

## Chapter 7

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# Agriculture and Climate Change in the Southeast USA

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For the southeastern agricultural sector, this chapter summarizes key vulnerabilities and impacts; describes the characteristics and importance; analyzes current and potential climate sensitivities and vulnerabilities; discusses uncertainties, summarizes subregion-specific impacts and opportunities as referred to in the literature; explores adaptation needs and opportunities; and concludes with recommendations for further assessment and research needs. We have taken into consideration a range of studies from within and outside the region to describe major impacts and likely projections for climate change in this region, which covers southeastern states, except Puerto Rico and the Virgin Islands.

## Key Findings

### *Changes in precipitation extremes*

- ▶ Drought is already a major stress for rain-fed crops in the Southeast (SE). Drought impacts are projected to become more frequent and severe, especially in the western part of the region, but there may be fewer droughts across the northern tier of the region and in the mid-Atlantic. Both dryland and irrigated agriculture will be further affected by drought as a result of greater irregularity of rainfall distribution and increasing competition with other sectors for water resources.
- ▶ Flood frequency likely will increase as a result of predicted increased numbers and intensity of storms in some areas of the region. Floods cause direct damage to crops, especially if they occur during fruit set or near crop maturity, as well as indirect damage through soil erosion, leaching of nutrients, and loss of future productivity.

### *Changes in temperature extremes*

- ▶ High temperature stresses are predicted to become more frequent and damaging to crops. Warm temperatures during the winter months reduce fruit set on blueberry, peach, and other crops that have a chilling requirement. These adverse impacts can be partly offset through the application of growth regulators, but such methods increase costs of production.
- ▶ Increasing summer heat stress will reduce crop productivity, especially if it occurs during flowering and seed set and if it is combined with drought.
- ▶ Heat stress already limits production of dairy and livestock, especially during summer months. An increased frequency of heat stress events will have the potential to force some dairy and livestock production northward.

### *Changes in tropical storm strength*

- ▶ Projected increases in strength of tropical storms likely will cause extensive damage to nearly all agricultural systems, particularly when storms occur during maturation and harvest. Wind damage to perennial crops is particularly expensive and long lasting.

- Storm damage will negatively impact crops by reducing yield and crop quality. In addition storms also damage agricultural land; product handling, storage, and distribution systems; and equipment and buildings.

#### *Increased atmospheric carbon dioxide*

- Atmospheric carbon dioxide concentrations have a direct benefit to photosynthesis, especially for plants with a  $C_3$  metabolism such as legumes, cotton, some cereals and most vegetable and tree crops particularly when under drought conditions. Many weeds also will benefit from increases in atmospheric carbon dioxide concentrations resulting in increased production costs associated with weed management.

## 7.1 Agriculture in the Southeast USA

The Southeast (SE) represents one of the most diverse agricultural production regions in the USA (Figure 7.1). Agriculture is a major economic contributor to the region's economy and communities. Seasonal and spatial variability of climate conditions, including rainfall and temperature distributions, soil types, and access to water for irrigation have led to the development of a diverse and intensive agricultural sector.

The SE has a land area of 135 million ha, which is 14.9% of the USA total. Although land use differs widely by county in the SE, 60% (about 79 million ha) is designated as forest, which is about 30% of the total forest land in the USA. Cropland in the SE totals about 21 million ha, which is about 15.7% of the region's landmass and 13% of the total cropland of the nation (Figure 7.1). Grassland pasture and ranges total about 11 million ha, which is 8.3% of the land in the region and 4.5% of the grassland pasture and ranges of the nation (Nickerson et al., 2011).

Diverse climate conditions, land-use options, access to water, availability of farm labor, proximity to urban markets, distribution systems, and financial farm income have led to large structural differences among the states and subregions. Beef cattle, most of which is grazed on improved pastures; poultry; and swine are raised throughout most of the SE. Georgia, Arkansas, and Alabama are the top three poultry producing states in the nation and North Carolina is the number two swine producing state in the nation. Crops grown in the SE include soybean, corn, fruits, and vegetables. Peanut and cotton are produced through most of the coastal plain from Mississippi to Virginia. Florida is the nation's largest producer of citrus and an important producer of sugar cane and winter vegetables. In addition to the products already mentioned, the Delta States also produce rice, sugarcane, and small grains. The Appalachian States are the nation's major producers of tobacco and horses as well as major producers of peanuts, cattle and dairy (USDA-NASS 2012).

Within the SE, Alabama, Georgia, and Florida have the largest share of urban land use, which is well above the national average. Kentucky, Tennessee, Virginia, and North Carolina also have urban shares of urban land use above the national average (Nickerson et al. 2011).

The SE produces more than \$55 billion in agricultural products annually, accounting for more than 17% of the total annual USA production (Figure 7.1). Of the total SE

annual sales, more than 50% are derived from animal production, with the top five commodities consisting of broilers, eggs and chicken products, cattle and calves, hogs, and dairy products (Table 7.1). Crops represent 40% of the annual production, and include fruits and vegetables, soybeans, greenhouse and nursery products, corn and cotton. The SE produces 66% of the nation's broilers, 29% of the chicken eggs, 27% of the turkeys, 50% of the aquaculture, 37% of the cotton, 62% of the peanuts, and 33% of the tomato production (Hatfield et al. 2011).

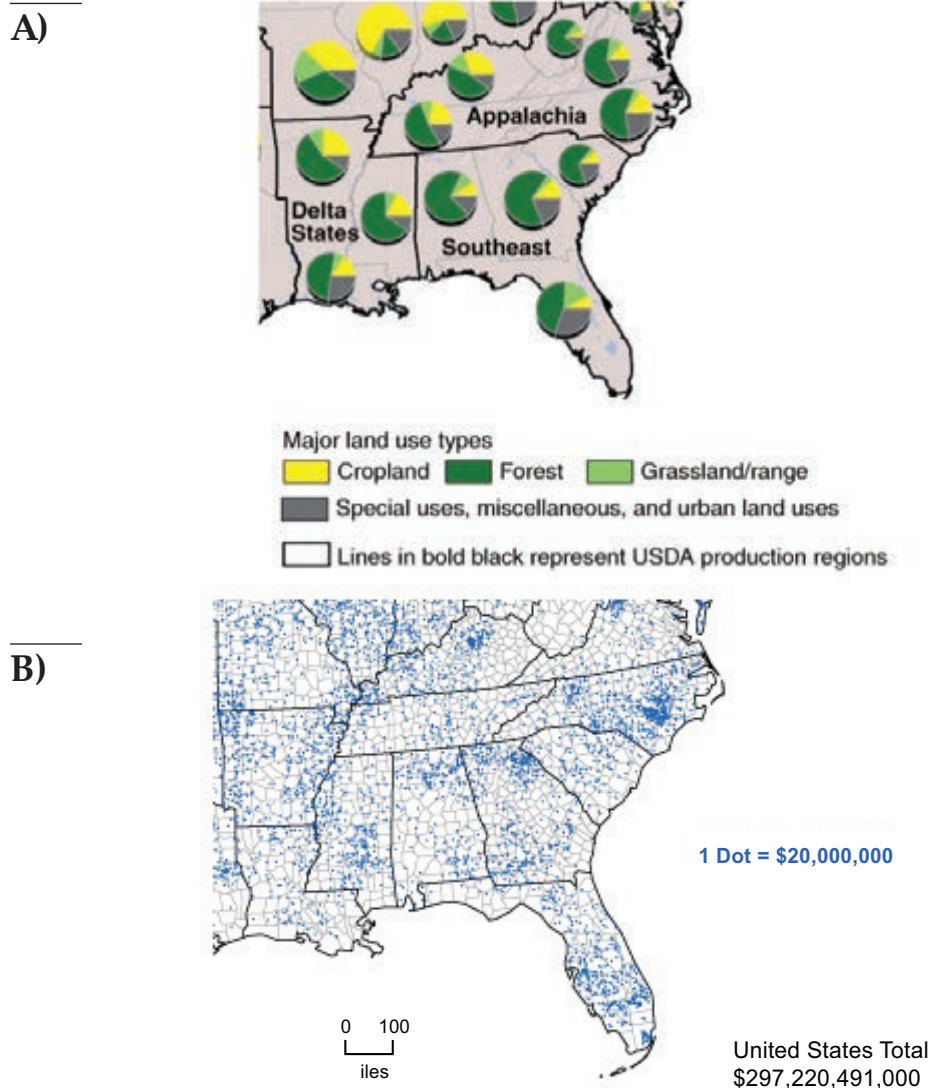


**Figure 7.1** Maps show (a) shares of land use in the Southeast and (b) distribution of market value of agricultural products sold. (a) USDA Census (2007) and (b) Hatfield et al. (2011).

**Table 7.1** Regional Population and Agricultural Sales in the Southeast.

|                           |             |
|---------------------------|-------------|
| <b>Population</b>         |             |
| Urban                     | 59,600,000  |
| Rural                     | 16,900,000  |
| Farms                     | 528,800     |
| <b>Annual Sales</b>       |             |
| Crop (Billion \$)         | 25.6        |
| Animal (Billion \$)       | 31.1        |
| <b>Total (Billion \$)</b> | <b>56.7</b> |

Source: USDA-ERS (2010).

Since 1985, agricultural land used for cropping, pasture, and ranges has consistently decreased as a consequence of expansion in non-agricultural land uses. Between the 1985 and the 2007 census the region recorded combined losses of agricultural land greater than 18% (7 million ha). Nationwide, cropping areas for the same period declined by more than 24 million ha, with the SE accounting for 36% of this loss. For the SE, there is a greater decrease in cropping land than in pastures. The states with the biggest net agricultural land loss were Georgia, Mississippi, Louisiana, and Florida (Nickerson et al. 2011). These long-term trends are linked to a number of factors, including changes in farm policies, commodity price fluctuation, crop insurance, land ownership, and urban encroachment as a result of population growth.

