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FROM CLIMATE VARIABILITY TO CLIMATE CHANGE: CHALLENGES AND OPPORTUNNITIES TO AGRICULTURAL EXTENSION

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1. INTRODUCTION

The value of the agriculture industry to the economy of the Southeast USA is enormous. In Florida alone, 44-thousand farmers grow more than 280 different crops on a commercial scale. Florida's agriculture and natural resources industries have an economic impact on the state's economy estimated at more than $62 billion annually and about 665-thousand jobs depend on these producers (FDACS, 2004). Weather is the most important cause of year-to-year variability in crop production, even in high-yield and high-technology environments (Reddy and Hodges, 2000). Since crops were first cultivated and livestock reared, farmers have acknowledged the overriding importance of climate in setting both potential levels of production related to sunshine and rainfall and achievable levels that depend on the severity of drought, wind, pests, and diseases (Monteith, 2000).

The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) concluded that global average mean temperature, evaporation, precipitation, and rainfall intensity will very likely increase in response to increased concentrations of greenhouse gases in the atmosphere. The IPCC report also concluded that due to improved understanding of anthropogenic warming and cooling influences on climate that the globally averaged net effect of human activities since 1750 has been one of warming. The combination of long-term change (warmer average temperatures) and greater extremes (hurricanes, heat waves, droughts, and floods) suggests that climate change could have negative impacts on U.S. agricultural production. Economic losses in agricultural regions could rise significantly as a result of greater climate variability, as well as increases in insects, weeds, and plant diseases (Rosenzweig et al., 2000). More recently, climatologists at the NASA Goddard Institute for Space Studies announced that 2006 was the fifth-warmest year in the past 100 years [www.nasa.gov/vision/earth/environment/2005_warmest.html]. Goddard Institute scientists estimated that the five warmest years on record were, in descending order, 2005, 1998, 2002, 2003, and 2006. Scientists used indirect measurements of temperatures before the 1890s to conclude that 2005 was probably the warmest year on the planet in thousands of years. In terms of annual average surface temperature, 2005 slightly exceeded the previous record year of 1998. This record is even more significant because a strong El Nino affected temperatures in 1998 but not in 2005.

The University of Florida recently established a climate extension program under the Agricultural and Biological Engineering Department and in cooperation with the Southeast Climate Consortium (SECC). The SECC (http://secc.coaps.fsu.edu/) is a consortium of six southeastern universities: Florida State University, University of Florida, University of Miami, University of Georgia, Auburn University, and University of Alabama at Huntsville. The main goal of the climate extension program is to develop a climate information system for the southeastern USA in which climate forecasts and information, together with decision support tools for agriculture, forestry, and water resource managers are made available to improve management decisions and reduce risks associated with seasonal climate variability. The main focus of the program has been on managing risks related to seasonal climate variability.

Our main hypothesis is that many aspects related to vulnerability, defined as the degree of sensitivity and ability to cope with climate variability, and adaptation, defined as adjustments to environmental stresses caused by climate variability, can also be applied to climate change. To date, we have been operating under the hypothesis that adaptation to seasonal climate variability may confer greater probabilities of being able to cope and adapt to long-term climate change. The question this paper addresses is whether and how research and extension efforts to define vulnerabilities and develop adaptation strategies to help farmers cope with seasonal climate variability can be extended to help farmers cope with longer-term climate change. In other words, how can we adapt seasonal risk analysis and seasonal risk management tools to climate change applications? We might also ask whether a climate extension program should promote agricultural management practices that help the agricultural industry reduce the emission of greenhouse gases into the atmosphere. Are there enough opportunities in agriculture to make a difference and would farmers be interested in such a program? This paper discusses the challenges involved and potential opportunities for the development and implementation of a climate change program, complementing the existing climate extension program under the SECC.

2. CLIMATE IN THE SOUTHEAST USA

Climate can be defined as the long-term pattern of a meteorological variable such as temperature or precipitation. Associated with the average states of climate variables are indications of their oscillations or variations about their mean values. Climate change refers to an overall alteration of mean climate conditions, whereas climate variability refers to fluctuations about the mean. A changing climate is likely to bring changing patterns of climate variability (Rosenzweig et al., 2000). These changes can be caused by processes internal to the Earth, external forces such as variations in sunlight intensity or, more recently, human activities.

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Natural, long-term changes occur in responses to fluctuations in the amount of solar energy reaching the Earth, changing ocean currents, formation or loss of ice sheets, and many other causes. Global climate also varies naturally in response to shorter-term events, such as volcanoes which send sun-blocking particles into the stratosphere to cool the Earth, or the Pacific Ocean event known as El Niño, which transfers thermal energy from one part of the planet to another. In addition to these natural causes of climate variability, human activities have been shown to influence climate in many ways. Land use changes like the irrigation of historically semi-arid areas for farmland, the paving and development of sprawling urban areas, the draining of wetlands and increased aerosols in our atmosphere are all anthropogenic forcings to our climate system. Perhaps the most significant human influence today is the increasing concentrations of greenhouse gases in the atmosphere, mainly carbon dioxide (CO_2) and methane (CH_4), which most scientists agree could cause a general warming of our planet.

It is well known that the majority of the recent warming has been measured in the continental northern hemisphere (over northern Canada and Siberia) in winter and much less warming in the tropics and subtropics. A close look at the climate data from the Southeast illustrates these results. For the three states, Alabama, Georgia, and Florida, long-term temperature trends vary from year to year and from state to state (Figure 1). Relatively warm periods occurred in the 1930's, the 1950's, and in the current decade, while temperatures in the 1970's were relatively cool.

