater irrigation, and increases in summer temperatures will have a range of effects that favor many new varieties but might decrease quality in some current favorites. Relative to other major wine regions in the United States and the world, the New York industry appears to be in less jeopardy and may benefit overall (White et al., 2006; Jones et al., 2005).

Although cold-tender *vinifera* grape varieties (e.g., Cabernet, Shiraz, Zinfandel) may do better with warmer winters over the long term, recent winter temperature variability has led to incidents of severe winter freeze damage, costing the Finger Lakes wine industry millions of dollars (Levin, 2005). Freeze damage can occur when excessively warm winter periods de-harden vines and make them more susceptible to damage during subsequent cold periods (Howell, 2000; Gu et al., 2001). There also can be the problem discussed for apples, above, where premature leaf out or bloom increases the risk of spring frost damage to young shoots or buds (Hanninen, 1991). The paradoxical phenomenon of increased freeze or frost damage to perennial plants in a warming world has been observed in other parts of the United States (Gu et al., 2008; Rochette et al., 2004). For New York growers, this phenomenon poses a new challenge in the short term, prior to the potential longer-term benefits of warmer winters being fully realized (see Adaptations, Section 7.4.2; and Case Study A. Frost Damage to Grapes).

7.4 Adaptation Strategies

Farmers have numerous adaptation strategies for minimizing the negative effects of climate change and for taking advantage of the opportunities. These range from changing crop varieties or diversifying cropping systems, to improving pest monitoring and pest control measures, to capital investments for expanded irrigation capacity or improved cooling capacity of dairy barns. Some adaptations will involve institutions and agencies beyond the farm gate, such as development of new crop varieties for the region, new information delivery systems and decision tools for farmers, improved crop insurance programs, financial incentives and assistance for adaptation investments, and policies to deal with inequities in climate change impacts and farmer capacity to adapt. A number of these are described in more detail below.

7.4.1 On-Farm Adaptation for Dairy and Other Livestock

The dairy producer has three avenues for adaptation to minimize the effect of heat stress: adjust diet and feeding management, increase use of existing fans and other cooling systems, and improve cooling capacity of existing housing facilities (also see Case Study D. Dairy Heat Stress).

Adjust Diet and Feeding Management

Cows housed in modern dairy barns often receive carefully formulated feed, which is nutritionally balanced and may include vitamins and nutritional supplements to optimize the cows' health and milk production. The ration should be regularly adjusted to reflect the animals' changing needs under different environmental conditions. Potential diet adjustments under heat-stress conditions include adding fat as an energy source to partially counteract the lower feed intake (Staples, 2007; Baumgard and Rhoads, 2009). Other adjustments include the following:

- Use more-easily-digested forages (plants eaten by livestock) to lower heat produced in the rumen (first large compartment of the stomach).
- Minimize overfeeding of rumen-degradable protein.
- Lower total diet protein and improve amino acid balance.
- Add buffers to the ration to improve the rumen environment.
- Add yeast or fungal cultures to improve feed digestibility.
- Add encapsulated niacin, which can help ameliorate heat stress.
- Add additional potassium, sodium, and chloride to the ration to replace these minerals lost by the cow due to increased respiration, sweating, and panting.
- Add propionic acid-based products to the ration to decrease heating and potential spoilage.
- Shift feeding times to the cooler parts of the day.
- Ensure adequate water supply. Daily water intake may increase by 20 to 50 percent under heat-stress conditions. The water system needs to be checked to determine if it is capable of delivering this additional quantity of water. In some herds, the water system may need to be modified to provide for the extra flow and pressure needed to supply the additional water.

These adjustments should be evaluated and considered on individual dairy farms. Even though research results have not always been consistent when these changes were applied under heat-stress conditions, they reflect current understanding of physiological processes.

Increase Use of Fans, Sprinklers, and Other Cooling Systems

Installing and increasing the use of cooling systems is an obvious adaptation to heat stress on livestock, but will bring with it increased expenditures for labor and energy costs. High energy costs in New York may put New York dairy farmers at a disadvantage compared to some other important dairy states. For example, in 2006, the retail electricity price was 5.2 cents per kilowatt-hour in Idaho, the fourth largest dairy state, compared with 16.3 cents per kilowatt-hour in New York. Some of these costs could potentially be offset by expanding the use of renewable-energy sources, such as solar (on large roofs of dairy barns), wind (many dairy operations have large land areas), and electricity production from anaerobic manure digesters (extracting energy from the abundant supplies of manure).

Improve Cooling Capacity of Housing Facilities

Barn design, ventilation systems, and water sprinklers are examples of components that can be altered to reduce heat stress on the cow (Brouk et al., 2005). The cost of these alterations can range from minimal to expensive (e.g., construction cost of a new barn). A dairy barn being built today should be designed for the heat loads expected in this century and not the last century. (For papers and tools that can be used to examine cow facility considerations related to heat stress, see www.ansci.cornell.edu/prodairy.program/facilities.html.) One study evaluated the pounds of milk production that had to be jeopardized by heat stress (per cow per day) to make it economically advantageous to use different fan types and install a tunnel-ventilation system in a number of freestall barn configurations, assuming a five-year payback period for the equipment installation. The study compared these calculations for 20, 40, 60, and 80 days of benefit from the tunnel-ventilation system. The benefit required to break even, in pounds of milk per cow per day, ranged from 2.6 to 6.6 for a 600-cow herd (Gooch et al., 2000). For an economic analysis of this discussion, see Case Study D. Dairy Heat Stress.

Options for Other Livestock

While the economic impacts of heat stress on other livestock species (including poultry, swine, beef, and sheep) in New York will be less than those on dairy cattle, they may still be significant. Most of the commercial poultry production (primarily chickens and turkeys) is already housed in confinement facilities with environmental controls to control temperature. The primary impact on these facilities of increasing temperatures would be higher energy costs. A majority of the swine produced is also housed in similar facilities. The majority of the beef cattle and sheep produced in New York are on extensive pasture-based systems during the summer months when heat stress could be a problem. As long as pasture-based systems continue to be used for these animals, there are limited opportunities for mitigation of heat stress. Simple structures to provide shade could be built. However, these would only be in a small area of the total pasture and would encourage animals to bunch up, thus reducing grazing activity and potential weight gains.

7.4.2 On-Farm Adaptation for Crops

A wide range of climate adaptations will be needed by New York farmers. Many are responses to challenges to maintain basic productivity, while some represent new opportunities in a warmer climate. Both kinds of adaptations may be associated with new costs and/or uncertainties.

Shifting Planting Date

Among farmer adaptation options, changing planting and harvest date can be an effective, low-cost option to take advantage of a longer growing season or to avoid crop exposure to adverse climate (e.g., high temperature stress, low rainfall). Predicting the optimum planting date for maximum profits will be very challenging in a future with increased uncertainty regarding climate effects on not only local productivity but also on supply from competing regions and on market prices.

Diversification of Crop Varieties and Crops

Given uncertainties regarding climate change projections, a more diversified farm may be buffered from negative climate change effects and be able to capitalize on opportunities. Some crops that are currently marginally produced in New York State, such as stone fruits, watermelons, cantaloupes, pears, and other warmer-season products, may become production opportunities for New York farms. A warming climate and longer growing season will also expand the list of winter cover crop options for farmers, and in some situations may open the door to double-cropping (two cash crops in a single year).

Varieties with improved tolerance to heat or drought or those adapted to take advantage of a longer growing season for increased yield will be available for some crop species. New molecular-assisted crop breeding strategies may provide new genetic types more tolerant of environmental stress, pests, and pathogens. However, to date, many such efforts have focused on a few major world food crops, such as corn and wheat, while high-value fruit and vegetable crops important to the New York agriculture economy have received less attention.

Changing varieties, like changing planting date, is a first line of defense for farmers to consider. There are a number of situations in which this might not be an effective strategy, however. Changing varieties for perennial crops, for example, is extremely expensive and new plantings take several to many years to reach maximum productivity. Whenever possible, changing varietal composition of plantings of perennials, such as grapes or apples, should be anticipated when existing stands are in age-related decline and need renewal. Capturing such opportunities will require forward-looking assessment of how climate change will impact the expected lifespan of each new planting. Breeding fruit crops also requires a much longer effort than is required for annuals. Additionally, consumers of fruit crops recognize and value specific varieties (i.e., McIntosh apples or Riesling wine grapes), so it is much more difficult to introduce new varieties of fruit crops than it is for beans, wheat, or corn. Even for annual crops, changing varieties is not always an easy or low-cost option.

In some cases, it may not be possible to identify an alternative variety that is adapted to the new climate, *and* is also adapted to local soils and farming practices, *and* meets local market demand regarding timing of harvest and quality features such as fruit size, color, and flavor. For example, resistance to Stewart's Wilt, a disease projected to increase in frequency and severity with climate change, has been identified in some sweet corn varieties, but in general these varieties do not currently meet market demands for taste, texture, and appearance.

Chemical and Non-chemical Control of Insects, Diseases, and Weeds

Climate change effects on the crop-weed-pest complex may favor the crop in some cases and lead to reduced usage of chemical controls by farmers. However, in general, as the New York climate warms, insect and disease pressure and pesticide applications are likely to resemble current conditions in more southern states. If this assumption is correct, increased pesticide loads are likely unless alternative control measures can be identified. For example, New York conditions currently result in 0 to 5 insecticide applications against lepidopteran (larval, caterpillar-like) insect pests to produce marketable sweet corn; Maryland and Delaware conditions result in 4 to 8 insecticide applications; Florida conditions result in 15 to 32 applications. For sweet corn pests, warmer temperatures translate to increased pest control measures to produce a marketable crop. This is cause for concern, since insecticides and their applications have significant economic costs for growers and environmental costs for society. Additionally, some classes of pesticides (pyrethroids and spinosads) have been shown to be less effective in controlling insects at higher temperatures. Reduction in the negative economic and environmental impacts of a trend for increased pesticide loads will require pre-emptive development of alternative non-chemical weed, insect, and disease-control strategies, as well as improved monitoring and rapid-response plans for targeted control of new weeds or pests before they become widespread.

Choices in types of pest control could also become an issue for debate under projected climate change. It is possible that genetically modified Bt sweet corn varieties will become a more economical choice for farmers if lepidopteran pest pressure in New York fields becomes similar to that in states to the south. It is also possible that genetically modified crops will become more acceptable in the marketplace as a result of the need to respond to higher pest pressure. However, one recent study shows that Bt plants grown in a carbon-dioxide-rich atmosphere had a 25 percent reduction in their insect resistance (Trumble and Butler, 2009).

Organic farmers may face particular challenges due to climate change since they rely heavily on cultural practices and biological control to manage pests, and will have fewer options for rapid response to new pests (Stacey, 2003). On the other hand, these systems may, in some cases, have increased natural resilience (e.g., more natural predators) because of their inherent crop and biological diversity.

Farmers who closely monitor the occurrence of pests in their fields and keep records of the severity, frequency, and cost of managing pests over time will be in a better position to make decisions about whether it remains economical to continue to grow a particular crop or use a certain pest-management technique. Those farmers who make the best use of basic integrated pest management (IPM), such as field monitoring, pest forecasting, recordkeeping, and choosing economically and environmentally sound control measures, are more likely to be successful in dealing with the effects of climate change. Adaptive management is likely to require increased investment in agricultural consultants and skilled employees by farms, as well as applied research and extension programs by universities. Intensive crop and pest monitoring is not free of costs. While this activity has the potential to provide jobs for pest and crop experts as farm consultants, the costs will need to be incorporated into production accounting and planning.