Agriculture consumes more than 80% of the water used in the USA (Schaible 2004). Competing demands for water from population growth, energy sector growth, and environmental needs have intensified. The development and maintenance of irrigation technology is an important factor to successful and optimal agriculture. In 2007, about 23 million ha (17% of all cropland) in the SE was irrigated. Since 1982 growth rates in irrigation have slowed down nationwide and in most parts of SE, except for large expansions in the Delta Region and Arkansas (Nickerson 2011). The SE region accounts for about 15% of the total USA water used for agriculture. Arkansas ranks second after California (Nickerson 2011).

Agriculture is a large contributor to CO<sub>2</sub> emissions. However agriculture also provides opportunities for carbon sequestration and increased storage that have the potential to offset high emission rates, while providing economic value to landholders and farming businesses. For the region, conversion to restorative land use and adoption of carbon sequestration practices can help to achieve a positive carbon balance in agriculture (Lal et al. 2011). Many practices that farmers implement as part of adaptations to climate changes will also mitigate carbon emissions. For example, carbon losses associated with grazing systems could be reduced through proactive management to conserve vegetative cover and to store soil carbon through integration of crop, pasture, and livestock production systems (Shepherd 2011). This topic will also be addressed in the up-coming 2012 ARS GRACEnet assessment (GRACEnet 2012).

The diverse and intensive agricultural sector in the SE is highly affected by climate conditions and requires appropriate, continuously improving management practices. Climate impacts on agriculture profits, spill over into the broader agribusiness sector. Severe climate events such as floods and droughts have large impacts on the financial performance of agricultural businesses. For instance, the 2011 floods in the Mississippi River area were estimated to cost the Arkansas agricultural industry more than \$500 million (Arkansas Farm Bureau 2011). The risks associated with such events are comparatively higher than in other industry sectors and require more intense risk management strategies. Relatively few of the crops grown in the SE are covered by government risk management programs, which tend to favor the major agronomic crops such as corn, soybean, and wheat, which are relatively less important in the SE.

Land and water are the most important production resources in the agricultural sector. The costs for using these resources in agricultural production are affected by a number of factors including urban encroachment, competition for water from other sectors, sea level rise, effects of weather and climate, and land degradation. Major input costs that influence agricultural production include fuels, chemicals, seeds, labor, resource management, and marketing. Between 2002 and 2007, farm-related production expenses have increased 39%. Individually, costs for fuel and fertilizers increased more than 80% during this time (USDA-ERS 2010). The complexity of the agriculture sector requires management decisions that maximize production and minimize environmental impact on soils and water resources, in addition to mitigation of climate change and the adaptation to its likely effects (Lal et al. 2011).

## 7.2 Climate Sensitivities and Vulnerabilities

Agriculture is highly sensitive to climate variability and change. Increasing temperatures, changes in rainfall, and higher atmospheric CO<sub>2</sub> concentration affect agricultural production through various physiological mechanisms. In combination, these factors will increase or reduce agricultural production; the net effect will depend on interactions among these factors. Sea level rise and the potential for increased frequency of major hurricanes will have direct and indirect negative impacts on agriculture in coastal areas. Climate sensitivities and vulnerabilities also will affect productivity and production costs for animal production, under both free-range and confined conditions.

Adverse impacts of climate change on other economic sectors may increase the vulnerability of agriculture. For example, tourism and real-estate are important parts of the economy in most areas of the SE that have coastlines. With rising sea levels and the degradation of vulnerable coastal areas by storms and floods, the tourism industry is predicted to be substantially affected (ASP 2011). A study by Luscombe (2010) estimates that property values in the Florida Keys alone could be reduced by \$11 billion by 2100 through the impact of sea level rise. A negative growth in the tourism and real estate industries will affect the region's important food service sector through reduced demand for locally produced food, representing an important market for many agricultural businesses in the region (Borisova et al. 2008).

### *Potential Impact of Rainfall Variability and Change*

Changes in rainfall amounts can have both negative and positive effects on agricultural

production. For example, in low rainfall environments higher rainfall will increase growth, where less rainfall will further limit plant production. In contrast, in high rainfall zones, too much rainfall can result in waterlogging, which damages crop growth (Dracup et al. 1993, Jiang et al. 2008) or result in nutrient leaching in sandy soils (Anderson et al. 1998). Additionally, reduced rainfall on these same soils will limit the negative impacts of waterlogging and nutrient leaching.

Rainfall distribution also plays an important role for determining crop yields. Rainfall around the time of anthesis ensures water supply during the grain-filling period and is particularly critical for grain yield in annual crops (Fischer 1979, Hatfield et al. 2011). Future changes in growing-season rainfall distribution therefore will have an impact on crop growth and yield. Balancing growth and water use before and after anthesis is one of the tools to manage uneven rainfall distribution. Options for managing the seasonal water use by crops include sowing time, nutrient management, plant density, and cultivar choice (Fischer 1979, Hatfield et al. 2011).

Extreme events are predicted to include a higher drought frequency in the western part of the region, but there may be fewer droughts across the northern tier of the region and in the mid-Atlantic (see Chapter 2, Section 2.4.3). A higher drought frequency in the western part of the region will lead to reduced crop production and yields below what is expected based on the average climate change (Easterling 2007). Particularly critical are changes in rainfall intensity and the distribution of small versus large rainfall events (Hayhoe et al. 2007), which can have significant consequences for crop production via the impact on soil infiltration depth, water balance, soil mineralization, and crop water use efficiency (Sadras and Rodriguez 2007). Extreme precipitation events have been increasing across the southeastern region, particularly over the past two decades (see Chapter 2, Section 2.3.2). The annual number of days with extreme precipitation is expected to increase across most of the region, particularly along the Southern Appalachians as well as parts of Tennessee and Kentucky (see Chapter 2, Section 2.4.1). The greatest impact of rainfall variability on livestock and poultry systems will be the indirect consequences of higher feed costs for purchased inputs. The impacts of changes in rainfall on forage production have not been as thoroughly researched as those for crop production, but prolonged droughts could significantly alter these systems as very little forage land is irrigated. Selection of drought tolerant forages and improvements in grazing management to buffer against drought could aid producers in adapting to more frequent drought conditions.

### *Potential Impact of Temperature Change*

Temperature affects plant and crop-level processes that determine yield for all crops. Where crops are grown near their genotype specific limits of maximum temperature tolerance (Hatfield et al. 2011), heat spells can be particularly detrimental (Ferris et al. 1998). Conversely, in cooler regions, increased annual mean temperature since the 1980s has contributed to the reported increase in agriculture production (Yang et al. 2007).

Higher temperatures can negatively affect plant production indirectly as accelerated phenology (Menzel et al. 2006, Sadras and Monzon 2006) provides less time for accumulating biomass (Amthor 2001, Menzel et al. 2006) analyzed phenological data

from 125,000 time series for 542 plants in 21 European countries and found that for the period 1971 to 2000, 78% of all leafing, flowering, and fruiting events occurred earlier. Sadras and Monzon (2006) modeled in detail the effect of recently realized changes in temperature on phenological development of wheat, and found earlier flowering. However, unexpectedly, no changes were noted in the duration from flowering to maturity due to the shift of flowering to cooler parts of the season.

Extreme temperature events can have large negative impacts on plant growth and yield as shown for wheat (van Herwaarden et al. 1998). Temperatures below 9°C and above 31°C around anthesis (or flowering), can reduce potential grain weight and therefore yield (Calderini et al. 2001). Higher average temperatures can reduce the frequency of frost and frost damage (Baethgen et al. 2003). However, indirect effects of temperature, such as shifting flowering to “cooler” parts of the season, may lead to the paradox of increasing frost risk at flowering (Sadras and Monzon 2006).

The impact of increasing temperatures can vary widely between crop species. Plants carrying out the C4 photosynthesis process have higher optimum temperatures for leaf photosynthesis and plant growth (i.e., more productive under high temperatures but less responsive to higher atmospheric CO<sub>2</sub> concentrations) than plants utilizing the C3 photosynthetic process (Goudriaan and Van Laar 1994, Hatfield et al. 2011). Species with a high base temperature for crop emergence such as maize, sorghum, millet, sunflower and some of the legumes (e.g. mung bean and cowpea) (Angus et al. 1981, Hatfield et al. 2011) might benefit from increasing temperatures in cool regions. For most of the cereals; legumes, such as field pea and lentil; and linseed and oilseed crops with a low base temperature (Angus et al. 1981), a warming climate will result in an advanced phenology. For example, Sadras and Monzon (2006) showed that the date of wheat flowering in different environments is advanced about seven days per degree increase in temperature.

Climate change is likely to have greater impacts on minimum than on maximum temperatures (Nicholls 1997), and such changes in diurnal temperature range can have different effects on various crops. An increase of average temperatures, in the frequency of hot days, warm nights and in the length of the freeze-free season is projected for the SE, but projections for changes in diurnal temperature range are not specified (see Chapter 2, Section 2.4.2). However, Lobell and Field (2007) analyzed historical yield data of wheat, rice, and maize from the leading global producers and showed that an increase in diurnal temperature range was associated with reduced yields of rice and maize in several agricultural regions worldwide. This reflects the nonlinear response of yield to temperature, which likely results from greater heat stress during hot days (Lobell 2007). Peng (2004a) suggested that rice yields declined by 15% per degree Centigrade in minimum temperature due to wasteful night respiration, but this interpretation was challenged in subsequent studies (Sheehy et al. 2006a, Sheehy et al. 2006b). Baker et al. (1995) observed 10% loss in rice yield per degree above 25°C mean daily temperature, based on extensive experiments in sunlit, controlled environment chambers.