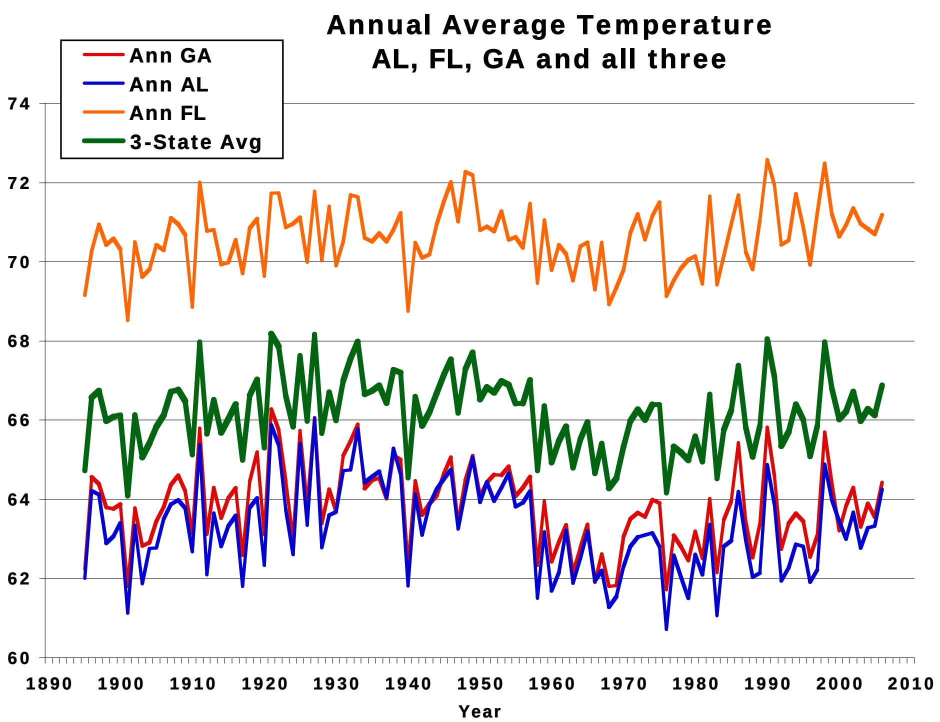

Figure 1. Annual average temperature for Alabama, Florida, and Georgia and for all three states from 1895 through 2006.

In all long-term temperature records, factors such as instrument changes, station moves, changes in observation times, and changes in exposure can introduce artificial jumps or trends into the data records. Because of heat island effects, weather stations that are located near cities and where wetlands have been drained show rising night-time temperatures, but unchanging or even declining day time temperatures. Most global or even regional temperature analyses, such as annual averages shown in Figure 1, do not account for these factors. Analyses of long-term records in Florida and Georgia indicate that most rural weather stations (located away from developed areas) show a cooling trend in average temperatures while those near urban areas show a warming (Zierden, personal communication, 2007).

Rainfall is among the most important climate variables for agriculture and water resource management. Observations of rainfall since 1895 in the three Southeast states indicate typical year to year climate variability, but no remarkable trend (Figure 2). All three states show a slight increase in amount of rainfall over time. Rainfall is also shown to fluctuate widely from year to year. For example 2006 was quite dry for all three states, but not as dry as 1954. It must also be stressed that annual averages by state mask a great deal of variation among and even within counties.

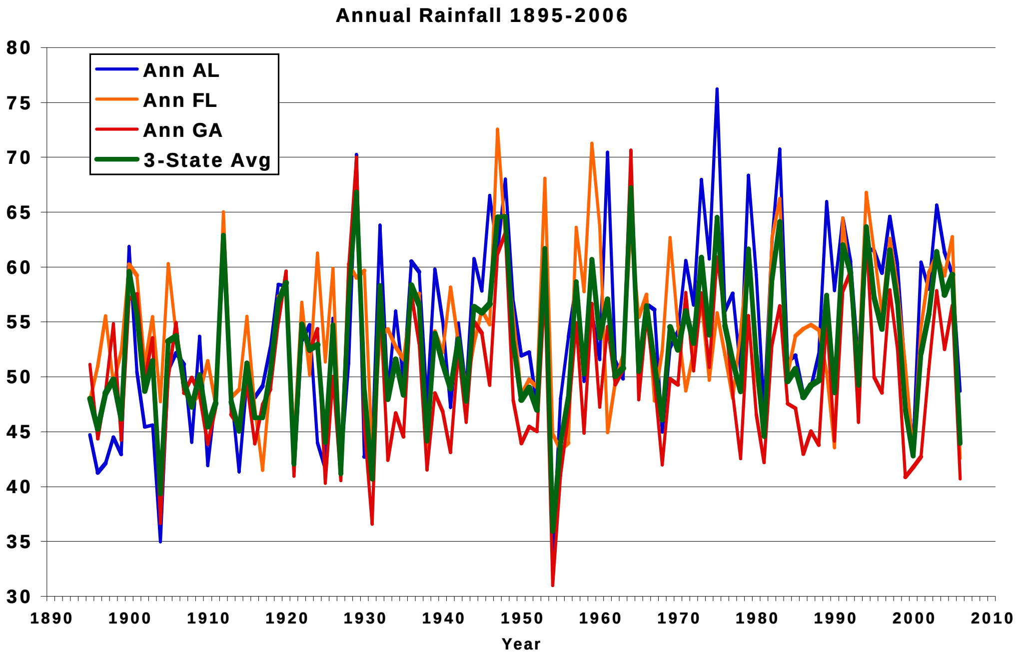

Figure 2. Annual average rainfall for Alabama, Florida, and Georgia and for all three states from 1895 through 2006.