Freeze and Frost Protection for Perennial Fruit Crops

Numerous strategies to avoid damage to spring frost events are well tested and have been recently reviewed (Poling, 2008). These strategies include careful site selection and the use of wind machines, helicopters, heaters, and overhead sprinklers. For mid-winter freeze problems, approaches might include changes in pruning strategies and mulching to insulate the trunk of young plantings. New research will be required to integrate weather forecasts into early-warning systems for extreme events like hard freezes and spring frosts to help perennial fruit crop growers through a phase of climate change transition that may include increased frequency of winter cold-damage risk. These warning systems could be linked to “cold hardening” models (Anisko et al., 1994) by tracking crop susceptibility to damage and the timing of hardening, end of dormancy, and bud break (Seeley, 1996). Also see Case Study A. Frost Damage to Grapes.

Expanded Irrigation Capacity and Other Major Capital Investments

Climate change could require significant capital investment to ensure survival of agricultural businesses or to take advantage of new opportunities. Examples include new irrigation or drainage systems, new planting or harvesting equipment for new varieties, new crop storage facilities, new equipment to allow more timely management, and improved cooling facilities for livestock. The challenge will be strategic investment in relation to the timing and magnitude of climate change.

7.4.3 Adaptation Beyond the Farm: Institutions, Agencies, and Policy

Climate change impacts on crops and livestock will have human health and societal impacts beyond the individual farmer. For this reason, adaptations that involve societal investment or private industry responses are also likely to be necessary.

Technological/Applied Research Developments

Technological/applied research developments might involve seed company development of new varieties and university development of decision-support tools and of cooling and irrigation technologies.

Information Delivery/Extension Systems

Examples of an information delivery/extension system might include delivery of real-time local weather data for integration into farm-management decision-support tools and better integrated pest management (IPM) monitoring of potential invasives. Improved delivery of state-of-the-art weather forecasts will be needed to prepare growers for extreme weather events and can be used for various farm management decision tools. A state- and grower-funded, weather-based pest-prediction network (NEWA) is active in parts of the state providing near real-time pest forecasts (http://newa.cornell.edu). However, many more than the current 50 stations will be needed for adequate coverage of all agricultural areas of the state. Current IPM programs will need to be strengthened and better linked at the regional level.

Locally Available Design and Planning Assistance

Assistance could be made available for farmers or for farm regions to help in designing new heat-resistant barns and on-farm drainage systems.

Disaster Risk Management and Insurance

Current crop insurance programs are not adequate for accurate and uniform assessment of economic losses associated with weather-related disasters. This is particularly true for high-value fruit and vegetable crops, where insurance personnel are not adequately trained on the diverse range of crops grown in the state.

Financial Assistance

Examples of financial assistance include low-cost loans and State and federal cost-share programs for adaptation investments. Many aspects of adaptation are potentially expensive even when solutions are clearly available, such as capital investments for new water management systems or livestock facility renovations to improve cooling capacity.

Major Capital Investments

Major capital investments could be required at a regional or State level and might include new dams or reservoirs and new large-scale flood-control and drainage systems.

Policy and Regulatory Decisions

These could be designed to facilitate adaptation by farmers, to alter regulations, to create financial incentives for adaptation investment, and/or to stimulate local renewable energy production. For example, Section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) currently allows the U.S. Environmental Protection Agency to approve emergency use of an unregistered pesticide in cases where new pests create several specific types of crises. Section 24C discusses Special Local Need applications, which are a second method to address crisis pesticide situations under the Act. Both of these processes, which can be initiated by land-grant universities, faculty, or industry groups, are likely to be used to address new agricultural pest arrivals under climate change conditions. A 24C pesticide application is reviewed on a state-by-state basis and requires an environmental risk assessment by a State agency (e.g., the New York State Department of Environmental Conservation), thus adding burden to State regulatory agencies in addition to adding pesticide load to the New York State environment.

Research on New Crops and Pests

Building adaptive capacity for the agriculture sector will require investment in new information, crops, and adaptation strategies (See Knowledge Gaps, Section 7.6.3, in Conclusions).

7.4.4 Co-benefits, Unintended Consequences, and Opportunities

Adaptations made to address specific climate change vulnerabilities may have additional effects beyond their primary intentions. In some cases these may raise new problems, while in others it is possible to design actions with multiple simultaneous benefits and to provide opportunities to New York State farmers.

Co-benefits

Climate change may provide an incentive for farmers and consumers to take advantage of some adaptation strategies that benefit both the farmer and the environment. Some of these may eventually be applicable to carbon-offset payments in emerging carbon-trading markets. New York State farmers could consider any or all of the following actions:

- Conserve energy and reduce greenhouse gas emissions (increase profit margin and minimize contribution to climate change).
- Increase soil organic matter (this not only improves soil health and productivity, but because organic matter is mostly carbon derived from carbon dioxide via plant photosynthesis, it reduces the amount of this greenhouse gas in the atmosphere).
- Improve nitrogen use efficiency (synthetic nitrogen fertilizers are energy intensive to produce, transport, and apply, and soil emissions of the greenhouse gas nitrous oxide increase with nitrogen fertilizer use).
- Improve manure management (reduces nitrous oxide, methane, and carbon dioxide emissions; also can be used as renewable energy in manure digesters).

Unintended Consequences

Described here are potential unintended consequences of adaptation strategies, which could potentially have cascading negative effects on rural economies.

Increased Water Use and Chemical Loads to the Environment
Increases in water and chemical inputs will not only increase costs for the farmer, but may also have society-wide impacts in cases where the water supply is limited, by increasing the reactive nitrogen and pesticide loads to the environment or by increasing the risks to food safety and increasing human exposure to pesticides.

Increased Energy Use
Higher energy use (and its attendant greenhouse gas emissions) may be associated with some adaptation strategies. Examples include increased running of cooling fans in livestock facilities, more energy to pump irrigation water as more farmers expand irrigation capacity (and in some cases pump from deeper wells), and increased energy use associated with greater use of products that are energy intensive to manufacture, such as some fertilizers and pesticides.

Changes in Land Use
Such shifts could result from changes in cropping systems and other farm adaptations. Harvesting of wooded areas for biofuel crops is possible, or increased diversion of corn acreage for biofuel markets. Such effects can be averted with appropriate strategic planning, and efforts towards this end have been initiated in the *Renewable Fuels Roadmap* (NYSERDA, 2010). Land clearing for expansion of food or forage crop acreage may occur, particularly if other production regions of the country are harder hit by climate change than New York due to water shortages or other factors.

Cascading Negative Effects on Rural Economies
These may be likely where farmers lack capital for adaptation (see Equity and Environmental Justice Considerations, Section 7.5).

Opportunities

Opportunities for NYS farmers could include the following:

- Possible extension of agricultural production on idle and under-used agricultural lands due to shifts in comparative advantage vis-à-vis other regions (see Chapter 4, “Water Resources”).
- Enter the expanding market for renewable energy using marginal land (e.g., wind energy, solar, biomass fuels, energy through anaerobic digestion of livestock manures and food processing wastes).
- Increase consumer support—from households to large institutional food services—of local “foodshed” networks, which can reduce greenhouse gas emissions from transportation of agricultural goods.

7.5 Equity and Environmental Justice Considerations

In New York State, there is a range of equity and environmental justice issues at the intersection of climate change and agriculture. Particular agricultural sectors, regions, and crops will be more at risk from exposure to climate change and burdened by the effort and costs associated with adaptation measures. Meeting the costs of adaptation to climate change will put additional stresses on the fragile and economically important dairy industry in the state. Regional vulnerabilities include farmers on Long Island facing a disproportionate risk of crop damage from sea level rise, saltwater intrusion, and coastal flooding. Finally, certain crops have disproportionate vulnerabilities, such as perennials for which the cost and economic risk of changing crops as an adaptation strategy is sometimes much higher than for annual crops.

Of these regions and groups, those most vulnerable to climate change include small family farms with little capital to invest in on-farm adaptation strategies, such as new infrastructure, stress-tolerant plant varieties, new crop species, or increased chemical and water inputs. Small family farms[2] also are less able to take advantage of cost-related scale economies associated with such measures. Small farmers, particularly those in the dairy sector, already face severe competitive pressures due to rising production costs and flat or declining commodity prices. Indeed, as noted earlier, current trends suggest that the total number of dairy farms will decline from approximately 7,900 in 2000 to 1,800 in 2020, with most of this decline resulting from closure or consolidation of smaller farms[3] in New York State (LaDue, Gloy, and Cuykendall, 2003; USDA, 2007). Climate change is likely to exacerbate cost pressures on small farmers, particularly if adaptation requires significant capital investments, thus accelerating trends toward consolidation within the industry. Survival for many smaller farms will hinge, in part, on making good decisions regarding not only the type of adaptation measures to take but also in the timing of the measures. The most vulnerable farmers will be those without access to training about the full range of strategies or those who lack adequate information to assess risk and uncertainty.

In addition to supply-side dimensions, climate change also may impact agricultural demand. These effects can be associated with both long-term regional disinvestment such as out of high-risk areas (floodplains), or one-time extreme events in areas with high demand for New York State produce (like a hurricane in the New York metropolitan region). These conditions may disrupt supply chains, close retail centers, or otherwise cut consumer access to markets, with especially detrimental effects on low-income or mobility-constrained residents. Low-income farmers with insufficient information and training or without access to credit or infrastructure are particularly at risk when conditions demand immediate flexibility, such as requiring quickly lining up alternative supply lines and retail locations.

Under such conditions, rural, resource-dependent communities may feel pressure to supplement incomes or diversify their business beyond agriculture, but may lack the training or capital necessary to engage such strategies. Decreasing yields and the high costs of adaptation may translate into significant downstream job losses and cascading economic effects across rural communities. Low-wage, temporary, seasonal, and/or migrant workers are particularly exposed to these shifts.

Examining equity in adaptation involves evaluating existing vulnerabilities, but it also requires evaluating the unintended outcomes, externalities (secondary consequences), and emergent processes of specific adaptation strategies. Successful adaptation by individual farmers or regions may create downstream inequities. As some farmers successfully adapt, other farmers may experience relative increases in inequality related to rural income and agricultural productivity. Certain industries (such as the grape and wine industries) also may consolidate in such ways that it becomes difficult for smaller businesses to enter the market. Increasing chemical inputs, such as fertilizers and pesticides, may create or exacerbate inequitable distributions of human health burdens, or negatively affect waterways, disproportionately impacting low-income or natural resource-dependent communities involved in hunting- and fishing-related revenue. Furthermore, degrading land and community health could drive down property values, exacerbating geographic inequities. Finally, increasing natural resource use, whether it is water for irrigation or energy for cooling, is likely to raise utility prices. These increases are felt the most by low-income families who proportionally spend more on these basic goods than middle- and upper-income families.

Addressing and avoiding spillover effects in the implementation of adaptation measures requires engaging local communities and agricultural managers in each stage of the planning process. This includes mechanisms for expressing and addressing property disputes and conflicting claims to resources, collaborative regional planning across sectors and communities, and training or retraining to provide information regarding strategies and best practices. In particular, adaptation strategies focused at regional or state scales have the capacity to marginalize local actors who are unable to capitalize on social or economic networks or access policymaking procedures.

Equity issues should be considered along every part and process of the agriculture food-supply chain. For low-income communities throughout the state, the connection between climate change and issues of food justice is an area of growing concern. Food justice issues, including lack of access to grocery stores in lower-income urban and rural communities, and inability of lower-income individuals to afford healthy, fresh foods, may be exacerbated by climate change. For example, climate stress on agriculture could affect the quality, accessibility, and affordability of local produce. This has implications for food security among low-income groups, those communities with fragile connections to markets offering nutritional options, or those otherwise burdened by pre-existing poor nutrition. Increased incidence of extreme heat or prolonged droughts may also affect the cost structures and productivity of community gardens and other local food production systems that serve lower-income urban areas.

7.6 Conclusions

Those aspects of climate change already occurring in New York or anticipated within this century that have known effects on crops, livestock, weeds, insects, and disease pests have been the primary focus of this ClimAID analysis. **Table 7.2** summarizes selected climate factors as linked to vulnerabilities or opportunities for the agriculture sector and adaptation strategies. A qualitative level of certainty is assigned to each of these components. The relative timing of when climate change factors and impacts are anticipated to become pronounced is also indicated, as this will be critical in setting priorities for adaptation. The table illustrates an approach and a possible useful tool for setting priorities and for climate action planning, but is not meant to be comprehensive. It can and should be modified for specific purposes and as new information and expertise become available.