An indirect effect of increasing temperatures due to climate change likely will be higher water demand by plants due to increased transpiration, which can potentially reduce plant production (Lawlor and Mitchell 2000; Peng et al. 2004b). In dry-land

agriculture, this will directly limit plant growth, while in irrigated systems increased temperatures could result in higher irrigation demands in combination with increased losses through evaporation. However, if future temperature changes are similar to the changes in the last 50 years, where global minimum temperatures have generally increased twice as fast as maximum temperatures, resulting in a reduced diurnal temperature range (Folland et al. 2001), the impact of increasing temperatures on vapor pressure deficit and therefore on atmospheric evapotranspiration would be small (Farquhar et al. 1978). In addition, higher atmospheric CO<sub>2</sub> concentrations can partially compensate for the increased water demands due to higher temperatures, through lower stomatal conductance, which reduces transpiration (Kimball 2010). Reduced leaf transpiration as a consequence of higher CO<sub>2</sub> will also increase leaf temperature with an increased chance of plant damage due to heat stress. Plants grown at higher atmospheric CO<sub>2</sub> tend to have a higher leaf water potential, which results in reduced drought stress (Wall 2001).

Higher temperatures can also adversely affect grain quality as shown for grain protein content (Triboi et al. 2003, Zhao et al. 2008) and dough quality of wheat (Randall and Moss 1990; Wrigley et al. 1994). For some crops, night temperatures are critical for grain quality, as shown for fatty acid composition in sunflower (Izquierdo et al. 2002).

Increasing temperatures could have profound impacts on livestock and poultry producers. Heat stress in particular may lead to significant detrimental effects on production and reproduction of some livestock species. Heat stress in dairy cattle can have a long-term effect (weeks to months) on both milk production and birthing rates (Klinedinst et al. 1993). Dairy cows perform best under cool temperatures, with the temperature optimum for maximum milk production between 4°C and 24°C. At high relative humidity (>80%) heat stress in dairy cows can begin at temperatures as low as 23°C, and stress becomes severe at 34°C. Dairy farmers could adapt to warmer temperatures by renovating barns to improve their cooling systems, but these costs would have to be weighed against potential risks and benefits. Poultry animals are primarily grown in housed operations, so the effect of climate change more directly affects the energy requirements for building operation rather than a direct effect on the animal. Similar statements can be made for swine production as the vast majority of the animals are housed. Temperature affects animals being moved from buildings to processing plants, but because these animals are moved quickly from production to processing, this is a problem only in extreme conditions (Hatfield et al. 2011).

### *Potential Impact of Elevated Atmospheric CO<sub>2</sub> Concentrations*

Elevated CO<sub>2</sub> has two main effects on crop growth. It increases the intercellular CO<sub>2</sub> concentration leading to increased net photosynthesis rates, and at the same time reduces stomatal conductance resulting in reduced transpiration and improved water use efficiency (Farquhar et al. 1978). Many experiments have shown that higher CO<sub>2</sub> concentrations increase plant biomass production and yield (Drake et al. 1997, Garcia et al. 1998, Ma et al. 2007, Morison 1985, Tubiello et al. 2007, Kimball 2010, Hatfield et al. 2011). However, C3 species respond differently to elevated CO<sub>2</sub> than do C4 species (Allen et al. 2011, Prasad et al. 2005, Kimball 2010, Hatfield et al. 2011) (see Table 7.2)

**Table 7.2** Examples of C3 and C4 Species.**C3 Species**

- Small grains such as wheat, barley, oats, and rye
- Grain legumes such as soybean, peanuts, various beans and peas
- Root and tuber crops such as potato, sweet potato
- Most fruit (peaches, citrus), nut (pecans), vegetable and fiber crops (cotton); and cool climate forage and grassland species

**C4 Species**

- Maize, sorghum, sugarcane
- Many warm-climate grass species (Bahia grass)

Increases in CO<sub>2</sub> concentration increase photosynthesis more than crop yield; at 500 to 550 ppm, yields of C3 crops will yield 15% to 30% more, whereas C4 crops will yield 15% to 25% more (Kimball 2010, Tubiello et al. 2007, Long et al. 2006, Hatfield et al. 2011). On average, doubling CO<sub>2</sub> concentrations increases photosynthesis from 30% to 50% in C3 species, and from 10% to 30% in C4 species (Kimball 2010, Tubiello et al. 2007). Lobell (2007) summarized CO<sub>2</sub> effects from a number of open-top chambers and Free Air Carbon-Dioxide Enrichment (FACE) experiments with 0.07% grain yield increase in wheat per ppm CO<sub>2</sub> increase for up to 550 ppm.

The response of pasture species to elevated CO<sub>2</sub> is consistent with the general response of C3 and C4 vegetation to elevated CO<sub>2</sub>. Pasture species with C3 metabolism increase their photosynthetic rates by up to 40%, but not those with a C4 pathway (Hatfield et al. 2011). Unlike croplands, the literature for pasturelands is sparse in providing quantitative information to predict the yield change of pastureland species. Current information indicates forage yield responses of C3 versus C4 perennial forages to be similar to corresponding C3 or C4 annual crops (Hatfield et al. 2011). The projected increases in temperature and the lengthening of the growing season should be, in principle, beneficial for livestock by increasing pasture productivity and reducing the need for forage storage during the winter.

The impact of elevated CO<sub>2</sub> on plant production depends on water and nutrient availability. The greatest response to elevated CO<sub>2</sub> is found under water limiting conditions (Kang et al. 2002, Manderscheid and Weigel 2007, Kimball 2010) because higher CO<sub>2</sub> concentrations increase leaf and plant level water use efficiency (WUE) (Wu et al. 2004, Kimball 2010, Allen et al. 2011). Low nutrient availability can reduce the positive impact of elevated CO<sub>2</sub> on yield (Kimball 2010). The impacts of elevated CO<sub>2</sub> at field and farm levels are probably lower than those estimated in well-controlled experimental conditions because, due to production limiting factors such as low nutrient availability, pests, and weeds (Tubiello et al. 2007). An important indirect effect of higher atmospheric CO<sub>2</sub> is reduced plant nutrient concentrations, which can result in lower grain quality (Kimball et al. 2001, Rogers et al. 1996).

An indirect effect of elevated atmospheric CO<sub>2</sub> is an increase in canopy temperatures due to a reduction in stomatal conductance and therefore less evaporative cooling

(Kimball 2010, Hatfield et al. 2011). There is evidence in C3 plants, as found in experiments with wheat and cotton, that selection for improved grain yields in breeding programs is more successful when selecting for high stomatal conductance, resulting in heat avoidance through evaporative cooling in hot environments (Amani et al. 1996, Lu 1994, Radin et al. 1994). Reduced stomatal conductance in response to increased atmospheric CO<sub>2</sub> might therefore have additional effects on crop growth and development similar to an increase in temperatures (Allen et al. 2011).

#### *Potential Impact of Tornados, Hurricanes, and Sea Level Rise*

High wind speeds of tornados and hurricanes can damage summer crops through lodging (falling over) which can make crops unharvestable. The impacts on confined poultry or livestock can be devastating if facilities are destroyed resulting in long periods without production and considerable animal mortality. Heavy rainfall from hurricanes can lead to soil water-logging, delays in harvesting, degraded crop quality and overall yield losses. Sea level rise will affect ground water availability for irrigation near the coast due to salt water intrusion. During drought periods, there can be greater levels of salinity intrusion up coastal rivers affecting surface water withdrawals. In addition, retreating urban populations from the current coast line will put pressure on agricultural areas (Spechler 2001).

#### *Potential Combined Impact of Climate Change*

Rainfall, temperature, and CO<sub>2</sub> concentrations do not change independently but interact with each other and are highly complex (Hatfield et al. 2011). To develop climate change adaptation strategies so that crop production can remain stable in a changing climate, it is important to sufficiently understand the complexity of natural systems and how these are affected by changing climatic factors (Boote et al. 2011). Wheeler et al. (1996) showed that a positive yield effect in wheat from 700 ppm elevated CO<sub>2</sub> in the UK could be offset by an increase in mean seasonal temperatures of 1°C to 1.8°C. It is important to understand the interactions before developing climate change adaptation strategies because, for example, adaptations to higher temperatures may be different from adapting to reduced rainfall (Ludwig and Asseng 2010, Tubiello et al. 2007). Another study by Allen et al. (2011) based on experiments with maize and sorghum, suggests that drought stress in C4 crop plants can be ameliorated at elevated CO<sub>2</sub> as a result of lower stomatal conductance and sustaining of intercellular CO<sub>2</sub> concentration. Furthermore the study suggests, that C4 crops may require less water under future higher atmospheric CO<sub>2</sub>.

In livestock and poultry production, Reynolds et al. (2010) stated that changing climate would affect the following: (1) the suitability of land, (2) availability of land due to sea level rise, (3) water availability and quality, and (4) production efficiencies under drought conditions.

As local environmental conditions change, so too will the spread of livestock diseases in response to the changes in prevalence of the host species and the suitability of environmental conditions for pathogen transfer. Van Dijk et al. (2010) found clear evidence that climate change has already changed the overall abundance, seasonality, and spatial spread of endemic helminthes (parasitic worms in cattle) in the UK. Warming

and changes in rainfall distribution may lead to changes in spatial or temporal distributions of those diseases sensitive to moisture such as anthrax, blackleg, *haemorrhagic septicaemia*, and vector-borne diseases (Hatfield et al. 2011). Pastureland response to climate change will likely be complex because, in addition to the main climate drivers, other plant and management factors might also influence the response (e.g., plant competition, perennial growth habits, seasonal productivity, and plant-animal interactions).