2.1 *Climate Change Projections*

Projections of future climate are based on climate models, complicated computer programs that attempt to describe how the atmosphere will behave through time in response to the forces that act upon it. According to the 2007 report of the Intergovernmental Panel on Climate Change (IPCC), the best estimates from these models indicate that the global average surface temperature would rise from 1.7°C (3°F) to 3.9°C (7°F) by the year 2099 depending on how much the concentrations of CO_2 and other greenhouse gases increase. Future climate conditions in the southeastern USA based on projections of the British Hadley Centre Global Climate Change Model (Johns et al., 1997) indicate that maximum summer temperatures will increase across the region by 1.3ºC (2.3ºF) on average, whereas maximum winter temperatures will increase by 0.6ºC (1.1ºF) by 2030. The mean annual temperature increases of 1ºC (1.8ºF) by 2030 and 2.3ºC (4.1ºF) by 2100 represent a smaller degree of projected warming than for other regions in the country. This model also predicts a slight increase in precipitation (3%) over the next 30 years and a larger increase (20%) by the end of the century. Overall, the Hadley Model scenario predicts a slightly warmer and wetter future for southeast USA than present (US Global Change Research Program, 2002).

An important question for agriculture is if a changing climate will also affect the occurrence of extreme events. Will droughts, floods, heat waves, freezes, or storms become more or less frequent? It has been theorized that a warmer planet would lead to more frequent and more severe extremes, but limitations in computer models keep us from answering that question conclusively. Another impact of climate change is on the height of the sea level. As average global ocean temperatures increases, ocean water is expands in volume, leading to rising sea levels. IPCC estimates sea level will to rise 20 to 58 cm (8 to 23 inches) by 2099 (the current rate is about 2.5 cm per decade). Sea level has risen steadily over the last 100 years at a rate of 21.6 cm (8.5 inches) per century with no acceleration. Florida has a long coastline, and human populations tend to be densest within 80 km (50 miles) of the coast, making these areas potentially vulnerable to sea rise.

3. POTENTIAL IMPACTS OF CLIMATE CHANGE ON AGRICULTURE

Potential impacts of climate change on agriculture are broad and not completely understood. Despite the potential challenges such as increased disease pressure and more frequent occurrence of extreme climate events, climate change may also bring opportunities for the introduction of new crops and increased yields.

3.1 Crops

There is general belief that the beneficial effects of an increase of atmospheric carbon dioxide (CO_2) on plants, the CO_2 fertilization effect, may compensate for some of the negative effects of climate change. However, increased C assimilation may results in nutrients being more limiting to growth, thus necessitating increased fertilizer applications, which may increase lodging and disease (Lawlor and Mitchell, 2000). Another important aspect is that photosynthetic rates of various species living in diverse conditions such as arid deserts, high mountains, and tropical rainforests differ greatly

(Salisbury and Ross, 1985). The biochemistry of photosynthesis differs among plant species, and this greatly affects their relative response to CO_2. Most economically important crop and weed species can be classified as either a C3 or C4 type, the names referring to whether the early products of photosynthesis are compounds with three or four carbon atoms. The C3 photosynthetic pathway is less efficient than the C4 pathway. Because of this, C3 plants benefit much more from increases in CO_2 than do C4 plants (Kimball, 1983; Cure and Acock, 1986). Over 90% of the world's plant species are the C3 type, including wheat, rice, potato, bean, most vegetable and fruit crops, and many weed species. However, C4 species are distributed in warmer environments and generally have higher optimum temperatures for photosynthesis and growth, and because their higher intrinsic water-use efficiency (the ratio of photosynthesis to transpiration) might better adapt to the greater evaporative demand that would result from warming (Bunce and Ziska, 2000). The C4 group includes the important food crops, maize, millet, sugarcane, and sorghum, as well as many pasture grasses and weed species.

Temperature is important for plant growth and development. There is an optimum temperature range for maximum yield for any crop. Temperature strongly affects the rate of plant development. Higher temperatures speed annual crops through their developmental phases. Thus, warmer temperatures shorten the life cycle of determinate species, such as grain crops, which only set seed once and then stop producing. Warmer temperatures also increase the water requirements of crops. If a crop variety is being grown in a climate near its temperature optimum, a temperature increase of several degrees could reduce photosynthesis and shorten the growing period. Both of these effects will tend to reduce yields (Wolfe, 1995). Most crops cultivated in the southeastern USA are at, or near, optimal temperatures for the CO_2 and water conditions that currently prevail. Substantial temperature increases, without corresponding increases in water and CO_2, could have significantly negative impacts.

A study on the potential consequences of climate variability and change in the southeast USA by the US Global Change Research Program (2001) used mechanistic models, CROPGRO for soybean and peanut and CERES for maize, wheat, rice, and sorghum, in DSSAT V 3.5 (Tsuji et al., 1998), to simulate dryland and irrigated crop production at the field level, using state- and crop-specific management practices throughout the southeast USA. The agricultural assessment used Hadley model scenarios using 20-year periods around 2030 (2021-2040, CO_2 level at 445 ppm) and 2090 (2080-2099, CO_2 level at 680 ppm). The study focused on the predominant agricultural areas in the southeast USA, where 10% or more of the land is devoted to cultivation, the Coastal Plain and the Mississippi Delta.