Below, key findings regarding vulnerabilities and opportunities, adaptation options, and knowledge gaps are highlighted and discussed in more detail.

7.6.1 Main Findings on Vulnerabilities and Opportunities

The climate risks, crop or livestock responses, and relative certainties indicated in **Table 7.2** have been integrated to develop this list of main vulnerabilities and opportunities.

- *Summer heat stress.* Warmer summers will bring an increase in the frequency of days that exceed high temperature thresholds negatively affecting crop yields, crop quality and livestock productivity. The ClimAID analysis for the dairy industry indicates significant milk production declines by mid- to late century; the high milk-producing cows being used today are particularly vulnerable.
- *Increased weed and pest pressure* associated with longer growing seasons (allowing more insect generations per season and more weed seed production) and

warmer winters (allowing more over-wintering of pests) will be an increasingly important challenge. New York farmers are already experiencing earlier arrival and increased populations of some insect pests, such as corn earworm.

- *Risk of frost and freeze damage* continue, and these risks are exacerbated for perennial crops in years with variable winter temperatures. For example, midwinter-freeze damage cost Finger Lakes wine grape growers millions of dollars in losses in the winters of 2003 and 2004. This was likely due to de-hardening of the vines during an unusually warm December, increasing susceptibility to cold damage just prior to a subsequent hard freeze. Another avenue for cold damage, even in a relatively warm winter, is when there is an extended warm period in late winter or early spring causing premature leaf out or bloom, followed by a frost event. This latter phenomenon may explain, in part, the lower apple yields in summers following warm winters. There is a low level of certainty regarding whether variability per se associated with recently observed freeze damage is a component of overall climate change in New York State (**Table 7.2**). This, however, will be a concern for tree fruit crops and other perennial species, at least in the short term (the next few decades).
- *Increased risk of summer drought* (defined here as crop water requirements exceeding water available from rainfall plus stored soil water) is projected for New York by mid- to late century. Compared to some agricultural regions, such as the western U.S., however, New York State is likely to remain relatively water rich. As indicated in **Table 7.2**, projections for future rainfall and drought severity are not as certain as those for temperature.
- *Increased frequency of heavy rainfall events and flood damage*. In addition to direct crop damage, wet springs delay planting and subsequently delay harvest dates. For some fresh market vegetable growers, much of their profit is based on early season production so this can have substantial negative economic effects. Use of heavy equipment on wet soils leads to soil compaction, which subsequently reduces soil water-holding capacity, water infiltration rates, root growth, and yields.
- *New crop options*. While climate change will add to the physical and economic challenges of farming in New York, there are likely to be new opportunities as well as vulnerabilities, such as developing new markets for new crop options that will come with longer growing seasons and warmer temperatures. The expansion in New York of the non-native and cold-sensitive European (*Vitis vinifera*) white wine industry over the past 40 years has benefited from the reduced frequency of severe cold winter temperatures over this time period. European red grape varieties such as Merlot could benefit with additional warming, as could other crops such as peaches, watermelon, and tomato. Some New York field corn growers are already experimenting with slightly longer growing-season varieties that produce higher yields.

Table 7.2 Climate factors, vulnerabilities and opportunities, and adaptation strategies for agriculture in New York State

Climate Factor	Climate Certainty	Associated Vulnerabilities/Opportunities	Certainty*	Timing	Adaptation Strategies	Adaptation Capacity
Increasing carbon dioxide	High	Variable plant response affecting growth, competitiveness, yield. Under optimum conditions, yield increases are possible. Some C_3 weeds will benefit more than crops and be more resistant to herbicides.	High, but large variation in effects depending on other environmental constraints to plant growth	Now	Minimize water, nutrient constraints to crop growth to take full advantage of any beneficial effects. Develop varieties that take advantage of the effect of increases of carbon dioxide concentrations. Increased weed control and new approaches to minimize chemical inputs.	Moderate
Warmer summers; longer growing seasons	High	*Crops and weeds* Opportunities to obtain higher yields with current crops and grow higher-yielding varieties and new crops. Eventual double-cropping opportunities. Weeds will grow faster and will have to be controlled for longer periods. Increased seasonal water and nutrient requirements.	Moderate to high	Now, with some effects occurring later this century	Cautiously explore new varieties, new crops; develop markets for new crops. Increased weed control and new approaches to minimize chemical inputs. Increased water and fertilizer applications.	High
		Insects More generations per season; shifts in species range.	Moderate to high	Now	Better regionally coordinated monitoring through integrated pest management. Increased pest control. Proactively develop new approaches to minimize chemical inputs.	Moderate

Climate Factor	Climate Certainty	Associated Vulnerabilities/Opportunities	Certainty*	Timing	Adaptation Strategies	Adaptation Capacity
Increased frequency of summer heat stress	High	*Livestock (dairy)* Reduced milk production; reduced calving rates.	High	Serious by mid-century	Increase cooling capacity of existing dairy barns. Increase use of fans and sprinklers. Change feed rations. Provide plenty of water. Design new barns based on projected future heat loads.	Moderate to High
		Crops Could negatively affect yield or quality of many cool-season crops that currently dominate the agricultural economy, such as apple, potato, cabbage, and other cole crops.	High	Serious by mid-century	New heat-tolerant varieties when available. Change plant dates to avoid stress periods. Explore alternative crops.	Moderate to high
Warmer winters	High	*Crops* Could increase productivity or quality of some woody perennials (e.g., European wine grapes), while by mid to late century negatively affecting those adapted to current climate (e.g., Concord grape, some apple varieties). More winter cover crop options. Depending on variability of winter temperatures, can lead to increased freeze or frost damage of woody perennials	High	Now, with some effects occurring later in century	Explore new cash crops and varieities; explore new cover crop options.	High
					Better freeze and frost warning systems for farmers; new winter pruning strategies.	Moderate
		Insect and weed pests Increased spring populations of marginally overwintering insects. Northward range expansion of invasive weeds.	High	Now	Better regionally coordinated monitoring through integrated pest management. Increased pest control. Proactively develop new approaches to minimize chemical inputs.	Moderate
Increased frequency high rainfall, flooding	High	Delays in spring planting and harvest, negatively affecting market prices. Increased soil compaction, which increases vulnerability to future flooding and drought. Increased crop root disease, anoxia and reduced yields. Wash-off of applied chemicals.	High	Now	Increase soil organic matter for better drainage. Shift production to more highly drained soils. Install tile drains. Shift to flood-tolerant crops. Change plant dates to avoid wet periods. Increased disease control and new approaches to minimize chemical inputs.	Low to moderate; some options are expensive
Increased summer drought	Moderate	Reduced yields and crop losses, particularly for rain-fed agriculture. Inadequate irrigation capacity for some high-value crop growers.	Moderate to high	Mid to late century	Increase irrigation capacity. Shift to drought-tolerant varieties. New infrastructure for regional water supply.	Moderate, assuming capital available and economics warrant investment
Changes in hydrology, groundwater	Moderate	Dry streams or wells in drought years. Increased pumping costs from wells.	Moderate	Mid to late century	Deeper wells, new pumps.	Moderate
Frequency of extreme events	Low	Major crop and profit loss due to hail, extreme temperatures, flooding, or drought. Particularly devastating if extreme events occur in clusters.	Moderate to high	Unknown	New climate science research to determine current trends and develop early-warning systems for farmers.	Moderate
Increased seasonal variability	Low	Crop damage due to sudden changes, such as increased freeze damage of woody plants as a result of winter variability and loss of winter hardiness or premature leaf-out and frost damage.	Moderate	Now, but not clear if part of climate change	New climate science to determine relation to climate change and better predict variations.	Low
Changes in cloud cover and radiation	Low	Important factor affecting plant growth, yields and crop water use. Cloudy periods during critical development stages reduces yields.	High	Unknown	New climate science research to determine current trends and better model these factors.	Low to moderate

* Climate certainty in this table is qualitatively consistent with more quantitative assessments in Chapter 1, "Climate Risks," and formulated from expert opinion from chapter authors and stakeholder groups.

7.6.2 Adaptation Options

Adaptation options are available for many of the vulnerabilities summarized above and listed in **Table 7.2**. A challenge for farm managers, however, will be uncertainties regarding the optimum timing of adaptation investment, and the optimum magnitude of adaptation investment relative to the risks. Also, adaptations will not be cost- or risk free, and inequities in availability of capital or information for strategic adaptation may become an issue to resolve at the policy level (see also Knowledge Gaps, 7.6.3, below).

- *Improved cooling capacity of livestock facilities*. Increasing the summer use of fans and sprinklers for cooling will be an early adaptation strategy for the dairy industry. New barns should not be designed based on the 20th century climate, but rather for the increased heat loads anticipated in the 21st century.

- *Increased pest control and new approaches to minimize chemical inputs*. While we can look to more southern regions for control strategies for weeds and pests moving northward, these may not always be directly transferable or desirable for our region, particularly if they involve substantial increases in chemical loads to the environment. New policies and regulatory frameworks may become necessary, involving good communication among farmers, IPM specialists, and State agencies.
- *Supplemental irrigation* will be a first-step adaptation strategy in New York, and investment in expanded irrigation capacity will likely become essential for those growing high-value crops by mid- to late-century. This assumes that summer droughts do not become so severe as to dry up major surface and groundwater supplies. Since New York does not currently have a significant regional irrigation water supply infrastructure, state-wide investments in such may need to be considered by mid- to late-century.
- *Drainage for wet conditions*. Adaptations for wet conditions include maintaining high soil organic matter and minimizing compaction for good soil drainage. In some cases this will not be sufficient and installation of tile drainage systems will be warranted, a costly adaptation strategy. Shifting crop production to highly drained soils is an effective adaptation, but would then require irrigation for the expected drought periods.

7.6.3 Knowledge Gaps

With timely and appropriate proactive investment in research, as well as support for monitoring and information delivery systems, and policies to facilitate adaptation, the agriculture sector of the New York economy will have the necessary tools for strategic adaptation to meet the challenges and take advantage of any opportunities associated with climate change. Some relevant needs include the following:

- *Non-chemical control strategies for looming weed and pest threats* are needed, as well as enhanced regional IPM coordination, and monitoring and rapid-response plans for targeted control of new weeds or pests before they become widespread.
- *New economic decision tools for farmers* are needed that will allow exploration of the costs, risks, benefits, and strategic timing of various adaptation strategies (e.g., the timing of investment in new irrigation equipment) in relation to various climate change scenarios and potential impacts on crops and livestock.
- *Sophisticated real-time weather-based systems for monitoring and forecasting stress periods and extreme events* are needed. Current guidelines for many agricultural practices are based on outdated observations and the assumption of a stationary climate.
- *Crops with increased tolerance to climate stresses* projected for our region, with emphasis on horticultural or other crops important to the New York economy but not currently being addressed by commercial seed companies, will be needed, and can be developed using conventional breeding, molecular-assisted breeding, or genetic engineering.
- *New decision tools for policy-makers* are needed that integrate economic, environmental, and social equity impacts of agricultural adaptation to climate change.
- *Regional climate science and modeling research* is needed to help farmers discern between adverse weather events that are part of normal variability and those that are indicative of a long-term climate shift warranting adaptation investment. There are some climate factors, such as increased climate variability and increased frequency and clustering of extreme events, that could potentially have severe negative impacts on the agriculture industry, but our current level of certainty about these climate factors is low.