### *Climate Change Impact in the Southeast USA*

A previous SE regional climate change assessment report summarized impacts of climate change on agriculture, forestry, air, and water quality (Ritschard et al. 2002). The effect of climate change on the crops studied in the report could be positive or negative, depending on location and crops. Dryland crops are expected to be more sensitive to climate change: a decline of 20% rainfall and an increase of 2°C temperature will cause yield losses from 10% to 15% by 2030 (Ritschard et al. 2002). Irrigated crop yields will decrease by 10%, except for rice, peanut, and soybean, which will increase 10% to 20% by 2030. The agriculture sector will likely be able to adapt to mild increase of temperatures of 1°C by 2030 provided rainfall increases. An increase in temperature will cause row crops growing in Alabama, north Florida, and southwest Georgia to shift north towards central Georgia, South Carolina, and North Carolina. Access to water for irrigation has been identified as the largest challenge to adapt to declining rainfall. Although some regions in the SE have access to shallow groundwater tables for irrigation, these areas are at risk of salt water intrusion from projected sea level rise (Ritschard et al. 2002). Also, competition for freshwater among the agricultural industry, urban communities, and ecological sectors will continue to increase. Recommended strategies to adapt to climate variability and change include improved seasonal forecasts, drought and heat stress resistant crops and livestock, adjustments of planting dates, and improved water management and fertilization practices to keep water reserves clean and available for the growing demands (Ritschard et al. 2002).

Hatfield et al. (2011) showed how future climate change likely will affect crops differently across the USA, due to different crops responses (e.g., C3 versus C4 plants), but also different base conditions (warmer in south versus cooler in north). For example, yields of maize and soybean likely will be less negatively affected in the Midwest than in SE, where increasing CO<sub>2</sub> (440 ppm) and temperatures (+0.8°C) will be more detrimental because of the fundamentally warmer climate in the South (Hatfield et al. 2011).

Higher temperatures will increase the atmospheric evaporative demand for water, thereby increasing evapotranspiration (ET). The effect of warmer temperatures on evaporative demand might be offset in part if warmer temperatures increase cloud cover. Higher atmospheric CO<sub>2</sub> is predicted to stimulate crop growth but also increase water use efficiency. Increasing temperature and CO<sub>2</sub> effects are of the same magnitude by 2040 in the USA (440 ppm, +0.8°C) but act in the opposite direction. The combined impacts of these effects will mean that the net changes to evapotranspiration likely will be minimal (Hatfield et al. 2011).

Climate changes will adversely affect the economic viability of livestock production systems. Surrounding environmental conditions directly affect mechanisms and rates of heat gain or loss by all animals. Lack of prior conditioning to extreme weather

events (such as extreme heat, frost, and flooding) often results in catastrophic losses in the domestic livestock industry. In the central USA in 1992, 1995, 1997, 1999, 2005, and 2006, some intensive cattle feeding operations lost in excess of 100 head each during severe heat episodes (Hatfield et al. 2011). Economic losses from reduced cattle performance (morbidity affecting measures such as rate of weight gain, milk production per day, eggs per day) likely exceed those associated with cattle death losses by several-fold (Mader 2003). The risk potential associated with livestock production systems due to climate variability can be characterized by levels of vulnerability, as influenced by animal performance and environmental parameters (Hahn 1999). When combined performance level and environmental influences result in a low level of vulnerability, there is little risk. As performance levels (e.g., rate of weight gain, milk production per day, eggs per day) increase, the vulnerability of the animal increases and, when coupled with an adverse environment, the animal is at greater risk. Combining an adverse environment with high performance pushes the level of vulnerability and consequent risk to even higher levels. At very high performance levels typical of much of the highly efficient production in the SE, any environment other than near-optimal may increase animal vulnerability and risk.

The potential impacts of climatic change on overall performance of domestic animals can be estimated using defined relationships between climatic conditions and voluntary feed intake, climate data, and Global Climate Model (GCM) outputs. Because ingestion of feed is directly related to body heat production, any change in voluntary feed intake or energy density of the diet will change the amount of body heat produced by the animal (Mader et al. 1999). Ambient temperature has the greatest influence on voluntary feed intake. Body weight, body condition, and level of production affect the magnitude of voluntary feed intake and the level of ambient temperature at which changes to voluntary feed intake begin to be observed. Predicted climate outputs from GCM scenarios have been used to develop production and response models for growing confined swine and beef cattle, and milk-producing dairy cattle (Frank et al. 2001). The goal in the development of these models was to utilize climate projections, primarily average daily temperature, to estimate direct climate-induced changes in daily voluntary feed intake and subsequent performance across the entire country. The production response models were run for one current (pre-1986 as baseline) and two future climate scenarios: doubled CO<sub>2</sub> (~2040) and tripled CO<sub>2</sub> (~2090) levels. This database employed the output from two GCMs—the Canadian Global Coupled (CGC) Model, Version I, and the United Kingdom Meteorological Office/Hadley Center for Climate Prediction and Research model—for input to the livestock production and response models. Across the entire USA, production levels for livestock showed declines, including days to market swine, which increased 1.2% for the CGC and 0.9% for the Hadley model; days to market for beef, which increased 2.0% for the CGC and 0.7% for the Hadley model; and dairy milk production, which decreased 2.2% for CGC and 2.1% for the Hadley model. Swine and beef production were affected most in the south-central and SE USA. Dairy production was affected the most in the Midwest and Northeast. In the east-central USA, per animal milk production declined 388 kg (~4%) for a July through April production cycle, and 219 kg (~2.2%) for an October through July production cycle as a result of global warming. Swine growth rate in this same

region was found to decline 26% during the summer months, but increased nearly 12% during the winter months as a result of climate changes. Between 1995 and 2010, the SE USA experienced a decline in milk production of about 37%. Approximately one-half of these summer domestic livestock production declines are offset by improvements in productivity during the winter.

Amundson et al. (2005) reported a decrease in pregnancy rates of cattle of 3.2% for each increase in average Temperature Heat Index (THI) above 70, and a decrease of 3.5% for each increase in average temperature above 23.4°C. These data were obtained from beef cows in a range or pasture management system. Minimum temperature had the greatest influence on the percent of cows getting pregnant. Clearly, increases in temperature or humidity have the potential to affect conception rates of domestic animals not adapted to those conditions.

A range of reviewed subregional and state-based assessments and impact studies predicting direct and indirect impacts on the agricultural sector in the SE region are summarized in the following sections. Examples of damages and losses associated with recent extreme events are used to illustrate current vulnerability to climate. Some opportunities for agriculture to contribute to mitigation are also highlighted.

**Virginia.** Increased storm surges and flooding are projected due to higher sea levels on 5,335 km of Virginia tidal shoreline. The state is highly susceptible to damage from hurricanes, storms, and water surges that are forecast to intensify and are likely to result in increasing economic damages and losses. Virginia can play an important role in reducing fossil carbon emissions as it has an abundance of required resources for biomass combustion, including mill and crop residues (Commonwealth of Virginia, ASP 2011).

**North Carolina.** In the last hundred years average temperatures increased by 0.67°C with a further 2.2°C projected for the next century (CIER 2008a). Such increase in global temperature likely will shrink North Carolina's booming \$70.8 billion agricultural industry by nearly 23% by the end of the century (CIER 2008a). Between 1996 and 2006, 14 tropical storms and hurricanes caused more than \$2.4 billion of damage to the state's agricultural industry (CIER 2008a). The state's 2002 drought cost the industry \$398 million and affected over 4,300 jobs (NCSL 2008). The Appalachian region livestock industry is projected to lose 10% of its yield through heat stress due to an increase of 5°C by the end of the century (CIER 2008a).

**Tennessee.** Temperature increases are predicted to negatively affect Tennessee soybean and corn yields and the industry (USDA-ERS 2010). Higher temperatures could impact negatively the lifespan of the Kentucky-bluegrass, an important turf grass (ASP 2011).

**South Carolina.** Agriculture accounts for 14.8% of South Carolina's GDP (ASP 2011). One-quarter of the state's 17.7 million hectares has been converted to farmland; and agriculture accounts for around \$17 billion annually which correspond to about 8% of the state gross domestic product. Expected temperature increases are likely to hasten the maturation of plants, thus reducing total yield potential (SCSCO 2012). The US Environmental Protection Agency projects that South Carolina's soybean and wheat yields will fall by 42%, and its corn yields by 32%, with predicted rising temperatures

by 1.7°C to 3.9°C between 2030 and 2100 (Carpio et al. 2008). Climate change will lower agricultural productivity in the long term for South Carolina due to increasing extreme weather events, pest infestations, and a northward shift of optimal production areas (von Lehe 2008).

**Alabama.** A study by Davenport (2007) suggested that in Alabama, traditional crops such as peach, apple, soybean, and wheat will suffer from climate change. In addition, more pesticides and herbicides will be required under any of the projected climate scenarios. However, increasingly favorable conditions are likely for cotton, corn, and new citrus crops. The Union of Concerned Scientists notes that 27% of the major roads, 9% of rail lines and 72% of ports within the region are built at or below sea level. Alabama's interconnectedness threatens its economy, inclusive of the agricultural sector (ASP 2011). Of the 70 natural disasters, related to extreme climate events, between 1980 and 2007 that caused \$1 billion or more in damage nationally, at least 21 affected Alabama (Lott and Ross 2006).

**Georgia.** Analysis based on the 2007 IPCC projections suggests that by 2020, corn yields will drop by 15% and winter wheat yields will drop by 20% in parts of Georgia (IPCC 2007). However, soybean and peanut yields could increase as much 25% in northern Georgia and drop by 5% in the southern part of the state (CIER 2008b). The 2007 drought cost Georgia \$1.3 billion in damages including crop losses of \$83.8 million in hay, \$160.1 million in cotton, \$92.5 million in peanuts, and \$63.1 million in corn (CIER 2008b).