Agronomic analyses revealed that most crops in the region are at, or near, their optimal temperatures for the CO_2 and water conditions that currently prevail. Substantial temperature increases, without corresponding increases in water and CO_2, could have significantly negative impacts. However, the effects of increased CO_2 substantially offset modest increases in temperature even with reductions in water, so that, if predicted levels of CO_2 increases materialize, agriculture would be only marginally affected and might even benefit overall. The report concluded that if regional climates change as suggested in the simulation scenarios, much of the row crop agriculture of southeast Alabama, north Florida, and southwest Georgia could shift gradually northward into central Georgia, South Carolina, and North Carolina. These results are mostly expected to accelerate existing trends, in which much of the specialty agriculture previously located in Florida has been moving northward, into Georgia and Alabama. The potential movement of row crops into South and North Carolina as suggested in the analysis is simply a further progression of this trend.

3.2 Weeds, Insect, and Diseases

Increases in the concentration of atmospheric CO_2 will likely stimulate the growth of weeds. Worldwide, weeds have been estimated to cause annual crop losses of about 12% (Oerke et al., 1995). According to Ziska (2004), the current paradigm that rising CO_2 will result in less weedy competition because many of the worst weedy species have C4 metabolism, a photosynthetic pathway that shows a minimal response to rising CO_2 concentration as discussed above, is overly simplistic. Many C4 crops, such as corn [*Zea mays*], grain sorghum [*Sorghum bicolor*], and sugarcane [*Saccharum officinarum*] have significant economic importance in the southeast USA. Moreover, there are many important C3 weeds, such as Sicklepod (*Senna obtusifolia*), Hairy indigo (*Indigofera hirsuta*), and Florida beggarweed (*Desmodium tortuosum*), that will certainly benefit from increased CO_2 levels in the atmosphere. Other weeds can also present particular challenges. Hydrilla, for example, is a major aquatic weed in Florida that costs millions of dollars each year to control. Hydrilla can change from C3 to C4 depending on the available CO_2 (Van Ginkel et al., 2001). This problem will likely exacerbate the recently reported apparition of "super weeds" as a result of over-use of a small group of herbicides in genetically modified crops.

Insect pests are responsible for major impacts on yield quantity. Insects are particularly sensitive to temperature because they are cold-blooded. In general, higher temperatures increase rate of development with less time between generations. Warmer winters will increase survival and possibly increased insect populations in the subsequent growing season (Gutierrez, 2000; Rosenzweig, et al. 2000). As an example the occurrence of pink bollworm in North American cotton is limited by winter frost; hence mild winters would increase its occurrence northward.

Climate factors that impact growth, spread, and survival of crop diseases include temperature, precipitation, humidity, dew, radiation, wind speed, circulation patterns, and the occurrence of extreme events. Higher temperature and humidity and greater precipitation result in the spread of plant diseases, as wet vegetation promotes the germination of spores and the proliferation of fungi and bacteria, and influences the lifecycle of soil nematodes (Rosenzweig et al., 2000). Hurricanes have played an important role in the spread of diseases with a great potential of adversely affecting US agriculture. Hurricane Ivan, which landed in the US in September 2004, is believed to have carried spores of Asian Soybean Rust (ASR) from infected fields in Colombia. Transport model simulations indicated that the area that likely received the heaviest deposition of spores was around Mobile Bay in Alabama where Hurricane Ivan made landfall. Louisiana was on the western border of the area of potential infection. Model output suggested that spore deposition occurred from central Louisiana east to northern Florida and as far north as Tennessee and the Carolinas [http://www.ceal.psu.edu/ivan04.htm].

The citrus industry in Florida has also suffered during recent hurricane seasons. The United States Department of Agriculture (USDA) announced in January of 2006 that it is no longer possible to eradicate citrus canker, a disease that is considered the greatest threat to the industry. Based on USDA analysis, the unprecedented 2004 and 2005 hurricane seasons spread the pathogen that causes citrus canker to the extent that a new management plan must be devised. The change in policy came after research indicated Hurricane Wilma may have spread the disease to the point where an estimated 168,000 to 220,000 acres of commercial citrus could be infected and exposed to canker. This acreage is in addition to more than 80,000 acres of commercial citrus that were affected by the 2004 hurricanes. The USDA also indicated that growers have said they cannot survive the loss of more than 25% of the state's citrus acreage and that federal costs to implement the 1900 foot tree removal would cost significantly more than the annual $36 million dollar federal appropriation as well as hundreds of millions more in compensation payments to growers (http://www.doacs.state.fl.us/press/2006/01112006_2.html).

The mild temperatures and frequent rainfall of the southeast US predispose the region to an array of agricultural pest problems causing the region to be a relatively high user of pesticides. Although the southeast accounts for only 14% of the nation's cultivated cropland, it consumes 43% of insecticides and 22% of herbicides used by farmers (USDA Census of Agriculture, 1994). If climate changes bring increased moisture and warmer temperatures to the region it is likely to exacerbate epidemics and prevalence of leaf fungal pathogens, and overwintering population of all pests. If extreme events become more frequent, such as the hurricanes that were responsible for the increased spread soybean rust and citrus canker, the combination of increased hurricane activity with potential increases in temperature and precipitation in the region, will pose significant challenges to the agricultural industry in the southeast US.