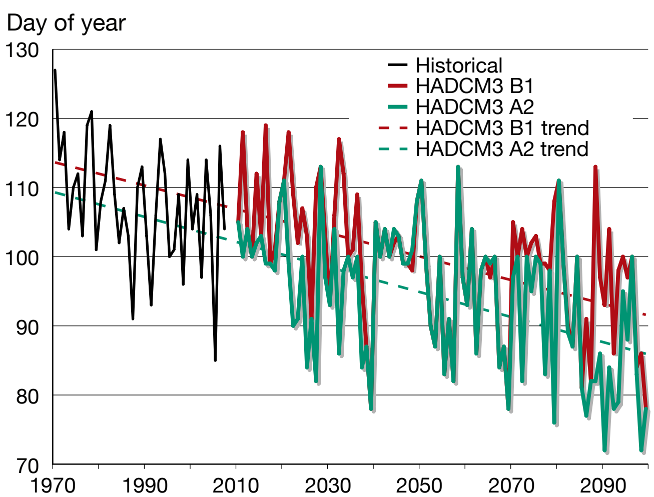
Case Study A. Frost Damage to Grapes

Warmer winters bring opportunities with the potential to introduce higher-value but less cold-hardy fruit varieties and may in the long term be beneficial to European wine grapes (*V. vinifera*) that are not native to the region. However, particularly in the near term, challenges associated with cold injury to crops may be problematic, as explored in this ClimAID analysis. In recent years these events have cost the New York agriculture industry millions of dollars (Levin, 2005). Warmer temperatures at the beginning of winter reduce cold hardiness and can raise the probability of mid-winter damage. In late winter or early spring (after the winter-chilling requirement has been met), a prolonged warm period may lead to premature bud break and increased spring frost vulnerability. Decisions related to variety selection thus require information on recent trends in winter-chill accumulation and projections of these values into the future. Assessing changes in spring-frost vulnerability is also necessary; typically, the lower the winter-chill requirement, the higher the risk of early bud break. Projecting such changes is important for New York State agriculture to meet its full economic potential in the context of a changing climate.

The date of the last spring freeze is a potential hazard for plants that have broken bud dormancy and begun active growth. **Figure 7.2** shows historical and projected values for last freeze dates at Fredonia. Fredonia's climate is currently moderated by its proximity to Lake Erie, making it a favorable location for tree fruit production and concord grapes. Since 1971, the date of the last occurrence of 28°F (the last spring freeze) at Fredonia has shifted from approximately April 25 (day 115) to April 15 (day 105). Overnight temperatures less than 28°F are now less likely to occur during April. This trend toward earlier last-freeze dates is expected to continue into the future. For example, based on downscaled minimum temperatures from the Hadley Centre Coupled Model, version 3 (HadCM3), under the low-emissions B1 scenario, the steady shift in the date of the last freeze reaches April 5 (day 95) by the end of this century. Under the high-emissions A2 scenario, this date moves into March, with the last freeze expected to occur on day 85 (March 26). This is nearly a month earlier than the 1971 date.

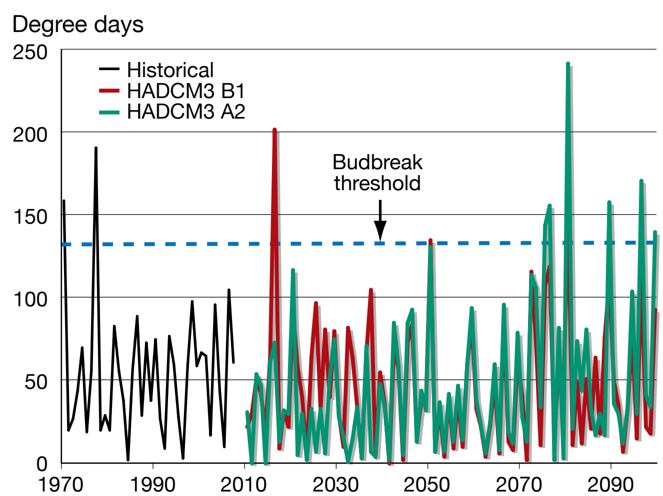
The projected trend for an earlier date of last frost does not necessarily reduce risk of spring frost damage if grapes are responding to an earlier spring with earlier leaf out and bloom (Wolfe et al., 2005). In fact, frost risk could possibly increase with climate warming because leaf and flower emergence are driven by a cumulative factor—the accumulation of daily average temperatures above 50°F (degree-days)—but it just takes a single frost event, occurring within the bounds of natural spring temperature variability, to cause severe damage.

Figure 7.3 shows the recent historical and projected growing degree-day accumulation in the interval preceding the last spring freeze for a region in western New York. It compares this to a threshold line of 133 degree-days, the average growing degree-days required for bud break of Concord grapes. Historical data from the 1971–2007 period indicate that, on average, only 50 growing degree-days accumulate prior to the last spring freeze, and the 133 degree-day threshold leading to bud break before the last frost was observed in only two growing seasons. There is some indication that the average value of pre-frost growing degree-days begins to increase in the post-2060 period, and there is a



Note: Black datapoints are the observed patterns from 1970 to 2007. Red trends are simulated based on the lower-emissions B1 scenario projections; green trends are simulated based on the higher-emisisons A2 scenario projections. Results are broadly consistent with other GCMs used in ClimAID.

Figure 7.2 Changing date of the day of last frost; vertical axis indicates the number of days after January 1 (Julian Day)



Note: The dashed blue horizontal line represents a threshold cumulative degree-day threshold that would lead to bud break prior to the last spring frost for Concord grapes, based on a 28-year phenology dataset in the Fredonia region. Those years exceeding the threshold are years with high risk of frost damage. Degree days for budbreak. Results are broadly consistent with other GCMs used in ClimAID. Source: Alan Lakso, personal communication, October 2009

Figure 7.3 Degree-day accumulations above 50°F occurring prior to the last frost dates shown in Figure 7.2

notable increase in year-to-year variability. For the higher-emissions scenario (A2), this results in a significant increase in the frequency of years near the end of the century with risk of frost damage—sufficient degree-day accumulation prior to the last frost to cause bud break (i.e., the 133 degree-day accumulation threshold line is crossed).

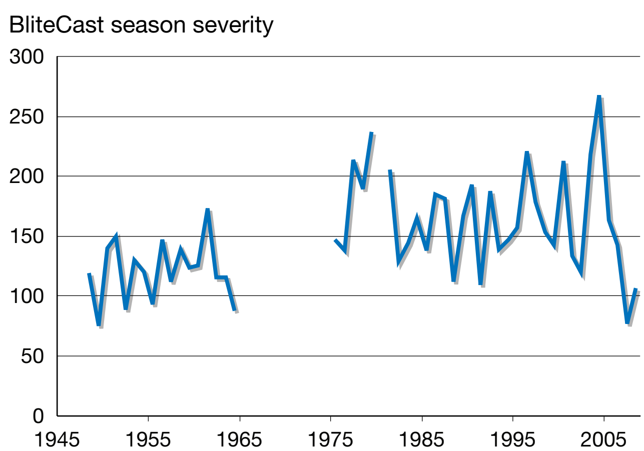
The projections in **Figure 7.3** reflect the interaction between climate change effects on earliness of bud and fruit development and the date of last spring frost, within the context of spring temperature variability. Results suggest that spring frost risk will not only persist, but could even increase by late century. Numerous strategies for avoiding damage from spring frost events are well tested and reviewed (Poling, 2008). Section 7.4.2 provides on-farm crop adaptation strategies and more details regarding freeze- and frost-protection strategies for perennial fruit crops.

Case Study B. Potato Late Blight

The potato late blight disease is a severe disease caused by the pathogen *Phytophthora infestans* (Fry, 2008). This is the same disease that caused the Irish potato famine starting in the 1800s. The disease is most severe in moderately cool, wet weather. Extended periods (typically more than 10 hours) of leaf wetness with moderate temperatures (54–72°F) are particularly favorable to the pathogen and lead to severe disease. This disease is a problem all over the world where potatoes are grown. There are about 20,000 acres of potatoes in New York. Based on the estimate that chemical costs are \$250 to \$500 per acre per year (Haverkort et al., 2008), New York growers spend \$5–10 million annually on fungicides to protect their crops from this disease.

Climate change could influence the severity of potato late blight disease in a variety of ways. Elevated temperatures could have the indirect effect of reducing the duration of wet periods, thus lessening disease severity. Less frequent rainy periods might also reduce the number and duration of wet periods, also lessening disease severity. Alternatively, heavier rainfall events would remove protective fungicide from the foliage and thus increase the disease severity. Also, disease might begin earlier and/or be more prolonged with climate change.

This ClimAID case study uses an extensively tested mechanistic simulation model (Andrade-Piedra et al., 2005) of potato late blight to estimate the impacts of New York climate change on fungicide use for control of this disease. The model uses weather data to predict pathogen development and is currently used to provide disease severity forecasts for farmers. The model also contains a sub-model of fungicide dynamics (Bruhn and Fry, 1982a; Bruhn and Fry, 1982b), so that the amount of fungicide necessary to suppress disease in any given environment can be assessed. We compare the fungicide load for protecting potato plants under current weather conditions with the fungicide load required for a similar level of control under weather conditions projected during the coming century, under the business-as-usual (A2) and lower (B1) emissions scenarios.



Note: Higher values are associated with wet and humid conditions and indicate greater danger of disease development.

Figure 7.4 BliteCast severity values based on historical weather records for Rochester

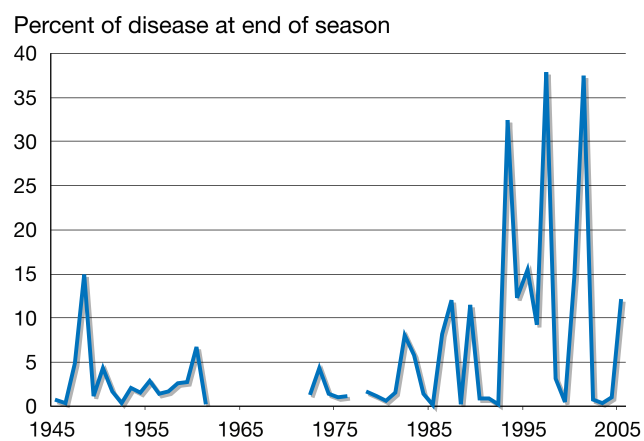


Figure 7.5 Likely prevalence of potato late blight disease forecast by BliteCast at the end of the season, considering both weather conditions and expected crop-management responses

First, weather data for Rochester from 1947 to 2008 were used to investigate the impact of historical weather on severity index values for potato late blight (i.e., potential for disease) predicted by the disease severity model, BliteCast (**Figure 7.4**). In general, during the latter part of this period (1977–2008) weather conditions led to higher disease severity. This period also showed greater year-to-year variability compared to 1947–1966.

The percent of potatoes with disease at the end of the growing season and the predicted amount of fungicide necessary to suppress the disease were also examined for the historical period. These predictions were obtained using the complex simulation model of the potato late blight disease (Andrade-Piedra et al., 2005). This model identifies the impact of weather on disease development and also identifies the impact of fungicide on disease development (Bruhn and Fry, 1982a). In agreement with the BliteCast severity index values (**Figure 7.4**), the percent of potatoes with disease was generally more severe with greater variance in the later (1977–2008) period compared to the earlier (1947–1966) period (**Figure 7.5**). Additionally, the amount of fungicide necessary to achieve adequate suppression of disease in the later period was greater than in the earlier period (**Figure 7.6**).

Using the same statistical models and approach as for the historical analysis describe above, projections of future disease severity and fungicide application needed for control were computed for the period 2040–2065. The models consist of three climatological input parameters: hourly temperature, hourly relative humidity, and daily precipitation to predict potato blight severity. Except for humidity, these variables were available from the standard suite of ClimAID climatological parameters discussed in Chapter 1, "Climate Risks." For humidity, the ClimAID Climate Team employed a statistical downscaling technique similar to that used for precipitation applied to global climate model grid-scale projections of specific humidity from five models (GISS, GFDL, UKMO, CCSM, and MIROC). Observed values of temperature and relative humidity at Rochester were converted to specific humidity and the delta change (1970–1995 versus 2040–2065) method applied to the specific humidity projections from the global climate models. The delta change in specific humidity was then applied to the three-hourly observations. The corresponding downscaled three-hourly temperatures were also obtained and used to calculate relative humidity projections. A cubic spline was fit to the three-hourly data to obtain the hourly resolution required by the potato late blight model.