**Florida.** Sea level rise, in combination with increased frequency and intensity of storms, projected increases in the number of major hurricanes, and associated seawater surges, is predicted to be the largest threat to Florida (see Chapter 2, Sections 2.4.5 and 2.4.6). For instance, a Natural Resources Defense Council report uses sea level rise projections of the 2007 IPCC Report to estimate that by 2060 16% of the Miami-Dade County will be inundated with water (IPCC 2007). Miami-Dade County produces more than \$661 million annually in agricultural produce (2007), and is the second largest agricultural producing county in Florida (Hauserman 2007, Stanton and Ackerman 2007, USDA-ESR 2010).

Hurricanes are predicted to cost the state economy, including agriculture, \$6 billion annually in 2025, increasing to \$25 billion by 2050 (Hauserman 2007, Stanton and Ackerman 2007).

Florida's agricultural industries are predicted to be affected by higher temperatures, water scarcity, flooding of farmland that will cause crop losses and erosion, increased water demands, and increased costs for irrigation. Higher temperatures might lessen the likelihood of crop damaging winter freezes. By 2060, some scenarios project that floods will claim 10,400 ha of farmland, 1,800 ha of pasture, and 2,800 ha of Florida's citrus crop (Stanton and Ackerman 2007, Borisova et al. 2008). Preserving a sustainable citrus production in Florida could provide opportunities to expand the production of ethanol from citrus waste (USEIA 2010).

**Mississippi.** Warmer temperatures and less rainfall are expected to require additional irrigation to maintain the \$4.8 billion agricultural industry in Mississippi (ERS, 2010,

Wilbanks et al. 2010). Higher temperatures are also predicted to increase pests and weeds, and reports suggest that one of the most used and cost-effective herbicides, glyphosate, will be less effective under conditions of higher concentration of carbon dioxide (ASP 2011). The state's vulnerable aquaculture industry (see Chapter 9) will be under threat as a result of shrinking freshwater supplies, increasing salinization, warmer water temperatures, and contaminated runoff from high precipitation events (Twilley and Miller 2001). Opportunities exist for increased soybean-based biodiesel production, cellulosic ethanol made from crop residues, and renewable energy production from swine, poultry and dairy industries. Mississippi already has the nation's first methane producing system from poultry waste (ASP 2011).

**Arkansas.** The agricultural industry in Arkansas contributes \$16.3 billion to the state's economy (UoA 2010). The impacts of climate change are predicted to lead to increased industry costs of production and reduced yields, causing a decrease in the sector's profitability according to an analysis of effects of 2009 weather conditions on crop production (Hignight et al. 2009). Twenty-two percent of the state's agricultural land lies in flood zones resulting in concerns over increased soil erosion (ASP 2011). Abnormal weather events, projected to increase in the future, caused an estimated loss of revenues close to \$397 million in 2009—204 million for soybeans and \$46 million for rice. Production levels of rice are expected to drop in the Mississippi Delta by 10% to 20% (Hignight 2009). Agriculture has great potential to help Arkansas reduce its carbon emissions through production of biodiesel and cellulosic ethanol using crop residues, which has the potential to replace 40% of the gasoline used in the state (ASP 2011, Cohen 2009).

**Louisiana.** The low-lying coast of Louisiana, including New Orleans, could be entirely under water by 2100 due to sea level rise (ASP 2011). The state currently loses wetlands at a rate of 6,200 ha annually (ASP 2011). Impacts of climate change include increased occurrences of storms, major hurricanes, and floods (Wilbanks et al. 2010) and also increased droughts in some regions (see Chapter 2, Section 2.4.3) that are expected to impact the state's agricultural industry (ASP 2011).

### 7.3 Adaptation to Climate Change and Variability in the Southeast USA

Climate change effects clearly will have impact on agriculture in the Southeast. Various types of adaptation can protect and even improve farm productivity. Adaptation has the potential to help farmers minimize negative effects or take advantage of positive effects of a changing climate. In most cases, adaptation to climate change in agriculture will occur locally, at the farm level, in response to and as preparation for local impacts of local or regional changes in rainfall and temperature and global changes in atmospheric CO<sub>2</sub> concentrations. Therefore, understanding the local impacts of regional climate change is a prerequisite for any adaptation strategy, since adaptations are devised at the local level in response to local conditions (Figure 7.2).

Most recent adaptations in agriculture in the SE USA relate to improved management in dealing with climate variability that includes frequent droughts, heat, frost,

and high wind speeds. Recently, a better understanding of seasonal variability has emerged from climate-related agricultural research in the SE USA (Alexandrov and Hoogenboom 2001, Garcia y Garcia et al. 2006, Persson et al. 2011), the forecasting of seasonal climate (Bannayan and Hoogenboom 2008, Garcia y Garcia et al. 2010b, Olatinwo et al. 2010, Olatinwo et al. 2011, Royce et al. 2011), managing anticipated seasonal variability (Alexandrov and Hoogenboom 2001, Garcia y Garcia et al. 2006) and the management of climate-related pest and diseases (Boote et al. 2008). Studies on managing seasonal climate variability include research on farm-level risk management using irrigation (Lin et al. 2008), alternative crop insurance indices (Deng et al. 2008), optimizing crop insurance (Cabrera et al. 2006), spatial drought stress assessments (McNider et al. 2011), and the development of weather research and forecasting decision support tools (Olatinwo et al. 2011). For example, management tools for adaptation are available through AgroClimate. This widely-used climate-based decision support system, includes tools for seasonal forecast for much of the SE, including planting date scheduler, growing degree days and chill units tools, drought indices, and a host of other decision aids delivered via the Internet ([www.agroclimate.org](http://www.agroclimate.org)) (Fraisie et al. 2006).

Due to the relatively small changes in past climatic factors (rainfall, temperature, and CO<sub>2</sub>), little adaptation has occurred that is exclusively related to historically experienced climate change. A number of researchers have studied the potential effects of

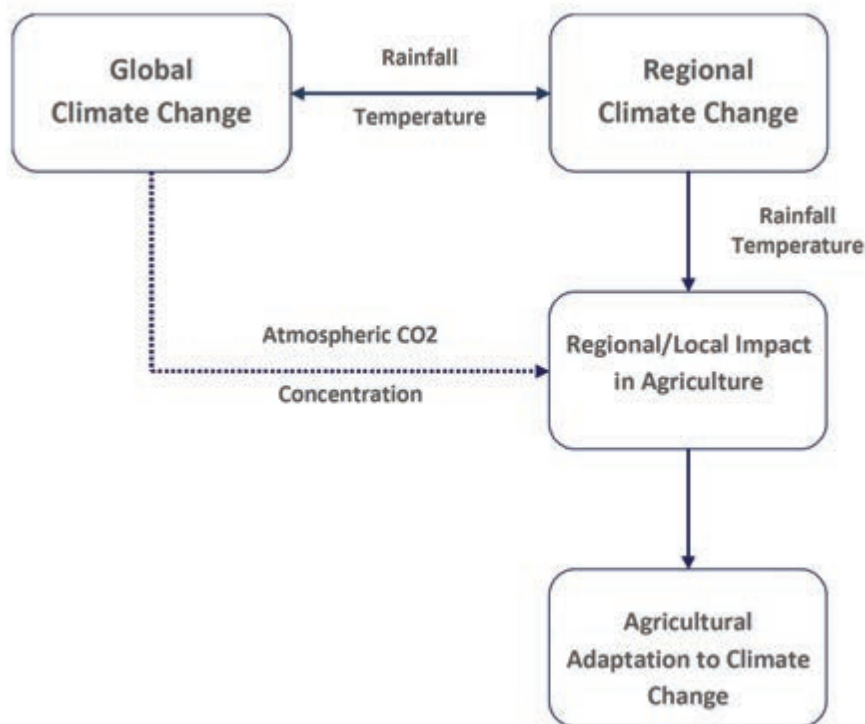


**Figure 7.2** Relationship of global climate change, regional/local climate change, agricultural impact and agricultural adaptation to climate change.

changing climate and atmospheric CO<sub>2</sub> on agriculture (Bannayan et al. 2009, Ben-Asher et al. 2008, Garcia y Garcia et al. 2009, Garcia y Garcia et al. 2010a, Yoon et al. 2009) to prepare for climate change. Others have investigated these impacts on the future of agriculture assessing the potential for adaptation (Crane et al. 2011, Furman et al. 2011, Persson et al. 2011, White et al. 2011). For instance, alternative crops for ethanol production, as an important strategy for climate change mitigation, have been investigated in a number of studies (Persson et al. 2010a, Persson et al. 2009a, Persson et al. 2009b, Persson et al. 2010b).

### *Current Adaptation Strategies in Crop Production*

Several possible adaptation strategies have been suggested to optimize crop production to local climate and to adapt to climate variability. Such methods will also assist in adapting crops to future climate change trends. Farmers in the SE have been testing a number of these new technologies, including sod-based rotation, conservation tillage, the usage of high biomass cover crops in combination with strip tillage and precision nutrient placement, optimum irrigation and fertilizing strategies, and decision support systems such as AgroClimate.

***Sod-based rotation.*** A sod-based rotation is a four-year rotation that includes two years of bahia grass pasture/hay, followed by peanut, a winter cover crop, and cotton. The system has greater water-use efficiency as a result of increased soil organic matter and increased root activity at greater depths. The root mass produced by perennial grass is 20 mg/ha, compared with annual cover crops that produce only 3 to 4 mg/ha root mass. In addition, this system achieves greater efficiency of nutrient with less nitrate leached into ground water, greater soil cover for moderation of high temperature extremes, and reduced erosion. Other benefits include slower decomposition of crop residues that enhance opportunities for C sequestration and better yields at lower than conventional rates of fertilizer N, potentially mitigating greenhouse gas emissions (Wright et al. 2012).