3.3 Livestock

Effects of climate change on livestock are likely to be variable, based on a number of factors such as the magnitude of temperature increase and animal feed prices. Dairy cows are particularly sensitive to heat stress, with temperature optimum for milk production between 4.5ºC (40ºF) and 24ºC (75ºF). Decline in performance usually occurs as the mean daily temperature approaches 24ºC. In addition to ambient temperature, humidity and wind velocity also affect performance (Harris, 2003). At high relative humidity (>80%) heat stress in dairy cows can begin at temperatures as low as 23ºC (73ºF), and stress become severe at 34ºC (93ºF). Heat stress can have a carryover effect to depress milk production and reproduction for up to 150 days (Wolfe, 2004). Long-term adaptation may include crossbreeding with more heat tolerant-breeds (Girolando, Senepol), and furthering research on heat tolerance in known milking breeds, such as the Slick Hair Gene (SHG) in Holstein (Olsen, Tim, Avila-Chytil, Manuel UF animal science)

Climate change will also affect other livestock industries such as beef cattle and poultry, both through direct effects on production, and indirectly through changes in grain prices, pasture productivity, or costs for cooling. Cooling costs are particularly worrisome in light of a steep upward trend in the price of fossil fuels. In general, analyses indicate that intensively managed livestock systems have more potential for adaptation than crop systems. Some of these adaptations may be enabled by the use of alternative energy sources on farm.

4. STRATEGIES FOR ADAPTATION AND MITIGATION

Interest of farmers in climate change impacts has recently increased in response to two years of intense hurricane activity and increased media coverage of climate change, including the much publicized record loss of sea ice in the Arctic. Recent press coverage of carbon offset markets also sparked a renewed interest about potential opportunities to generate additional income. Some extension agents have expressed interest in engaging in climate change education, even if claims of linkage between global warming and hurricane activity are premature and if risks that climate change poses to farmers are still uncertain. In other parts of the world farmers have also recently expressed concern about climate change.

In spite of increased interest in climate change, there has been relatively little call for farmers to address the issue. According to Grubinger (2004), an extension program on climate change faces the same challenges that innovative programs such as nutrient management and food safety faced in the past. The information provided, however useful or necessary is not always what stakeholders want to hear or think they need. Farmers eventually accepted these programs because the topics were addressed in a manner that did not threaten or blame farmers, and the recommended actions were practical, affordable, and even profitable over the long term. Grubinger also reported specific concerns by extension agents, based on responses to a pilot presentation addressing climate change and agriculture given to an agricultural in-service meeting in November 2003 and a survey completed by extension educators in 2004:

- Climate change isn't important to farmers so it will be difficult to interest or engage them in the issue.
- Farmers are small contributors to climate change so they should not be singled out to make changes to address it.
- Short-term business survival is more important and farmers don't have the luxury of spending a lot of time on a long-term global issue like climate change.
- Climate change education would be nice but it is not a priority.
- Educators need to develop their own knowledge about climate change issues before they will be comfortable offering or preparing programs for their clients.
- There is fear of blaming agriculture disproportionately for its contribution to global warming. Why is action needed if farming is a relatively small contributor?
- A lot more specific data needs to be gathered to answer questions that producers and leadership will have on the extent to which certain practices affect greenhouse gases and global warming.

Extension agents and farmers also demonstrated some receptivity, if not enthusiasm, for climate change education. Comments reflecting that viewpoint included:

- Climate change is likely to have a significant impact on farming and whether people accept that or not at present, so we should move forward on the issue.
- It is important to improve our understanding of the issue even if we are not completely sure of the agricultural implications or recommendations.
- Some actions that address climate change are simply good management practices such as: efficient N fertilizer and manure use, farm energy efficiency, cover cropping, and development of local markets.
- Innovative farming practices that may address climate change can also enhance profitability and environmental quality. Examples include use of bio-diesel and alternative fuels, on-farm energy generation, and reduced tillage systems.

Recent media coverage of climate change and potential impacts on society may have modified farmers' perception of climate change. Nevertheless the list of concerns and positive feedback above leaves no doubt that there is some confusion about what should be the focus of the proposed extension program. The list includes not only issues related to vulnerability and adaptation but also climate change mitigation. A successful climate change extension program would probably have to address both, with different emphasis according to location and industry sector. It seems imperative that an ex-ante assessment should be done with stakeholders in the state to better understand needs and expectations of a climate change extension program.

4.1 Adaptation

The development and dissemination of management practices that are best adapted to seasonal climate variability is the main focus of the SECC climate extension program. The approach used to mitigate risks associated with seasonal climate variability must be site and crop-specific and focuses primarily on techniques such as shifting planting dates, changing crop varieties, and cultural practices. Adapting to climate change might require farmers to use management practices and technologies that are beyond those existing today. Research must play proactive role to generate necessary responses and technologies that farmers will need to handle such future challenges. Nevertheless, the education process involved in establishing an extension program aimed at mitigating production risks associated with climate variability seems to be an efficient and effective way to introduce a climate change program. The following adaptation strategies could be part of a combined climate variability/change extension program:

- Changing planting or harvest dates are effective, low cost options. The major risk in implementing these strategies could be shifting to a different market window with lower prices.
- Changing varieties is another low cost option, although some varieties can be more expensive or require investments in new planting equipment. In reality this is a continuous process. Examples are the development of new peanut varieties resistant to Tomato Spot Wilt Virus (TSWV) disease, a major threat to peanut production in the southeast US, and the increased adoption of genetically modified cotton varieties resistant to certain types of herbicides and pests.
- Increased use of irrigation, fertilizer, herbicide, and pesticide may be necessary to achieve maximum benefits from increased atmospheric CO_2. Climate change is also likely to increase weed and pest pressure in most cases as discussed above.
- Changing crop species or livestock produced could bring new profits, but is a risky and more expensive option because the necessary infrastructure or marketing mechanisms may not exist locally.
- Investments in new irrigation or drainage systems or other capital items are likely to be essential if climate change increases climate variability.