Averaged across the five models, the projected BliteCast seasonal severity index for the A2 and B1 emissions scenarios for 2040–2065 (data not shown) was similar to the observed values in the 1995–2008 period of **Figure 7.6**. Despite an increase in temperature in both scenarios (favoring disease), relative humidity actually decreases slightly in the projections and, as a result, disease severity shows little change. Nonetheless, projected fungicide application rates required for adequate control (based on the models by Andrade-Piedra et al., 2007 and Bruhn and Fry, 1982a) significantly increased in most years in the higher-emissions A2 scenario (**Figure 7.7**). On average, the

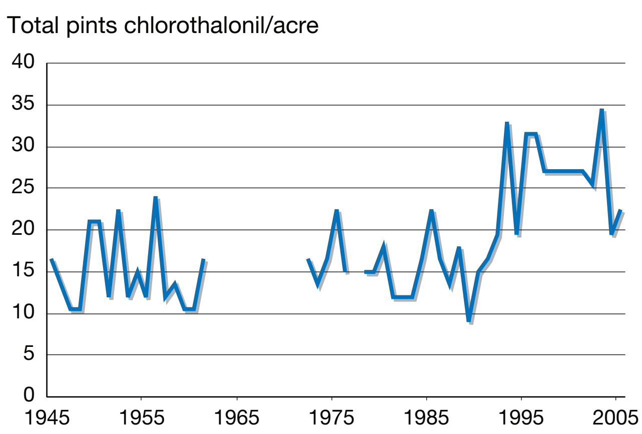


Figure 7.6 Total fungicide application recommended by BliteCast for each season of the historical record

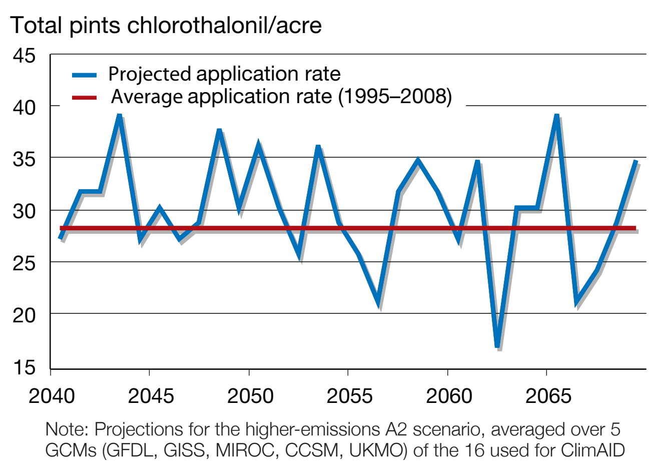


Figure 7.7 Projected total seasonal fungicide (chlorothalonil) application rate required for control of late blight for years 2040–2065 in comparison to the average application rate required for control during the 1995–2008 period

application rates for the 2040–2065 period under the A2 scenario increased to 34 pints per season, i.e., higher than the average of 28 pints for the latter half of the historical period (1995–2008, **Figure 7.6**). For the lower-emissions B1 scenario, the simulations suggest that application rates will remain similar—less than 30 pints—to the rates observed during the 1995–2008 historical period.

This analysis projects a significant increase in fungicide application required for control of late blight in 2040–2065 under the higher-emissions A2 scenario compared to today. There are several possible explanations regarding why the simulation projects an increased need for fungicide application, despite little change in the projected BliteCast severity index. Warmer temperatures in the A2 scenario may speed up pathogen development and, perhaps, cause disease outbreak to occur earlier, thus expanding the duration of required fungicide application without necessarily affecting severity values. Fungicide effectiveness is particularly sensitive to the occurrence and amount of precipitation and resulting wash-off of residual fungicide from the plant surface. This is not captured by the BliteCast seasonal severity index, but it is captured by the fungicide application models.

Case Study C. Drought

New York currently benefits from a moderately humid climate with a relatively uniform distribution of precipitation throughout the year. However, a considerable amount of winter precipitation is lost as runoff from saturated soils, and summer precipitation is

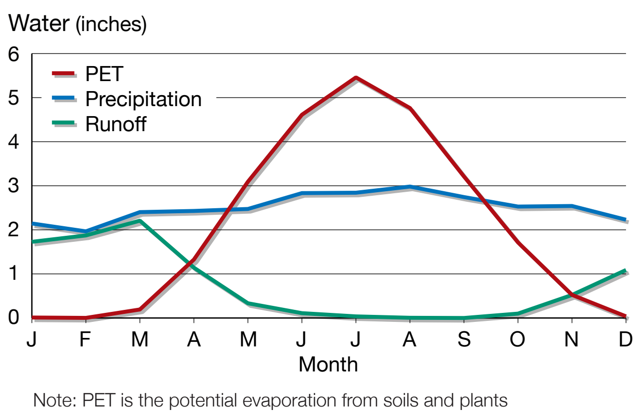


Figure 7.8 Historical (1901–2006) average monthly soil-water balance parameters at Rochester[6]

not, on average, adequate to meet all potential evapotranspiration (PET) of a fully developed crop canopy or other dense vegetation (**Figure 7.8**). Depending on soil-water storage capacity, timing of rainfall, and crop growth stage, supplemental irrigation is currently warranted in many years to fully meet crop water requirements for maximum yield (Wilks and Wolfe, 1998). This case study examines the effect of climate change on future summer water deficits in seven climatic regions (**Table 7.3**) chosen because they had more than 100 years of weather records for evaluating drought frequency. **Figure 7.9** provides a graphical representation of three of these regions: Indian Lake (Adirondacks, northern New York with a relatively wet climate), Elmira (southern New York), and Rochester (western New York, an area with major production of high-value fruit and vegetable crops as well as dairy).

For this analysis, the ClimAID Climate Team provided a tailored product, in which climate projections from five global climate models (GFDL, GISS, MIROC, CCSM, and UKMO) were used for calculation of the Palmer Drought Severity Index (Palmer, 1965). These results are used to estimate seasonal water deficits. The water deficit index values (in inches of water) in **Table 7.3** and **Figure 7.9** were calculated from PET (June to September) minus precipitation (Pcp), Runoff, and available soil water (ASW) (the amount of total soil water stored that plants can extract without negative effects on growth):

$$\text{Deficit}_{\text{jun-sep}} = \text{PET}_{\text{jun-sep}} - (\text{Pcp}_{\text{jun-sep}} - \text{Runoff}_{\text{jun-sep}} + \text{ASW})$$

It is important to note that PET provides an estimate of water demand by mature plants at or near full canopy ground cover (i.e., maximum light interception and transpiration potential). This analysis assumes that actual evapotranspiration is equal to potential water demand for the entire June through September period. This is most applicable to perennial plants, grasslands, and ground covers, but tends to overestimate water deficits for early (June) or late (September) parts of the growing season for annual row crops, when actual crop water demand is less than PET because plants have reduced transpirational surface (leaf) area. Future planned analyses, discussed in more detail at the end of this section, will address this issue for row crops.

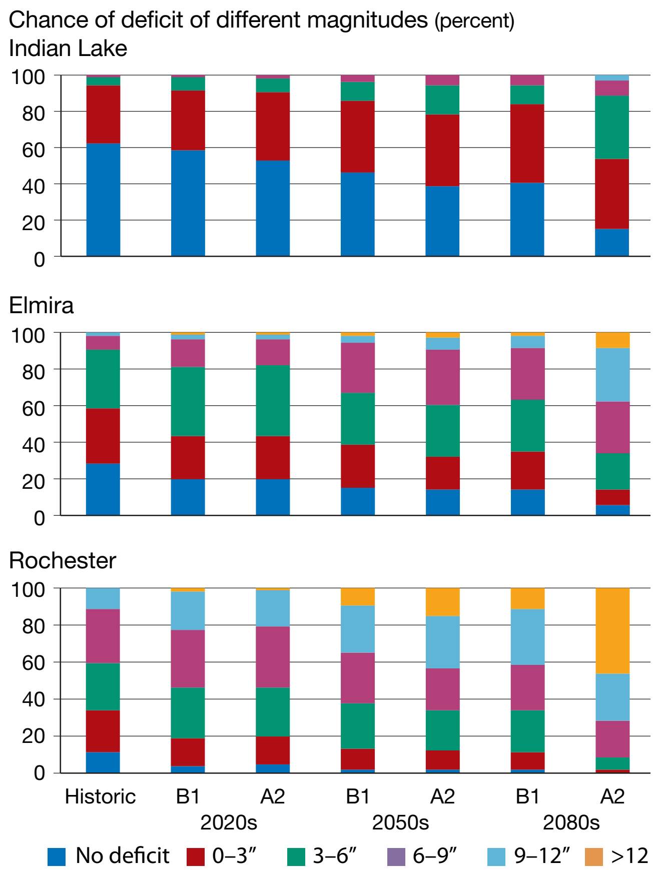
Maximum soil-water storage of 6 inches was assumed in the original Palmer Drought Severity Index calculations, and, in New York State, soils often begin the growing season in June near this level. Maximum available soil water was assumed to be half of total stored water, or 3 inches. This was based on prior work from many regions that has documented that, for many crops, depletion of soil water below 50 percent of maximum is a threshold at which plants become stressed and irrigation is recommended to maintain growth and productivity.

Warm season water deficits vary across the state, primarily due to variations in summer precipitation and summer temperatures used to calculate PET (**Table 7.3**). Current June through September cumulative precipitation averages 14.4 inches across the state for the seven weather stations used in this analysis, with a high of 16.1 inches in Port Jervis and a low of 11.4 inches in Rochester. In general, summer precipitation decreases from east to west across the state and is particularly low along the shoreline of Lake Ontario in the western half of the state. The cumulative deficit from June through September currently averages 2.1 inches for the seven stations representing the state,

		June to September Average Temperature °F						
Re-gion	Station	His-torical	B1; 2020s	A2; 2020s	B1; 2050s	A2; 2050s	B1; 2080s	A2; 2080s
1	Rochester	66.9	69.2	69.2	70.7	71.9	71.8	75.5
2	Port Jervis	68.5	70.5	70.7	72	73.1	72.9	76.2
3	Elmira	67.3	69.5	69.6	71	72.2	72.1	75.7
4	NYC	72.6	74.6	74.7	76.1	77.2	77.1	80.3
5	Albany	67.4	69.4	69.6	70.9	72.1	72	75.3
6	Watertown	65.6	67.8	67.9	69.3	70.5	70.4	74.1
7	Indian Lake	60.2	62.3	62.5	63.9	65.1	64.9	68.5
All	Average	66.9	69.1	69.2	70.5	71.7	71.6	75.1
		June to September Total Precipitation, inches						
1	Rochester	11.4	11.4	11.6	11.5	11.6	11.5	10.8
2	Port Jervis	16.2	17.1	16.8	16.9	17.3	17.2	16.9
3	Elmira	14.1	14.6	14.6	14.9	14.6	14.8	14.2
4	NYC	16	16.7	16.4	16.8	16.9	16.6	16.9
5	Albany	14	14.7	14.3	14.7	14.9	14.9	14.6
6	Watertown	13.9	14.5	14.3	14.4	14.5	14.5	13.8
7	Indian Lake	15	15.8	15.5	15.6	15.7	16	15.5
All	Average	14.4	15	14.8	14.9	15.1	15.1	14.7
		June to September Cumulative Water Deficits, inches						
1	Rochester	4.7	6.2	6	7.1	7.8	7.7	11.1
2	Port Jervis	1.2	1.7	2	2.7	3	2.9	5.3
3	Elmira	2.2	3.2	3.2	3.9	4.8	4.4	7.5
4	NYC	2.9	3.7	4	4.8	5.5	5.6	7.9
5	Albany	2.4	3.1	3.4	3.9	4.5	4.5	7
6	Watertown	1.8	2.5	2.7	3.5	4	4	6.9
7	Indian Lake	-0.6	-0.2	0	0.6	1	0.8	2.9
All	Average	2.1	2.9	3.1	3.8	4.4	4.3	7
		Absolute Increase in Precipitation Deficit Relative to Historical Average, inches						
1	Rochester		1.54	1.35	2.39	3.14	3.03	6.46
2	Port Jervis		0.44	0.77	1.43	1.75	1.68	4.06
3	Elmira		0.91	0.99	1.62	2.52	2.21	5.24
4	NYC		0.8	1.11	1.9	2.56	2.7	4.95
5	Albany		0.68	1.03	1.5	2.15	2.07	4.61
6	Watertown		0.74	0.91	1.68	2.25	2.2	5.16
7	Indian Lake		0.35	0.59	1.16	1.54	1.42	3.53
All	Average		0.78	0.97	1.67	2.27	2.19	4.86

Figures for representative stations from all seven climate regions of New York, assuming maximal plant water demand (i.e., potential evapotranspiration), calculated assuming full canopy cover for the entire period; see text for more discussion). Historical temperature and precipitation values represent averages of weather station data over the period 1901–2006 using 5 GCMs (GFDL, GISS, MIROC, CCSM, and UKMO) of the 16 used in ClimAID.