***Sustainable soil management strategies.*** Conservation tillage is one of the sustainable soil management strategies adopted in the SE. Conservation tillage is defined by USDA-NRCS as a system that leaves enough crop residues on the soil surface after planting to cover at least 30% of the soil area. Conservation tillage reduces climate risks through reduced runoff, increased water infiltration, increased plant-available water, reduced soil water evaporation, and reduced diurnal temperature fluctuations (Smith et al. 2011).

***High biomass cover crops with strip tillage, and precision nutrient placement.*** The use of high biomass cover crops and limited tillage reduces impacts from weather extremes such as intense rainfall events, short-term spring/summer droughts, and extreme soil temperature during critical crop reproduction periods. Keeping the soil covered year round with crop residue, cover crops, or cash crops reduces soil erosion, improves water infiltration, reduces evaporative moisture loss, and moderates soil temperature. Precise nutrient placement improves nutrient efficiency during weather extremes.

**Variable-rate irrigation.** Variable-rate irrigation (VRI) is an innovative technology that retrofits existing center pivot systems and integrates GPS positioning with a control system that cycles individual sprinklers or groups of sprinklers on and off and varies travel speed to achieve desired irrigation rates within management zones. VRI reduces climate-related risks through reduction of total irrigation water volume required to grow field crops, exclusion of non-crop areas from water application; enhanced ability to tailor water application to varying crop needs across the field; better matching of irrigation application to site-specific soil types, textures, and topography reduction of nutrient leaching by application of optimal irrigation volumes; and reduction or elimination of runoff by better managing water application.

**Micro-irrigation.** Micro-irrigation is the slow, frequent application of water directly to relatively small areas adjacent to individual plants through emitters placed along a water delivery line, for example, drip irrigation. Micro-irrigation can help farmers adapt to climate changes through improving water use efficiency and reducing irrigation water volume required to grow crops, flexible irrigation based on the difference between potential and actual crop evapotranspiration, reduced nutrient leaching, optimal timing of nutrient applications, and application of fertilizer directly in the root zone. In addition, micro-irrigation is compatible with plastic mulch, which helps soil water conservation and protects fertilizer from leaching. Micro-irrigation via micro-sprinklers also provides freeze protection for small, high-value crops, such as strawberries. Information on these various methods is available through publications from IFAS ([www.edis.ifas.ufl.edu](http://www.edis.ifas.ufl.edu)).

**Sensor-based, variable-rate nitrogen management.** A sensor-based, variable-rate nitrogen application (SVNA) system for irrigated and dry land cotton reduce, production costs through the use of a nitrogen-rich calibration strip (NRCS) that guides mid-season nitrogen fertilization. The NRCS guidelines are adjusted for seasonal climate variability that arises in response to El Niño and La Niña events. Although the system will not mitigate risks from drought, excess rainfall, and temperature extremes, the technology can significantly reduce the nitrogen footprint for crop production to reduce greenhouse gas emissions.

**AgroClimate: Information and tools for climate-smart agriculture.** AgroClimate is a Web-based climate information system that includes seasonal forecasts and numerous management options for different crops/climate scenarios and tools that help producers in much of the SE plan for the season ahead. Users can also monitor variables of interest such as growing degree days, chill hours, disease risks for selected crops and drought conditions. Growers can use AgroClimate to reduce climate-related risks through tracking seasonal climate outlooks to better understand how climate conditions might affect crops, learn how El Niño and La Niña events affect the local climate, to explore how El Niño and La Niña phases affected crop production in much of SE USA, to help determine optimal planting dates for predicted climate, to select crops and varieties better suited for the expected climate, and to improve monitoring of disease risks for selected crops. In addition growers can monitor soil moisture conditions using several drought indices and be alerted via e-mail and mobile phones about

detrimental soil conditions for specific crops (Fraisie et al. 2006). For more information and to use AgroClimate, go to [www.agroclimate.org](http://www.agroclimate.org).

***Livestock and poultry adaption strategies.*** Livestock production systems have adapted slowly over a long period of time to suit local environmental conditions, such as water and forage availability. In animal agriculture, adaptation technologies have been studied far less than mitigation options. Priorities include (1) use of species-rich mixtures, legumes, and better adapted forage species and cultivars adaptation in forage lands; (2) permanent pasture management by changes in grazing frequency to favor the maintenance of high-digestibility species and to increase tolerance to drought stress; (3) use of intercropping with legumes and use of  $C_3$  and  $C_4$  species of feed crop mixes; (4) integrated control options to reduce the spread and impacts of gastrointestinal parasites, especially in ruminant production systems; (5) provision of more shade or water in extensive grazing systems and development of improved technologies for reducing heat stress impacts in confined systems; (6) changes in livestock and poultry breed selection and selection to favor animals that are more tolerant of local conditions; and (7) development of improved tools to provide producers with warnings of when temperature heat indexes are nearing threshold levels so that producers can take action to avoid losses.

### ***The Capacity for Agricultural Stakeholders to Adapt to Climate Change***

Adaptive capacity is an emergent property that confers resilience to perturbation (shocks), giving ecological and human social systems the ability to reconfigure themselves with minimum loss of function. In human social systems, it is demonstrated by the stability of social relations, the maintenance of social capital and economic prosperity (Gunderson and Holling 2000, Folke et al. 2003, Yohe and Tol 2002). One past example of adaptive capacity in the SE USA was the ability of the citrus industry to relocate southward from its original location around Charleston, SC, to its current location in Central and South Florida, following a series of disastrous freezes starting in the late 19th century. Another case was the widespread adoption of zebu or Indian cattle breeds along the gulf coast that are more resistant to heat and tropical diseases than the traditional European cattle. In general, hardier, more heat-resistant varieties of fruits and vegetables have been developed and adopted for the subtropical SE USA. It must be emphasized, however, that these adaptations were purely technical and reactive.

The capacity for agricultural stakeholders to adapt proactively to climate change is determined by more than their access to appropriate technologies or management practices. For instance, social, political, and economic factors also shape adaptive responses. These include, but are not limited to, the ways in which agricultural stakeholders perceive the impacts and risks of long-term climate change, their access to and use of climate information; the ways in which they are actively connected within knowledge and community networks; and their capacity to address problems at household and farming system levels, in addition to those infrastructural, market, and policy barriers that limit options for adaptation.

A politicized struggle to shape public understanding of climate change in the USA has polarized the debate in the media. The scientific consensus is framed through

elements of dread and uncertain risk, while climate change deniers portray climate change as natural, familiar, and improbable (Weber and Stern 2011, Leiserowitz et al. 2008). Within this context, many agricultural stakeholders in the SE USA may find it difficult to assess the risks that climate change presents (Ingram et al. 2012). Furthermore, because farmers manage many different types of risks on a day-to-day basis, the potential impacts of long-term climate change might not always motivate immediate concern (Ingram et al. 2012). Studies have shown that political ideologies also correlate strongly with belief in climate change as seen among organic farmers (Furman, et al. 2009) and African farmers in the southeastern states (Bartels, et al. 2012a, b). Another study demonstrated, for instance, that conservative white males are more likely to be climate skeptics (McCright 2010). In the SE, only one-eighth of the farm operators are women, with an average age from 56 to 58. The majority of farmers in the SE who are likely to make management decisions in the agricultural sector are older, more conservative, white men (USDA 2007).

The challenge of communicating about climate change with more skeptical audiences is being addressed within the SE Climate Consortium (SECC) by focusing initial discussions on climate-related issues that are of more urgent concern to growers. At state and local scales, governments are also engaged in cross-agency collaborations to communicate about issues that are linked directly (and indirectly) to managing climate-related risks. For instance, the Water and Agricultural Policy Division of the Florida Department of Agriculture and Community Services is engaging agricultural stakeholders around issues of water quality and quantity through best management practice programs. The manner in which scientists or government agency representatives begin to engage with farmers about climate change can influence their receptiveness to exploring adaptation options. By focusing on climate issues that resonate strongly with growers, researchers can open the door to future discussions about longer-term changes (Bartels et al. 2012a). For example, due to the strong influence of La Niña and El Niño on agricultural production in the SE USA, seasonal variability and extreme events are areas where scientists have the best potential to engage with farmers in implementing on-farm adaptation strategies (Ingram et al. 2012). In surveys conducted with row crop farmers, extension specialists, and researchers, respondents indicated that weather or seasonal forecasts were more useful to them than longer-term projections (Figure 7.3, Bartels et al. 2012a). This was also demonstrated in studies by Crane et al. (2010) and Furman et al. (2011). A large body of research and extension within the SECC has centered on providing farmers and extension professionals with seasonal climate forecasts and coproduction of decision support tools to reduce climate-related risks (Breuer et al. 2008, Breuer et al. 2009, Cabrera et al. 2008, Furman et al. 2009, Fraisse et al. 2009, Fraisse et al. 2006, Ingram et al. 2012). Approaches developed and knowledge gained from projects that have helped farmers manage risks from seasonal climate variability are now being applied to new projects to help farmers adapt to climate change.