Adaptation strategies could also include changes in tillage practices, selection of varieties with greater drought and heat tolerance, and development and implementation of improved Integrated Pest

Management (IPM) programs for better management of crop pests and diseases. The extent of adaptation depends on the affordability of such measures, access to know how and technology, the rate of climate change, and biophysical constraints such as water availability, soil characteristics and crop genetics.

Research is an important component of the adaptation process. Very little work has investigated prospects for natural adaptation of crop species to climate change, and the results of the few studies that do have been inconclusive. However, there appears to be a wide range of resistance to heat stress within and among crop species. For example, moderately large genetic variation in tolerance to heat-induced spikelet sterility has been reported among and between indica and japonica rice genotypes (Matsui et al., 1997). Some rice cultivars have the ability to flower early in the morning, thereby potentially avoiding the damaging effects of higher temperatures later in the day (Imaki et al., 1987).

Prospects for genetic improvement of crops appear to be more optimistic than for natural adaptation. Intraspecific variation in seed yield of soybean in response to elevated CO_2 was observed by Ziska et al. (1998). Differences among soybean cultivars in how they partition assimilates between vegetative and reproductive tissues may influence reproductive capacity and fecundity as atmospheric CO_2 increases, with subsequent consequences for future agricultural breeding strategies (Ziska et al., 1998). However, no significant intra-specific variability in responses to elevated CO_2 was detected in studies with wheat and temperate forage species (Lüscher and Nösberger, 1997; Batts et al., 1998). To promote adaptation to an environment of high CO_2 and high temperature, plant breeders have suggested selection of cultivars that exhibit heat tolerance during reproductive development, high harvest index, small leaves, and low leaf area per unit ground to reduce heat load (Hall and Allen, 1993). However, prospects to improve adaptation of crop species to elevated CO_2 remain very uncertain, and more research in this direction is required.

4.2 Mitigation

Dissemination and promotion of emission reduction strategies in the agricultural sector to help mitigate climate change would be a new activity under the existing climate extension program. Management of forestry and agricultural activities is regarded as an important option for greenhouse gases (GHG) mitigation. Activities in these sectors can reduce and avoid the release into the atmosphere of the three most important GHGs: carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). A number of opportunities to mitigate climate change, while reducing costs and increasing profitability, may be available for farmers. The main goal of this program would be to shift agriculture from a net source to a net sink for greenhouse gases. Florida ranks sixth in among the states in total GHG emissions, and is 30th among the world's top 75 emitters among states and nations (Center for Climate Strategies 2007). Florida produced 255.4 million metric tons of CO2 in 2004. From 1990 to 2004, Florida CO2 emissions increased 37 percent, second in growth only to Texas (Environment Florida 2007). Most of this increase in CO2 emissions came from increases in the transportation sector, specifically gasoline consumption, while most CO2 emitted was produced by power plants. Because 18.6 percent of Florida electrical power comes from petroleum, petroleum used for transportation and power generation constitutes the largest source of CO2 by fuel type, followed by coal and natural gas. Given the present trajectory, Florida's GHG emissions will grow by 88 percent by 2020, compared with 50 percent for the US as a whole (Center for Climate Strategies 2007).

Although the GHG sources and sinks in the forestry and agriculture sectors of Florida are minor portions of the total emissions profile, they represent significant potential for offsetting and reducing the projected increases in emissions over future decades. Activities in forestry and agriculture with potential for GHG mitigation include afforestation, improved forest management and protection, soil carbon sequestration, agricultural CH_4 and N_2O mitigation, and biofuels offsets.

Soil carbon sequestration has additional appeal because practices that enhance soil carbon also improve soil quality and soil fertility; thus, enhancing several ecosystem services. Soils store carbon for long periods of time as stable organic matter, which reaches an equilibrium level in natural systems that is determined by tillage and other management practices, climate, soil texture, and vegetation. When native soils are disturbed by agricultural tillage, fallow, or residue burning, large amounts of CO_2 are released (Allmaras et al., 2000). However, a significant portion of the carbon captured by plants through photosynthesis can be sequestered by soils managed with direct seeding and other techniques that minimize soil disturbance. Irrigation can enhance carbon sequestration over native soil levels by overcoming the moisture limitation to increased plant biomass production. Examples of management practices with the potential to increase soil organic carbon include:

- Adoption of conservation and no-tillage practices;
- Optimize crop rotations by using legumes, rotations crop-pasture, green manures;
- Improved fertilization to stimulate biomass production and root growth, also enhances photosynthesis;
- Optimize manure management;
- Promotion of land use shifts that enhance soil organic matter (e.g. forest, wetlands), mixed cropping systems that combine annual and perennial crops (e.g. agroforestry).

Agriculture alters the terrestrial nitrogen cycle as well. Through nitrogen fertilization, annual cropping, mono cropping, and improper water management, nitrogen is more prone to being lost to ground or surface water and to the atmosphere. Nitrous oxide (N_2O), a common emission from agricultural soils, is a potent greenhouse gas (296 times more than CO_2). Atmospheric concentrations of N_2O have increased by 15% during the past two centuries (Mosier, 1998) but reductions can be achieved through improved nitrogen management.