Table 7.3 Current and projected summer (June to September) water deficits and related temperature and precipitation



Note: Each multi-colored bar adds up to 100 percent probability of what a given year will be like, and the chance of a water deficit of a particular size is shown by the lengths of different colored segments within each bar. The distribution of colors within a single bar illustrates the underlying variability of weather patterns from year to year during a particular current or future time period. Different bars moving from left to right show how climate change will progressively alter these distributions, increasing the likelihood of years with larger summer water deficits.

Figure 7.9 Magnitude (inches) of total summer water deficit (June through September) under current and projected future conditions[5] ranging from a minimum of -0.6 inches at Indian Lake to a high of 4.7 inches in Rochester. The slightly negative value for Indian Lake indicates that available soil water is, on average, not sufficiently depleted during the summer to compromise plant growth in that region.

Warming temperatures under global climate change will affect summer water deficits primarily by increasing PET through higher temperatures. Precipitation is actually predicted to increase somewhat for New York, but most of this increase is expected to come in the winter months when it will contribute to increased runoff and do little to offset summer moisture deficits. Both the monthly magnitude and average number of months with net deficits will increase due to warming temperatures and cause seasonal water deficits to become more severe throughout the state. It is clear from **Table 7.3** and **Figure 7.9** that the frequency of years with high water deficits is projected to increase across the state, including in historically wet locations such as Indian Lake as well as regions with historically a relatively more dry climate (e.g., Rochester).

While New York is likely to remain a state relatively rich in water resources (see Chapter 4, "Water Resources"), summer water deficits are projected to increase. The fundamental trend is in qualitative agreement with the assessment of another study (Hayhoe et al., 2007) that used a different hydrological modeling approach, and projected that the frequency of short-term droughts (one to three months in duration and defined by low soil moisture contents) will occur as often as once per year in the northeastern United States by end of century under a high emissions scenario. The ClimAID analysis provides a more detailed analysis for regions of New York State that have different historical rainfall patterns.

It would be premature to place a high degree of certainty on the exact magnitude or time course of the drought development projected. Results are very sensitive to how PET is calculated, for example, and further analysis and research is needed. As emphasized in the introduction to this case study, the results presented here are a worst-case scenario for annual row crops, because the analysis assumes maximum crop water demand (actual crop water use is at full potential, i.e., equal to PET) throughout the June to September growing season. Further analyses are refining the estimates of seasonal crop water demand by multiplying PET by a crop coefficient (between 0.2 and 1.0) determined from crop growth stage and canopy development. This will probably have little impact on water deficits for July and August when crops are typically at full canopy (and therefore at PET levels), but it will reduce the magnitude of water deficits for the early and late parts of the growing season for annual row crops and for the whole season to values below those reported in **Table 7.3** and **Figure 7.9.** Also, numerous algorithms and modeling approaches exist for estimating PET (Hatfield, 1990). The Palmer Drought Severity Index, and thus this analysis, is based on the Thornthwaite PET model (1948), which primarily relies on temperature inputs. The Penman-Montieth model (Penman, 1948; Allen et al., 1998), includes solar radiation and other parameters and is more widely used for irrigation scheduling. The Penman-Montieth model, however, is difficult to use for climate projections because of the uncertainties in the projections of the inputs required for the model (e.g., radiation, humidity). A preliminary comparison of the two PET models using Rochester climatic data suggests that Thornthwaite may underestimate current PET and summer deficit values, but predicts twice the level of increase in deficits compared to Penman-Montieth model in response to climate change projections.

Further analysis will refine the projections of future water deficits, but it is not likely that these additional analyses will alter the fundamental conclusion that there will be increasing soil water deficits with climate change by mid- to late century. Supplemental irrigation is already recommended in New York State during most years in order to fully meet crop water requirements (Wilks and Wolfe, 1998; **Figure 7.8**). The results of the analysis indicate that increased irrigation capacity, particularly for production of high-value horticultural crops, will become essential for New York farmers in the coming decades.

Case Study D. Dairy Heat Stress

To assess heat stress impacts on cows with different baseline milk production potential, ClimAID used the Cornell Net Carbohydrate and Protein System (CNCPS) simulation model of dairy cow physiology and productivity (Fox and Tylutki, 1998), parameterized for herds of average and high productivity (65 and 85 pounds of milk per cow per day, respectively). High-producing cows are becoming more common and are inherently more sensitive to

Current Temperature, °F	Previous Temperature, °F	Predicted Milk, lbs/cow/day		Predicted Dry Matter Intake, lbs/cow/day		Income Over Feed Cost, $/cow/day	
		65 lb max	85 lb max	65 lb max	85 lb	65 lb max	85 lb max
68	68	65	85	45.4	51.2	4.90	6.66
76	70	62.3	85.5	44	50.5	4.54	6.33
84	76	59	75	43.9	49.5	4.12	5.91

Table 7.4 Effect of temperature on dairy cattle performance

Climate Conditions — Historical Conditions (1970-2000)					Impact on Milk Production			
Current week		Previous month			lbs/cow/day		lbs/cow/year	
°F	RH	°F	RH	days/yr	65 lbs	85 lbs	65 lbs	85 lbs
79.1	68.0	70.3	68.0	0.9	-3.0	-5.1	-2.7	-4.6
77.8	71.2	70.9	71.2	1.9	-3.3	-4.4	-6.3	-8.4
76.0	71.4	69.0	71.4	5.4	-2.4	-3.5	-13.0	-18.9
74.3	71.8	69.3	71.8	7.9	-1.8	-2.4	-14.2	-19.0
72.3	72.6	68.9	72.6	12.1	0	-1.4	0	-16.9
70.7	72.2	68.3	72.2	17.0	0	-0.2	0	-3.4
						total lbs/cow/yr	-36.2	-71.2
						$/cow/yr($0.15/lb)	-5.4	-10.7

Climate Conditions — 2050s with A2 emissions					Impact on Milk Production			
Current week		Previous month			lbs/cow/day		lbs/cow/year	
°F	RH	°F	RH	days/yr	65 lbs	85 lbs	65 lbs	85 lbs
84.4	70.8	76.4	70.9	0.5	-6.9	-9.0	-3.4	-4.5
83.2	66.2	76.5	66.9	2.6	-5.5	-7.4	-14.3	-19.2
81.3	68.9	74.4	67.9	4.0	-4.5	-6.4	-18.0	-25.6
79.7	67.5	74.1	68.1	8.2	-3.5	-5.1	-28.7	-41.8
77.8	70.5	74.2	68.3	9.1	-2.5	-4.3	-22.8	-39.1
76.2	68.8	73.6	68.7	18.2	-1.4	-3.0	-25.5	-54.6
74.3	69.0	73.1	68.7	16.1	-0.6	-2.1	-9.7	-33.8
72.6	69.9	72.0	69.1	16.1	0	-1.2	0	-19.3
70.7	70.5	69.0	68.9	15.2	0	-0.5	0	-7.6
						total lbs/cow/yr	-122.4	-245.5
						$/cow/yr($0.15/lb)	-18.4	-36.8

Climate Conditions — 2080s with A2 emissions					Impact on Milk Production			
Current week		Previous month			lbs/cow/day		lbs/cow/year	
°F	RH	°F	RH	days/yr	65 lbs	85 lbs	65 lbs	85 lbs
88.1	62.5	81.0	63.0	0.7	-8.1	-10	-5.7	-7.0
86.8	63.4	82.1	64.4	2.6	-8	-9.4	-20.8	-24.4
84.9	64.9	81.1	65.1	5.4	-6	-8.2	-32.4	-44.3
83.2	63.4	79.8	64.3	7.9	-4.9	-6.6	-38.7	-52.1
81.3	65.6	79.2	66.1	10.7	-3.9	-5.9	-41.7	-63.1
79.7	65.7	78.2	65.5	16.6	-3	-4.8	-49.8	-79.7
77.9	65.3	77.3	65.1	16.3	-1.9	-4.1	-31	-66.8
76.2	66.4	76.1	66.6	14.0	-1.4	-2.9	-19.6	-40.6
74.3	67.7	73.2	67.1	13.8	-0.6	-2.1	-8.3	-29
72.5	68.5	71.8	67.8	12.4	0	-2.1	0	-26.0
70.7	71.1	71.1	68.7	10.5	0	-0.4	0	-4.2
						total lbs/cow/yr	-248	-437.3
						$/cow/yr($0.15/lb)	-37.20	-65.6

Table 7.5 Heat- and humidity-based reductions in milk production for Rochester, under historical conditions and projected to the 2050s and 2080s for the A2 emissions scenario averaged over 5 GCMs (GFDL, GISS, MIROC, CCSM, and UKMO) of the 16 used in ClimAID

heat stress due to their high metabolic rate. The model uses as inputs relative humidity, "previous" temperature (average over the prior month), and "current" temperature (a weekly average). Current feed and milk prices are also used to evaluate the economic impact of these changes. **Table 7.4** illustrates the model sensitivity to average temperature when relative humidity is constant (68 to 71 percent for all runs). At 68°F, the cows are not stressed and give milk at their specified production levels of 65 or 85 pounds per day. As average temperature increases to 84°F, there is a decrease in dry matter intake, milk, and income over feed cost. When fat was added to the ration, milk production was partially restored back toward unstressed values by 1 to 5 pounds per cow per day (data not shown), improving income over feed cost by $0.15 to $0.35 per cow per day over the range of rations used in this evaluation. Thus, manipulation of the ration allows partial amelioration of heat stress effects, but not full recovery.

The CNCPS simulation model was used to compare heat-stress-induced milk reductions for historical conditions (1970–2000) and air temperature and relative humidity projections to the 2050s (2040–2069) and the 2080s (2070–2099) derived from five global climate models (GFDL, GISS, MIROC, CCSM, and UKMO) and the high-emissions A2 scenario. The model runs assume dairy barns with standard ventilation cooling capacity for today's conditions. **Table 7.5** shows the predicted lost milk production based on the number of days per year with various weekly average values of temperature and relative humidity. Historical (1970–2000) values are compared to future A2 emissions scenarios where the proportion of days at higher temperature increases. Two levels of milk production are considered, with unstressed baselines of 65 versus 85 pounds per day. The first two columns on the left show the effect per day of different temperature categories on production, and the second two columns show the annual impact weighted by the average number of days spent in each temperature category during a summer. Total annual milk loss in pounds per cow per year was translated into an estimate of monetary loss that assumed a price of $15 per 100 pounds of milk. All values for milk loss reported in **Table 7.5** assume that the cows have already had temperature-appropriate feed adjustments (e.g., adding fat to the ration) as discussed above to partially ameliorate the stress effects.