Enhancing farmer use of climate information also requires an understanding of the social nature of risk management and information processes. For instance, social networks are important for processing information (Crane et al. 2010). Farmers discuss weather and climate at social gatherings, when doing business with buyers and brokers, or at meetings with extension agents (Crane et al. 2010, Furman et al. 2011). The

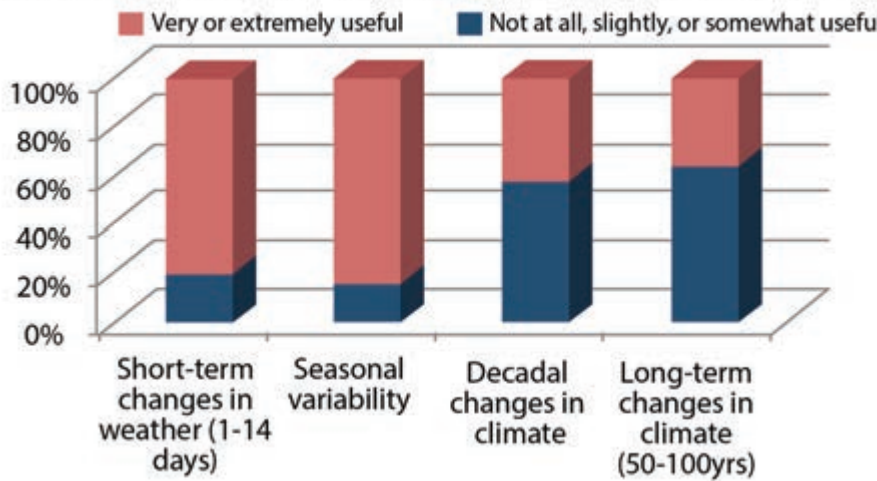
**Perceived usefulness of forecasts and projections at specific timescales (N=57)**

**Figure 7.3** Perceived usefulness of forecasts and projections at specific timescales among row crop stakeholders (N=57) in the SE USA (Bartels et al. 2012a).

extension systems within the land-grant universities provide boundary organizations that link scientists to farmers for information diffusion and decision support. A survey of Florida extension agents found that between 2005 and 2009, knowledge and willingness to use and provide climate information to end users increased on average, and extension agents had refined their understanding of the types of climate information that are most useful (Breuer et al. 2010). These findings highlight the importance of receiving feedback from stakeholders about technologies. Such feedback can guide the development and dissemination of decision support tools that are accessible and relevant to the specific needs and goals of farmers. Valuable stakeholder input can be assessed further through interactive, participatory methods that explore farmers' perceptions, attitudes, long-term goals, and other cognitive and decision-making information before and during the development of decision support tools and systems (Breuer et al. 2008, Breuer et al. 2009, Cabrera et al. 2008, Fraisse et al. 2006). Fraisse et al. (2009) provide a framework for developing an extension program that combines climate variability and climate change (Figure 7.4).

Interactive venues in which farmers can exchange knowledge about adaptation technologies can enhance learning among all stakeholders. In this way, the thoughtful design of stakeholder engagement processes becomes a powerful social tool for improving adaptation decision support (Bartels et al. 2012b). A regional climate working group in the SE that includes farmers, extension agents, and researchers from Alabama, Florida, and Georgia meets biannually to foster knowledge exchange about climate and adaptation among scientists, farmers, and extension professionals. Historical timelines and storytelling have revealed the many ways in which growers have adapted to past changes and seasonal variability in climate. In assessing the barriers and opportunities for adapting farming systems these workshops reveal that farmers are familiar with several farm-and-field level management practices and planning decisions that can

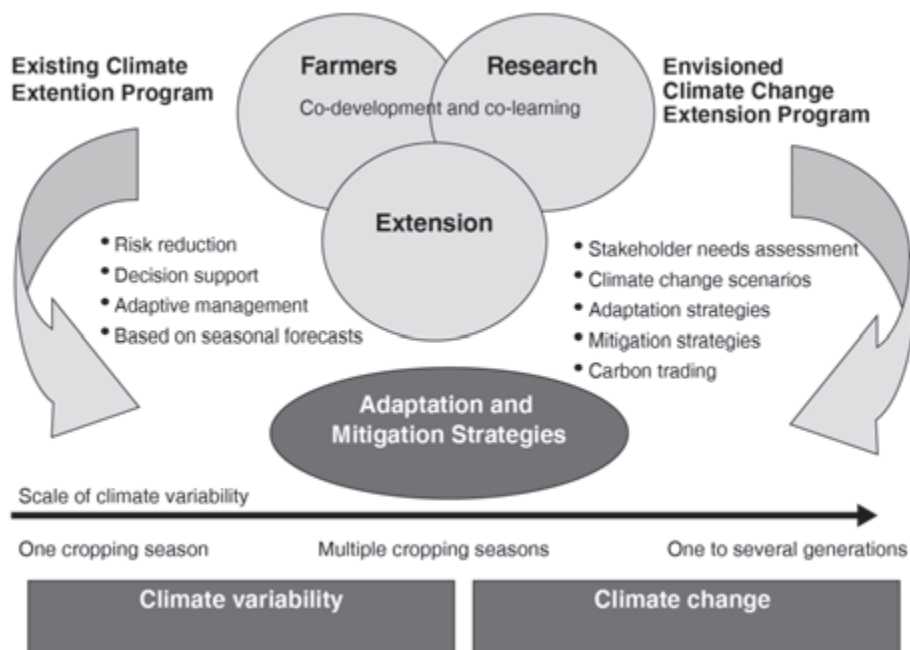


**Figure 7.4** Framework for a combined climate variability and change extension program (Fraisie et al. 2009).

reduce climate-related risks. They are able to change crops or varieties, planting dates, tillage practices, or pesticide and irrigation schedules. However, they perceive a lack of control over other factors, such as the federal farm bill, access to industrial infrastructure such as peanut shellers and cotton gins, and changes in commodity prices that drive planting decisions. One grower, for instance, reported that “as far as what crops were going to be grown 20 years from now, the farm bill probably impacts what farmers are gonna’ grow more than anything.” These findings point to the importance of moving discussions beyond farm-level decision making to embrace other scales of influence, for example, policy making circles that can influence the availability of potential adaptation options such as irrigation systems, crop insurance, or credit services (Bartels et al. 2012a).

Farmers constantly navigate and negotiate biophysical and socio-economic processes. Values, norms, meanings, and goals affect the way farmers perceive and respond to climate information. In addition, some livelihood systems are more flexible than others in terms of the ease with which farmers can integrate new technologies (Crane et al. 2010). For example, although awareness has grown among organic farmers in Georgia about the potential economic incentive offered by emerging markets for carbon credits, these farmers are not always able to implement practices that reduce emissions and sequester carbon. Smaller farms, including most organic farms, are easier to manage with manual tools than larger farms and new farmers might be less likely to afford the extra labor and costs required by strategies that seek to reduce carbon emissions (Furman et al. 2011). Farmers in central and northern Florida, who

have more diversified and smaller operations, tend to place more importance on seasonal climate variability and are better positioned to respond to climate predictions (Breuer et al. 2010). Similarly, dryland farmers face very different adaptation challenges than do farmers who have irrigation systems. Therefore, to be effective, climate communication and education strategies must be designed to target specific commodity audiences, farming systems, and household types rather than a one-size-fits-all approach to adaptation (Bartels et al. 2012a, Furman et al. 2011, Crane et al. 2011). When viewing agriculture as a complex system of practices, climate information should be integrated gradually and experimented with over time. In this way, farmers will learn to employ these new technologies and adapt them to their own particular circumstances (Crane et al. 2010). For example, an Alabama extension professional and member of the row-crop climate working group reported that long term changes in agriculture are needed but that such changes are difficult. “It’s about like trying to turn a cruise ship, you know. You don’t turn a sharp left or a sharp right, ok, but you can start bending in one direction or another... I think that this kind of climate data and information can help make those minor shifts in one direction or another” (Bartels et al. 2012a).

## 7.4 Assessment and Research Needs

Climate change impact and adaption research needs in agriculture include general research needs relevant also to other agricultural regions and other sectors. However, some of the research needs are more specific to agriculture in the SE USA.

### *General Research Needs*

Current climate change impact and adaption assessments are often local-, method- and assumption- specific and therefore not comparable. Standard assessment approaches and protocols (e.g. comparable baselines), multi-GCM climate change scenarios and multi-impact model applications to quantify the uncertainty of impact assessments with links to local, national and international trade and market models are urgently needed to better understand climate change impact and enable the development of appropriate adaptation strategies, as outlined in the Agriculture Model Intercomparison and Improvement Project-AgMIP (Rosenzweig et al. 2012).

The application of climate change impact models is also limited by the lack of suitable climate datasets for historical and projected climates. These climate datasets need to provide daily data that include maximum and minimum temperatures, precipitation, and solar radiation. To date, attempts to produce datasets through dynamical or statistical downscaling of global climate models (GCMs) have not been successful.

Mechanistic crop simulation models have been important tools in efforts to extrapolate how future climate will affect future crops. These mechanistic crop simulation models use knowledge gained from experiments conducted in fields, controlled-environments, across climate zones, rainfall regions, soil types, management regimes, and crops, in order to project how crops will perform under different climate change scenarios. Researchers have used these models to explore the impact of individual climate change components and the combined effects of climate change scenarios on

crop production and externalities. These models allow testing of various management options and, to a lesser extent, varietal traits that can counteract the negative impacts of climate change and maximize potential benefits of climate change. While these models are simplifications of reality, they allow a first assessment of the complexity of climate change impact and adaption options in agriculture. However, there are a number of gaps in the global knowledge that apply to the SE USA that are needed to improve mechanistic crop models and their application in climate adaptation studies. These gaps include a better understanding of how combinations of various climate change factors affect crops, in particular heat stress; how specific climate change factors affect plant-water relations; how climate change affects internal crop feedbacks such as sink-source relations; and how extreme events will affect crops. These needs are briefly discussed in the following paragraphs.