About 65% of the methane in the atmosphere is attributable to agricultural sources (Duxbury, 1994), with a significant portion arising from dairy cows. Methane traps heat about 23 times more effectively than does CO_2. Most modern dairies utilize a lagoon system for animal waste treatment, a practice that leads to large emissions of methane and nitrous oxide. Closed-system anaerobic digestion of the manure has the potential to eliminate most methane emissions from lagoons while conserving more nutrients and also producing a renewable energy source. Livestock production in Florida includes both confined animal operations and pastured animals. The increase in production and concentration of intensive livestock operations along with increased urbanization of rural regions have resulted in greater awareness and concern for the proper storage, treatment, and utilization of livestock manure. Pastured animals offer limited opportunity for managing livestock manure to lessen greenhouse gas emissions. The principal opportunities for altering manure management, therefore, occur in dairy and poultry operations with confined livestock. Table 1 gives the CH4 emission estimates for confined dairy and poultry production with their CO2 equivalent global warming potential. Greenhouse emissions from broilers account for more than twice that of dairy cows, while the layer population produces around one-sixth of the emissions of dairy operations.

Table 1. Estimated methane emissions from manure management of confined animal populations in Florida.

Animal Type	**No. of Animals**	**CH4 Emission** kg/animal/yr	**CH4 Emissions** Gg/yr	**CO2 Equivalent** Tg CO2/yr
Dairy cows	**135,000**	**54**	**7.29**	**0.153**
Poultry layers	**10,700,000**	**0.117**	**1.25**	**0.026**
Poultry broilers	**139,800,000**	**0.117**	**16.36**	**0.343**
Total			**24.90**	**0.523**

1 FASS (2005), 2 IPCC (1996).

Models have been used to simulate mitigation scenarios based on carbon market drivers as well as the markets for forest and agricultural products. Examples include the model employed by the US EPA known as the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG; US EPA 2005) and the Integrated Assessment Model (McCarl & Schneider, 2001). The Integrated Assessment Model portrays farmers' choices across regions among a set of crop and livestock management options that includes tillage, fertilization, irrigation, manure treatment, and feeding alternatives. An example of the outcome of the FASOMGHG model is shown in Figure 3.

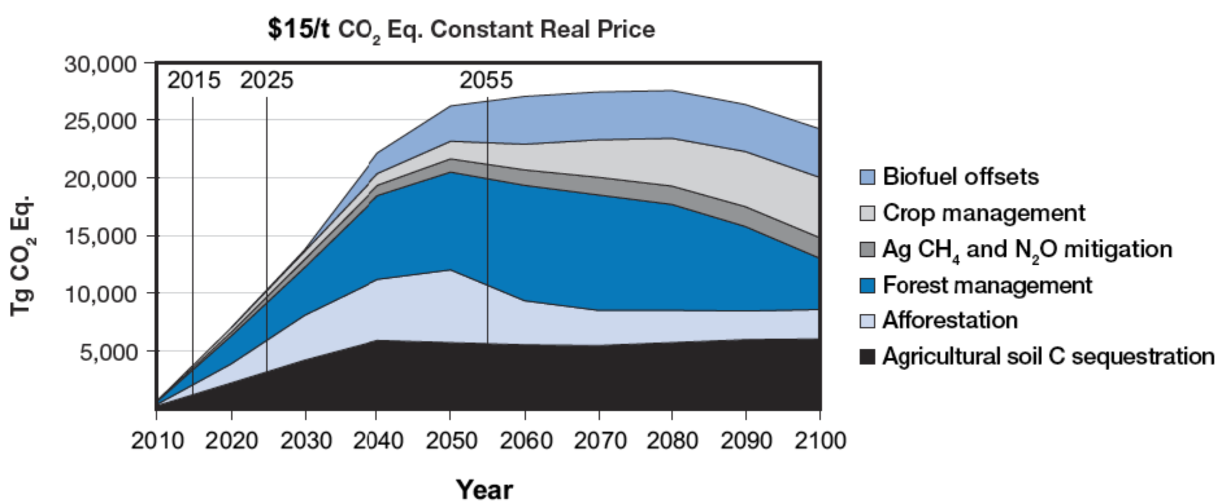

Figure 3. Cumulative mitigation of greenhouse gases over time as an example of output from FASOMGHG (reproduced from Figure 4-6, US EPA 2005).

5. VISION FOR A CLIMATE CHANGE EXTENSION PROGRAM

The main goal of our climate extension program is to reduce risks associated with climate variability. We co-develop information, decision aids, and partnerships that decision makers can use to increase profits, reduce economic risks, and increase resource use efficiency. This program includes provision of educational material and training programs to help agricultural and natural resource managers understand and use this technology effectively in their decision making process. Adding the perspective of climate change to the existing program is an attractive option given the existing focus on developing adaptation strategies and training of stakeholders to add climate forecasting as part of their decision making process. Dissemination and promotion of mitigation strategies should also be included, especially strategies that increase the efficiency of inputs, improve soil quality, and may allow the participation of producers in the carbon trading market. The first step towards developing a climate change extension program should be to undertake initial or ex ante assessment to understand farmers' perceptions, attitudes, long–term goals, and other cognitive and decision-making information through participatory methods. Once enough data had been elicited and analyzed, we may start to developing adaptation and mitigation strategies targeting and end-goal of economic and ecological sustainability. A win-win situation must be the main goal of the program.

Initial analysis of adaptation strategies for coping with climate variability indicate that similar strategies can be used for coping with climate change. Figure 4 shows some of the main activities or strategies that a climate extension program could engage in, if the existing program was expanded to include climate change. Many adaptation strategies such as changing planting dates and crop varieties are common to climate change and climate variability. Decision support tools would suggest adaptations based on scenarios for climate change. Other major differences include strategies such as crop insurance and marketing that are only available for mitigating risks associated with seasonal climate variability and potential change of crops or livestock in the case of climate change.