Effects of Climate Change on Milk Production

Based on this simulation, the average yearly losses in milk production associated with heat stress for the historical period was 36.2 pounds per cow per year for the 65-pound-per-day cows and 71.2 pounds per cow per year for the 85-pound-per-day cows (**Table 7.5**). Projections of climate change effects on future milk production decline show more than a six-fold increase compared to the historical average by end of century (2080s), with milk production dropping by 248 pounds per cow per year for the 65-pound-per-day cows and 437 pounds per cow per year for the 85-pound-per-day cows. The projected end-of-century economic losses associated with heat stress are approximately $37 and $66 per cow per year. For both levels of milk production, the greatest impact on annual milk losses does not come from the highest stress levels experienced, but from intermediate stress levels that occur for a larger number of days over the season. Even relatively low losses experienced in a chronic manner can result in substantial cumulative losses.

The simulated historical values in **Table 7.5** seem low based on observation of actual losses during the 1970–2000 period, suggesting the model may be conservative in estimates of heat stress on milk production decline. This may be, in part, due to the focus of this model on short-term milk production decline, but not on potential long-term impacts from stress during critical periods as mentioned above and discussed in more detail in the Vulnerability section (7.3.5). Also, this analysis assumes good barn ventilation and that barn temperatures are the same as ambient temperatures. However, barn temperatures can become higher than ambient temperatures in poorly ventilated barns, and this could become a more significant problem as the climate warms.

The projections used in this analysis involved a drop of relative humidity by the 2080s by as much as 5 percent on an annual basis and 7 or 8 percent in the hottest months of the summer (**Table 7.5**). This has a natural compensatory effect, because the lowered relative humidity improves evaporative cooling and makes the cows *less* susceptible to high temperature stress. Again, this makes the results presented conservative, because the depression in milk production is attributable to a future condition projected with high confidence (temperature increases), while the ameliorating factor (relative humidity) is one with much lower confidence (relative humidity decreases). If the analysis assumed no change in relative humidity in the future, milk losses would be greater.

Costs of Adaptation: Improving Cooling Capacity

Modifying feeding management and providing adequate water can help to ameliorate heat stress in cows (see Adaptation, Section 7.4.1), but improving cooling capacity of the housing system is typically a more effective approach. Important features characterizing barn cooling systems include 1) air turnover capacity per hour, to prevent the build-up of heat, humidity, toxic fumes, and airborne pathogens, 2) air speed at cow level, and 3) the possible injection of mist and sprinkled water to provide evaporative cooling.

Most of the smaller herds (less than 100 cows) in New York are housed in tie-stall barns. Many of these are older facilities that can be difficult to modify. Tunnel ventilation is an option for cooling cows housed in some styles of tie-stall barns. In tunnel ventilation, a group of fans is located at one end of the barn and draws air from inlets at the other end of the barn, cooling the animals.

A “partial budget” analysis or a simple payback methodology is commonly used to calculate benefits of relatively small investments. Such analytical frameworks, when used at a microscale, provide straightforward evaluation of the net returns ensuing from a particular change in operation, such as investing in cooling systems. Their value lies in the nature of the information required, which is usually available. For example, partial budget analysis only requires estimation of the potential changes in revenues and costs resulting from a particular investment (Turner et al., 1997; Dhuyvetter et al., 2000). An interactive web-based program is available to calculate the costs and the pounds of avoided milk production decline needed to pay for the tunnel ventilation system (www.prodairyfacilities.cornell.edu/TunnelVent/Intro.aspx).

An example simulation was done for a 70-cow dairy herd producing 75 pounds of milk per cow per day. The cost for the tunnel ventilation system was $7,694 ($110 per cow). This included the operational cost and the interest on a five-year loan to pay for the system. It was assumed that the system would run 16 hours a day for 40 days during the year. It would require a change of 5 pounds of milk per cow to break even with this system. If the system ran 60 days per year, the pounds of milk required to break even would be reduced to 4 pounds per cow. This interactive model can be used to estimate payback period with each specific herd using their data for number of cows, milk production, system costs, and days of operation. A number of herds have installed tunnel systems in tie-stall barns and paid for them in one to two years.

When ventilation systems alone cannot keep cows from overheating, sprinkler and mister systems can be added to provide evaporative cooling. Sprinklers can be used as an option with tunnel ventilation and other configurations that provide high airspeeds at cow level. In these systems, the cow’s skin is soaked with water at periodic intervals and then the water is removed by the use of fans. This is an effective method of cooling cows in climates with moderate to low humidity. The cost of these systems is relatively low at about $5 to $10 per cow (Dhuyvetter, 2000). One concern of dairy producers is the quantity of water required. These systems use about 25 to 50 gallons of water per cow per day. There are two primary considerations: making sure that an adequate supply of water is available, and making sure the quantity of additional water that enters the manure system is stored and later hauled to the fields. Although much of the water applied, especially that which directly wets the coats of the animals, is evaporated away, a large amount of residual water becomes mixed with the manure. On a large dairy farm, this can be a significant quantity of water and is likely to be a concern in the future with potential drought due to climate change.

As herds get larger in free-stall barns, they tend to be placed into groups of animals that are at different stages of development or different stages of the production system. Each such group has unique sensitivities and potential responses to heat stress and reduction techniques. As dairy producers consider providing ventilation systems to change the environment in their barns, they need to consider each group of animals and the potential for response and economic return. The following is a list of areas and animal groups in approximate order of priority for cooling during hot periods:

- holding area (area where cows wait to enter the milking parlor)
- milking area
- close-up dry cows (cows within three to four weeks of calving)
- calving area
- fresh cows (cows that have recently calved)
- high-producing cows
- low-producing cows

Cows in the holding area typically are very close together, touching each other. Even though they may be in this area for only a short time, heat stress and the thermal heat index (THI) can be very high. The preferred option for this area is to provide both fans and sprinklers. One report indicated that cows cooled in the holding pen produced 1.7 to 4 pounds more milk per day than cows not cooled in the holding area. A 1993 trial in Arizona indicated that cows cooled in the holding area produced 1.9 pounds more milk per cow per day than cows that were not cooled (Armstrong, 2000).

Priorities can be set for where the fans should be placed in barns. If funds are limited, the first choice would be to place fans over the feed bunk area. In addition, fans could be placed over the cow resting area (stalls). Ideally, fans would be placed over both areas. Tunnel ventilation is sometimes a good option (Gooch, 2008), but several other styles of ventilation system may be more appropriate depending on barn structure and site configurations.

Herd Size and Economies of Scale in Ventilation Systems

Many ventilation systems are inherently more cost-effective when deployed for larger animal housing situations. An interactive program available from Cornell University's Prodairy website can be used to calculate the costs and pounds of milk needed to break even with a tunnel ventilation system. This program calculates initial investment, operating costs, loan payments, days of fan operation, and the pounds of milk needed to break even. Using a five-year loan period and a milk price of $15 per 100 pounds of milk, model runs for both a small, tie-stall barn (50 or 100 cows) and a free-stall barn (300 or 600 cows), and assuming that the fans would operate 50, 100, or 150 days per year, provide the following results for initial investment (not including loan interest):

- 50 cow tie-stall barn = $262 per cow
- 100 cow tie-stall barn = $132 per cow
- 300 cow free-stall barn = $144 per cow
- 600 cow free-stall barn = $72 per cow

The degree to which milk production must be increased through avoidance of heat stress effects in order for the cooling systems to pay for themselves over a five-year payback period is shown in **Table 7.6** for each combination of barn style and herd size and considering three different scenarios of how many days per year reached stressful temperatures. Larger numbers for milk production in the same column imply that higher, more stressful outside temperatures would have to be experienced before installing a cooling system for a given barn style and herd size represented a cost-effective investment. In both styles of barns, there is a distinct economy of scale, with larger herds reaching cost-effectiveness at smaller minimum savings in milk production.

To summarize, to adequately ameliorate the effects of high temperatures, both adequate ventilation at high airspeeds directly over the cows and appropriately deployed sprinkler systems will be needed in the future. Many dairy barns already have both fans and sprinklers, but a significant number do not. The greatest cost in this configuration lies in the fans, but sprinklers without fan systems are not effective. While these cooling systems represent added investments, the literature shows that they have a high likelihood of paying for themselves over time through increased milk production. With projected climate change, adequate cooling systems will be increasingly important for the future of New York's dairy industry.

	Milk Production Savings (lbs/day) Needed to Pay Back Investment in Cooling Fans		
	50 heat stress days/yr	100 heat stress days/yr	150 heat stress days/yr
50 cow tie-stall barn	10.94	7.12	5.75
100 cow tie-stall barn	5.47	3.63	2.87
300 cow free-stall barn	5.9	3.9	3.1
600 cow free-stall barn	2.97	1.97	1.56

The values in the body of the table are levels of milk production increase (lbs per cow per day) that must be realized when cooling fans are employed in order to make the fan investment cost-effective, as described in the text. Three scenarios are considered showing that if fewer days of heat stress are experienced per year, the impact per day must be high to make installation cost effective. Tie-stall and free-stall barns are compared, each at two relevant herd sizes.

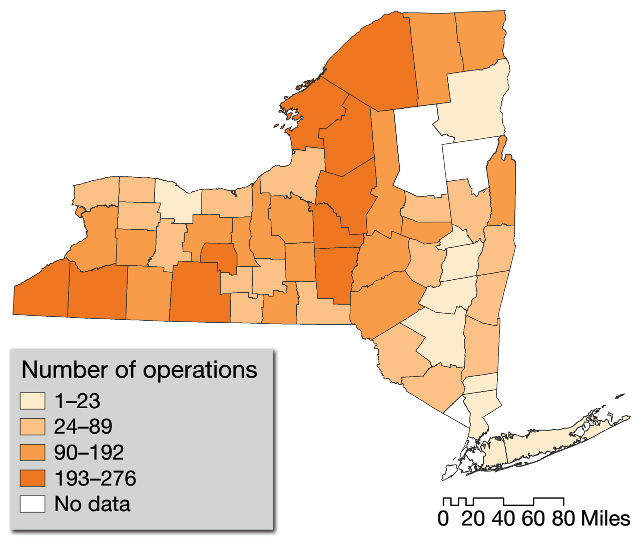
Table 7.6 Magnitude of potential heat stress losses required for fan and cooling systems to pay for their own installation and operation over a five-year pay-back period

Equity and Environmental Justice Issues

Vulnerability and capacity to adapt to climate change may vary substantially across different dairy regions in New York State (**Figure 7.10**) due to differences in climate change exposure, regional cost structures, farm sizes, and overall productivity. Should climate change have a highly detrimental effect on dairy farming in the state overall, those regions with higher concentrations of dairy farms are likely to experience a more substantial economic disruption. On the other hand, farmers in regions with higher concentrations of farms may also have some advantages associated with external economies of scale that facilitate adaptation to climate change, such as ability to learn from other farmers in the area regarding best adaptation practices or pooling of resources for different types of services that are needed to foster adaptation.

Regional comparison of the location of dairy operations in New York in 2007 (**Figure 7.11**) reveals that dairy farms are particularly abundant in the western parts of the Northern New York and Central Valleys Dairy Regions and in the Western and Central Plateau Region. Measured in terms of annual sales of milk and dairy products (**Figure 7.12**), the regional pattern is slightly different. The counties with the highest concentrations of dairy sales are located in the western portion of the Northern New York Region (also a region with the highest number of operations) and in the Western and Central Plain Region. According to the U.S. Census of Agriculture, the three New York counties with the highest sales in milk and other dairy products in 2007 are Wyoming County ($179 million) and Cayuga County ($140 million), both located in the Western and Central Plain Region, followed by St. Lawrence County ($113 million in sales) in the Northern New York Region.