**Temperature and CO<sub>2</sub>.** Effects of elevated CO<sub>2</sub> and temperature are often not considered in crop models although they may be significant. For example, reduction of transpiration canopy cooling as a result of elevated CO<sub>2</sub> and stomata closure can increase pollen sterility in rice (Ziska and Bunce 2007). As the frequency of extreme high temperatures (>32°C (89.6°F)) during the growing season increases, interactions with elevated CO<sub>2</sub> need to be understood and considered (Attri and Rathore 2003). Amthor (2001) indicated a reduction of yield with elevated CO<sub>2</sub> in combination with warming for wheat, compared with elevated CO<sub>2</sub> alone. Alonso and et al. (2008) found a higher photosynthetic temperature optimum in cereals under elevated CO<sub>2</sub>. No such beneficial interactive effects were observed for rice, soybean, peanut, dry bean, or sorghum, although independent main effects of temperature or CO<sub>2</sub> were present (Boote et al. 2005, Hatfield et al. 2011).

Crop models need to be tested with data sets of interactive effects to ensure validity for climate change scenarios as suggested by Boote et al. (2010). Similarly, interaction effects of elevated CO<sub>2</sub> and flooded conditions; salinity (Ziska and Bunce 2007); and soil constraints, such as compactions, sub-soil toxicity, or transient waterlogging are unknown, but need to be considered (Probert and Keating 2000). Due to the interactive effects and feedbacks that emerge when climate factors are combined, experiments in which only single factors are manipulated are likely to be inadequate to fully predict the impacts of future climate change (Dermoddy 2006).

**Warming, reduced water, and elevated CO<sub>2</sub>.** Studies have simulated elevated CO<sub>2</sub> and warming with reduced water supply, specific rainfall patterns, and a range of soil water holding capacities under various climate impact scenarios. Elevated CO<sub>2</sub> and increased temperatures will have different effects on physiological processes (Triboi et al. 2006), such as sink-source (or demand of grains for assimilates versus supply of assimilates from photosynthesis and remobilization) relationships of grain yield (Fischer 2008, Sinclair and Jamieson 2006). For example, wheat grain yield has been reported to be reduced under elevated CO<sub>2</sub> in sink-manipulated shoots (e.g., by removing growing grain from ears), implying that a high source-sink ratio might down-regulate photosynthetic capacity to an extent that more than offsets the stimulating effect of elevated CO<sub>2</sub> (Uddling et al. 2008). However, these models have never been tested with experimental data with such interactions as treatments even though the combined effects could

be very different to the sum of single factor effects. For example, in one study, the net primary production response of grasslands to increased atmospheric CO<sub>2</sub>, temperature, rainfall, and nitrogen deposition differed greatly from simple combinations of single factor responses (Shaw et al. 2002). In addition, simulation studies generally ignore the different response of genotypes to increasing CO<sub>2</sub> concentrations shown in some experiments (Manderscheid and Weigel 1997, Slafer and Rawson 1997). However, Boote et al. (2011) conducted model simulations of genetic improvements in soybeans and found certain traits gave a greater response under elevated CO<sub>2</sub> than under ambient CO<sub>2</sub> and that heat-tolerance traits for grain set were more beneficial under elevated temperature conditions. Such analysis gives plant breeders a chance to target genetics to adapt to future climate change. Linking crop models with the underlying genetic structure of crops (Hammer et al. 2006) might help identify and incorporate genetic traits that will help crops adapt to future climates. However, little is known about CO<sub>2</sub> acclimatization of crops and hence this is also absent from simulation studies.

**Potassium and phosphorus.** Most crop models consider nitrogen (N). Other nutrients such as potassium and phosphorus can also limit growth under elevated CO<sub>2</sub> conditions (Hungate et al. 2003, Ziska and Bunce 2007), but models do not usually consider them in climate impact studies. Both model simulations and field experiments indicate that response to CO<sub>2</sub> is less under N-limitation while response to CO<sub>2</sub> under water limitation is greater in field experiments and model simulations (Boote et al. 2010, Kimball 2010). Nutrients could also limit crop growth when climate change alters soil factors or restricts root growth needed for nutrient uptake (Brouder and Volenec 2008).

**Yield quality.** Climate factors often affect yield quality, such as protein composition and oil content (Kimball et al. 2001), but models do not simulate these effects as well as they simulate yield. Simulation studies on climate change impacts will require incorporating a better understanding of the physiology of yield quality into crop models.

**Temperature thresholds.** Changes in specific climate thresholds could become critical. For example, changes in minimum or maximum temperatures are likely to have greater importance than changes in mean temperatures for grain yields, so crop models may require modifications to respond appropriately to changes in minimum and maximum temperatures (Fischer 2007).

**Modeling growth events.** In developmental stages of growth, crops can be sensitive to various climate-related stresses. For example, cereals are highly sensitive to frost during flowering. Models still face challenges in representing and quantifying growth impacts from extreme events such as heat stress, frost, and flooding at specific growth stages.

**New cultivars and farming systems.** In addition to improved modeling capacities and adaptation options in agriculture, research is needed to investigate new cultivars and better adapted species for the projected climate change scenarios (Tester and Langridge 2010). In particular, crop varieties are needed that take advantage of elevated atmospheric CO<sub>2</sub> concentrations, resist heat stress and frost events, and are more water-use efficient. Also needed are drought-tolerant farming systems (Katsvairo et al. 2006) as well as methods for sequestering more carbon in soils (Lal 2004). For many agricultural

regions, new crop varieties, cropping systems, and agricultural management strategies are needed to provide options to farmers to counterbalance climate changes (Boote 2011).

***Livestock and poultry.*** Livestock and poultry production have many similar research needs to those of crops, though there has been less research to improve understanding of climate change effects on livestock and poultry production systems. Interactions exist among temperature, humidity, and other environmental factors which, in turn, influence energy exchange. Indices or measures that reflect these interactions remain ill-defined, but research to improve them is underway. Developing new breeds and genetic types, improving animal health, and enhancing water and soil would support adaptation measures over the long term. An improved understanding of climate change impacts on pastureland should be sought through comprehensive studies that include grazing regimes, mutualistic relationships (e.g., plant roots-nematodes; nitrogen-fixing organisms), as well as the balance of carbon, nutrients and water (Hatfield et al. 2011). Studies addressing the impacts of climate changes on parasites and pathogens that affect livestock and poultry are needed.

***Seasonal forecast models.*** As rainfall in the SE USA is variable and likely to become more variable, skillful seasonal rainfall forecasts also will be crucial. Similar seasonal forecasting systems are needed for extreme events, including heat, frost, hurricanes, and tornados to improve planning and adaptation to seasonal climate variability and change.

#### ***Specific Research Needs for the SE USA***

With its diversity and production of specialty crops, the SE USA has specific research needs unique to the region in addition to those mentioned in the previous section. Such research is essential for agriculture to remain socially, economically, and environmentally sustainable in light of a changing climate and growing population. Following are some of those needs.

***Climate datasets and collaboration between agricultural and climate modelers.*** To be used in impact simulation models, especially agriculture and hydrology, GCM and downscaled outputs must be evaluated at a daily time-step. Climate modelers do not generally evaluate the performance of models based on daily data outputs; they generally analyze seasonal or annual averages. Appropriate application of models to conditions in the SE requires climate datasets that provide daily data including maximum and minimum temperatures, precipitation, and solar radiation.

Initial efforts to include daily information from SE regional climate models (RCMs) in crop simulation models were unsuccessful because the RCMs simulated small amounts of rainfall daily rather than as discrete storm-related events (Jagtap 2005, pers. comm.). Efforts to use statistically downscaled general circulation models outputs for the SE also failed because the datasets included freeze events during summer months (Baigorria 2011, pers. comm.), a condition that does not currently exist and is not projected to occur in the future. Clearly, enhanced collaboration between climate and agricultural simulation modelers would benefit both parties (Rosenzweig et al.

2012) and would help identify anomalous events, such as a freeze during the summer, thereby helping climate scientists improve their methods.

***Integrated, participatory, systems research approaches.*** Traditional agricultural research has followed a linear approach from research scientist to extension agent to farmer. To address the complex issues of sustainability in the face of changing and variable climate, research should follow a new paradigm—one that emphasizes the integration of research, teaching, and extension; invites the participation of decision makers throughout the research process; and assembles the diverse elements of agriculture through a systems approach (e.g., Breuer et al. 2009 and 2010, Bartels et al. 2012a, Roncoli 2006). Plant and livestock breeding and management research also are important elements to the overall agricultural research portfolio regarding climate change, but they should be incorporated into integrated approaches to assure that they contribute to agricultural sustainability. There is also a need for specific research in integrated climate impact and adaptation assessment in agriculture for Puerto Rico and the Virgin Islands as part of the SE, which is currently lacking.

***Water and land resource policies.*** Population increases in the SE have led the nation for several decades and are likely to continue. As a result, urban sprawl and water demands from municipal, energy, and other sectors will increasingly compete with agricultural uses. Initial research shows that there is a strong interaction between changes in agricultural land use/land cover and regional climate. Policy research will be essential to balance these competing demands for land and water resources. Research on water resource issues should evaluate agricultural competitiveness in the SE both for its ability to meet food, fiber, and fuel needs of the region as well as its contributions to the national and global production (Marcus and Kiebzak 2008).

***Mitigation and adaptation technologies and systems.*** Researchers are working with farmers in the SE to develop and assess technologies to mitigate and adapt to climate variability and change. Additional, albeit similar, research is needed to identify, develop and incorporate adaptive technologies into agricultural systems. These technologies should be evaluated based on their carbon, energy, water, and nutrient balances as well as life cycle, risk, and economic analysis, though such analyses are rarely applied to agricultural research and development.

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