A climate change extension program should also include mitigation strategies that are technically sound and affordable. Examples include conservation tillage, energy conservation, biofuels, conservation practices, and improved N management. Many of these are already being promoted due to increased competition and high energy costs. A program to help to educate farmers about potential opportunities in carbon trading markets and establishment of base line carbon levels for different ecosystems and agricultural activities should also be undertaken to promote farmers engagement.

6. CONCLUSIONS

The existing climate extension program at the University of Florida should be expanded to include an education component on adaptations strategies to help farmers cope with potential climate change impacts and to help mitigate adverse impacts of climate change. An initial or ex ante assessment to understand farmers' perceptions, attitudes, long–term goals, and other cognitive and decision-making information as related to climate change should be undertaken at the beginning of the process of implementation. The expanded program should also include aspects related to potential opportunities in carbon trading markets and activities to document local climate change evidences in order to increase stakeholder involvement and interest in the topic. Initial evaluation of temperature trends in Florida and Georgia indicates that most rural weather stations (located away from developed areas) show a cooling trend in average temperatures while those near urban areas show a warming trend. Observations of rainfall since 1895 in Alabama, Florida and Georgia indicate typical year to year climate variability, but no remarkable trend. Analysis of local trends will help engaging farmers in the education process and also help guide research needed to develop site-specific adaptation strategies. Mitigation strategies should be developed in partnership with other extension programs such as agronomy, alternative energy, soil and water, and agricultural economics.

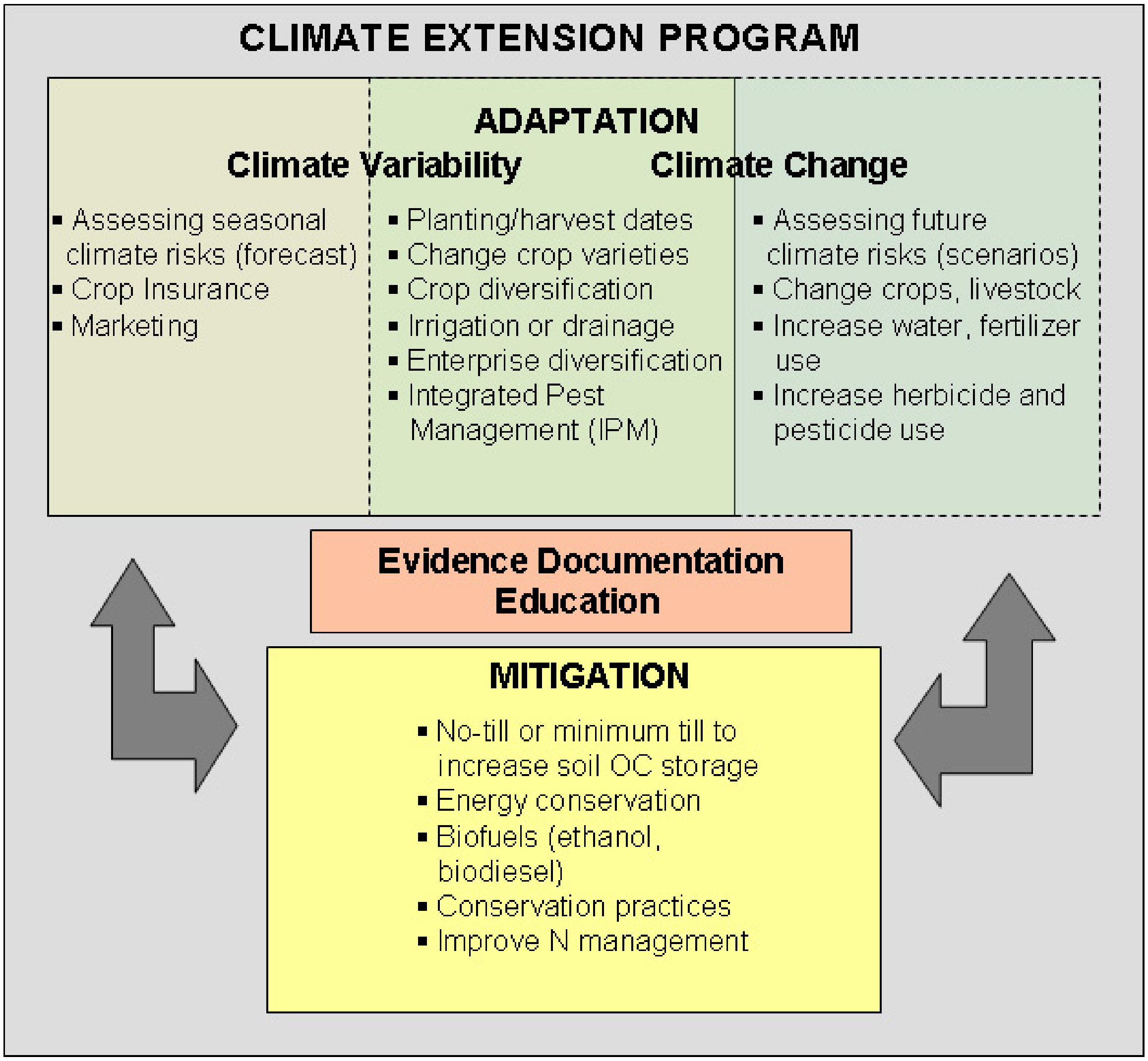

Figure 4. Examples of adaptation and mitigation strategies under a combined climate variability/change extension program.

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