In addition to differences in numbers of farms and total sales, the major dairy regions within the state also exhibit different characteristics in terms of size and profitability. Detailed data that permit comparisons



Source: U.S. Agricultural Census, 2007

Figure 7.11 Locations of dairy operations in New York State

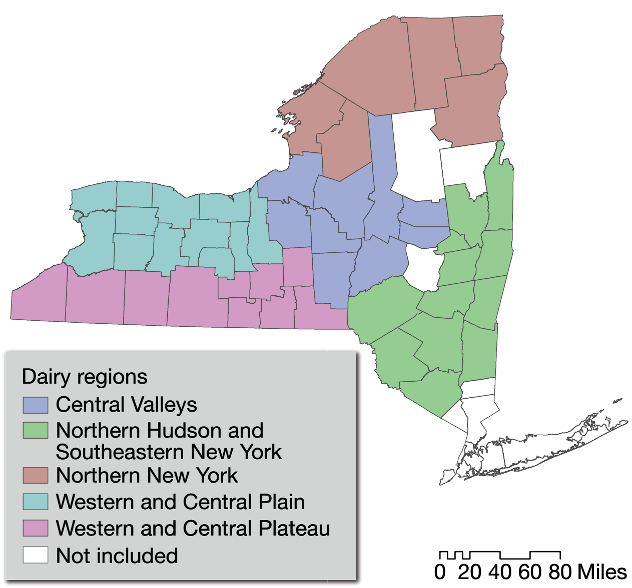
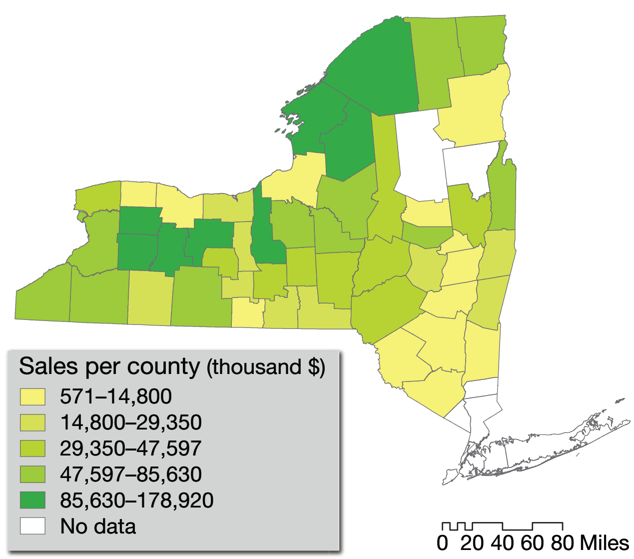


Figure 7.10 Dairy regions in New York State



Source: U.S. Agricultural Census, 2007

Figure 7.12 Dairy sales by county for New York State among regions in New York are available from the Cornell Cooperative Extension's Dairy Farm Business Summary and Analysis Project. Because participation in the survey is voluntary, these data do not represent a statistically robust sample. In particular, the data may contain some overrepresentation of farms with better organization and record keeping, as these farms are more likely to participate in the survey on a continuing basis. Nonetheless, the data provide useful insights into some of the major differences in the characteristics of dairy farms among the regions of the state (**Table 7.7**).

Examination of **Table 7.7** suggests that larger farms are concentrated in the Western and Central Plain region, where the average farm size within the Cornell sample has 673 cows and more than 1,200 tillable acres. The smallest average farm size is in the Western and Central Plateau region, where the average farm within the sample has 168 cows on 417 tillable acres. Costs of milk production range from $17.04 per hundredweight of milk in Northern New York to $18.63 per hundredweight in the Northern Hudson and Southeastern New York Region. Some factors that account for these regional differences include land and labor costs, which are likely to be higher in the areas closer to metropolitan New York. The Western and Central Plateau Region (which also has the smallest farms) is another region with relatively high costs of $18.03 per hundredweight of milk sold. These differences in milk production costs across regions may influence capacity to adapt to climate change, particularly in cases where adaptation requires additional expenditures for energy and pest control due to higher summer temperatures.

Differences in farm and herd size are also potentially significant factors in determining vulnerability and capacity to adapt to climate change. Comparison of small versus large farms throughout the state reveals significant differences in costs, milk sales per cow, capital efficiency, income, and profitability (**Table 7.8**). All of these differences may affect the overall capacity of smaller farms to adapt to climate change, particularly if such adaptation requires significant new outlays of capital for purchase and installation of ventilation systems in dairy barns, as well as additional costs associated with energy for operating this equipment.

While it is difficult to know precisely how different-sized dairy farms will be affected by climate change, the

	West & Central Plateau	West & Central Plain	Northern New York	Central Valley	North Hudson & Southeastern NY
Average number of cows per establishment	168	673	372	289	210
Tillable acres	417	1241	848	707	495
Total cost of producing milk ($ per hundredweight)	$18.03	$17.16	$17.04	$17.33	$18.63
Average price received ($ per hundredweight)	$20.62	$20.09	$20.06	$20.77	$20.95

Source: Cornell University, Dairy Business Summary and Analysis Project (Knoblauch et al., 2008)

Table 7.7 Characteristics of dairy regions in New York State

	Small Farms (39 farms)			Large Farms (83 farms)		
Farm Size	2007	2008	% chg	2007	2008	% chg
Average number of cows	52	52	0.0	773	797	3.1
Total tillable acres	40	41	2.5	1,482	1,595	7.6
Milk sold (lbs)	975,626	976,710	0.1	18,500,129	19,671,976	6.3
Costs						
Grain and concentrate purchases as a percent of milk sales	24%	31%	29.2	24%	30%	25.0
Total operating expenses per hundredweight sold	$16.29	$17.51	7.5	$16.32	$17.87	9.5
Capital Efficiency						
Farm capital per cow	$11,880	$12,576	5.9	$7,981	$8,772	9.9
Machinery and equipment per cow	$2,152	$2,382	10.7	$1,309	$1,467	12.1
Income and Profitability						
Gross milk sales per cow	$3,817	$3,678	-4.4	$4,870	$4,753	-2.4
Net farm income (w/o appreciation)	$54,680	$28,117	-48.6	$939,605	$483,799	-48.5
Income per operation per manager	$20,267	-$5,257	-126	$388,494	$128,755	-67
Farm net worth	$498,120	$502,664	0.9	$4,421,159	$4,658,105	5.4

Source: Cornell University, Dairy Business Summary and Analysis Project, Knoblauch et al., 2009 and Karszes et al., 2009

Table 7.8 Small versus large dairy farms in 2007 and 2008 effects of other types of shocks can help to illustrate which types of farmers might be more or less vulnerable to climate change. Comparison of how farms in the Cornell study performed in 2007 (a relatively profitable year) versus 2008 (a more challenging year due to spikes in input prices including feed, energy, and fertilizer) provides a glimpse into how shocks affect farms of different sizes. Similar types of input price shocks may also occur under climate change, because more frequent extreme weather conditions could lead to higher feed and energy prices. Policies intended to reduce emissions may also contribute to higher energy prices, though such effects are likely to be more gradual as taxes or other mechanisms to mitigate climate change are put into place.

Data from the Cornell dairy survey reveals that both small and large farms experienced significant challenges in coping with these conditions in 2008, but small farms appear to have fared worse (**Table 7.8**). Small farms experienced no increase in milk sold and had a 4.4 percent decline in gross milk sales per cow from 2007 to 2008. By contrast, large farms increased sales by 6.3 percent and experienced a 2.4 percent decline in gross milk sales per cow. Small farms also experienced relatively larger increases in purchased input costs (29.2 percent for small farms compared to 25 percent for large farms), but smaller increases in total production costs (7.5 percent for small farms compared to 9.5 percent for large farms). While net farm income for both small and large farms declined by approximately 48 percent between 2007 and 2008, income per farm operator or manager declined much more precipitously for small farms. Overall, the typical small farm operator experienced an income loss of 126 percent, while large farms operators experienced losses of 67 percent.

Collectively, these ClimAID results suggest that small farms may be less able to withstand shocks related to climate change without some type of adaptation assistance.

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Appendix A. Stakeholder Interactions

The ClimAID Agriculture team gathered information and enlisted participation from key stakeholders in the agriculture sector through existing relationships and collaboration with the New York State Department of Agriculture and Markets, Cornell Cooperative Extension and Integrated Pest Management specialists, crop consultants, farmer commodity groups (e.g., Sweet Corn Growers and Finger Lakes Grape Growers Associations), and individual farmer collaborators. Below are some specific aspects of stakeholder involvement associated with the project.

Meetings and Events

Two important half-day meetings were held with stakeholders early on to gather expert opinions, with formal presentations followed by an opportunity to provide feedback:

1) Conference with approximately 35 Cornell Cooperative Extension staff from across the state, held in Ithaca on November 11, 2008. The expertise of these specialists ranged from fruit and vegetable crops to dairy and grain crops. The conference included presentations and breakout group input on high-priority vulnerabilities and potential opportunities, feasible adaptation strategies, and needs for additional information, decision tools, and/or resources to help farmers cope with climate change.
2) Briefing at New York State Agriculture and Markets headquarters (Albany, November 12, 2008) attended by the Agriculture Commissioner and approximately 15 other key department leaders.

Other presentations of preliminary results have included the 2009 November "In-Service" training for Cornell Cooperative Extension staff in Ithaca, and the NYSERDA Agriculture Innovations Conference in December, 2009, held in Albany.

Focus Group and Technical Working Groups of the Climate Action Plan

A focus group of several stakeholders has been used for frequent feedback as this project proceeds. In addition, results have been shared with individuals at New York State Agriculture and Markets.

1 Abbreviations are for counties in geographic areas: N = Northern (Jefferson, Lewis, St. Lawrence); NE = Northeastern (Clinton, Essex, Franklin, Hamilton, Warren); W = Western (Erie, Genesee, Livingston, Monroe, Niagara, Ontario, Orleans, Seneca, Wayne, Wyoming, Yates); C = Central (Cayuga, Chenango, Cortland, Herkimer, Madison, Oneida, Onondaga, Oswego, Otsego); E = Eastern (Albany, Fulton, Montgomery, Rensselaer, Saratoga, Schenectady, Schoharie, Washington); SW = Southwestern (Allegany, Cattaraugus, Chautauqua, Steuben); S = Southern (Broome, Chemung, Schuyler, Tioga, Tompkins); SE = Southeastern (Columbia, Delaware, Dutchess, Greene, Orange, Putnam, Rockland, Sullivan, Ulster, Westchester); LI = Long Island (Nassau, New York City, Queens, Richmond, Suffolk).

2 Small farms in New York State are defined as those with total acreage of less than 100 acres and/or annual sales of less than $50,000. Approximately 51 percent of farms in New York State are less than 100 acres in size, and approximately 75 percent of New York farms have revenue of less than $50,000 (USDA, 2007).

3 Within the dairy sector, small farms are defined as having 80 or fewer cows and no milking parlor (Knoblauch et al., 2009).

4 Precipitation is in liquid-water equivalents for rain or snow; PET is the potential evapotranspiration (evaporative water loss from soil and plants); runoff is the fraction of precipitation that exceeds soil holding-capacity and passes either into deep groundwater or into streams. PET calculations in this figure assume full leaf-area development throughout the growing season and are not specific to any particular crop's growth and development.

5 Predictions are shown for Indian Lake in the Adirondacks, Elmira, and Rochester, and include historic values (based on the period 1901–2006) and climate change projections for two different carbon dioxide emissions scenarios, B1 (low emissions) and A2 (high emissions). Calculations were derived from the same dataset as Table 7.3, which assumes maximal plant water demand (i.e., potential evapotranspiration, calculated assuming full canopy cover for the entire period; see text for more discussion). Projected changes in monthly temperature and precipitation used to calculate deficit probabilities were derived from ClimAID data generated from (GFDL, GISS, MIROC, CCSM, and UKMO) GCMs as appropriate for each of the timeslices and emissions scenarios.