Agricultural Responses to Climate Variability and Climate Change
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Introduction

Globally, the mosaic of agricultural systems has been shaped over time by a number of factors, including abundance and quality of land and water resources in an area, social, cultural, economic, and political conditions of human settlers, and climate. Because agriculture is so sensitive to climate, agricultural practices have evolved that explicitly or implicitly take into account risks associated with local climate variability on seasonal to multi-annual time scales. Examples of these practices include diversification of crops and varieties, grain storage, irrigation, protected cultivation (e.g., greenhouses), incorporation of biological capital (e.g., livestock), etc. These responses to uncertain climate conditions on annual to decadal time scales are common in both developed and developing countries. Many of these responses have evolved over centuries, particularly those in developing countries where subsistence agriculture is the main activity of more than two-thirds of the population.

Many of these agricultural systems and the societies that manage them are being threatened by both global and local phenomena. Increasing populations in areas of the world where subsistence agriculture is practiced are increasing pressures on land and water resources in order to produce sufficient food. Traditional practices of fallow management (rotating crops to allow fields to regenerate their nutrients and structure) are giving way to continuous cropping systems, deforestation, overgrazing of grasslands, and consequent land degradation and decreasing capacity to produce food. Thus, many societies are increasingly vulnerable to annual fluctuations in food production associated with climate variability.

Also, climate change may further jeopardize many of these societies; many are in the Tropics where higher temperatures would likely lead to decreases in yield and increasing demand for already-limited water supplies in some regions. One of the troublesome features of climate change in these areas is that even small changes in climate, such as an increase in drought frequency from 1 in ten years to 2 in ten years could result in major food shortages and permanent damage to societies that barely are able to produce

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sufficient food to meet yearly demands. During recent history, we have witnessed severe food shortages associated with droughts in different parts of the world.

Although these comments primarily address the situation in many developing countries, agricultural systems in developed countries may also face increasing risks associated with climate change and variability. Recent climate change studies have emphasized that increasing climate variability and extreme events could be the biggest threat to agricultural systems in developed countries in temperate regions like the USA. Also, climate change is not likely to be uniform across the globe, and some highly important food production regions could be affected in ways that could affect global food prices and food availability. Spatial averages that may show little potential impact on an aggregate basis (say at country, region, or global scales) hide enormous variability over the landscape. The developed countries should be more able to adapt to climate change and take advantage of increasing knowledge of climate variability than developed countries. However, this will not happen automatically. Efforts are needed in both developed and developing countries to allow societies to adapt to climate variability and climate change in ways that will lead to greater stability in food supply.

Agricultural Response to Climate Change

What is agriculture doing about the potentially devastating threats to societies that climate change might bring about? Considering my remarks above, one may be led to believe that agriculture at all levels (from farmers to local institutions and businesses to governments and international agroenterprizes) are investing considerable attention and resources on how to adapt to climate change. That is not really the situation. Although there are some very important developments underway, many of those were not initiated on the basis of climate change information. Some have been influenced by climate change information, however. One example is the breeding of crop varieties that are more tolerant to high temperatures and drought.

It may be overstating the situation to say that farmers are not making decisions based on climate change information. But my observations are that:

- Climate information is and has been important in the evolution and design of existing agricultural systems and in investment decisions such as land purchases, infrastructure investment, and new enterprise development,
- Climate information is used in disaster relief and insurance, but
- Climate information is used very little by farmers who make routine decisions about production in existing farming systems.

Why is this so? Agricultural systems are highly complex. Farmers are faced with many challenges, including uncertain prices, access to needed inputs, governmental policies, marketing, pests and diseases, and of course, weather. If one conducts a survey among farmers in any commodity, asking the respondents to list and prioritize problems that they face in production, weather (which would include climate in some sense) will typically be on every list. But it will seldom if ever be the top priority problem, and climate change would not even be on the list. There are many decisions that farmers have to make during a season in response to the many other exogenous and endogenous conditions; something that is likely to happen over decades will not invoke an immediate decision response, especially when there is so much uncertainty in how much climate will change and how it will affect him or her in their local environments. What can they do? What should they do? These two questions are difficult to answer for agriculture at the grass roots level.

Agricultural Responses to Climate Variability, Climate Forecasts

General. The influence of El Niño-Southern Oscillation ENSO on agricultural production and an ability to forecast climate four to six months in advance provides an opportunity to tailor agricultural decisions for higher profits and better use of resources. However, the agricultural sector is complex, with many different types of production systems, individual and institutional decision makers, and nonlinear interactions among its physical, economic, political, and social environments. Furthermore, seasonal climate forecasts are probabilistic. Agricultural decision makers need to understand these uncertainties, in terms of their own local production systems and other sources of risks, before they can effectively use them. They need to know the expected impacts of using climate predictions as well as risks they take if the climate deviates from the mode or expected value of the forecast. Effective application of climate forecasts depends on (1) the availability of regional forecasts of adequate lead time and accuracy, (2) the vulnerability of agriculture to weather variability, (3) the existence and awareness of options for using knowledge of future weather to improve agricultural practices, and (4) the ability and willingness of decision makers to modify their decisions based on climate forecast information.

In the SE USA, we have found that the agricultural sector is highly interested in climate variability and climate forecast information. In the Southeastern Climate Consortium (SECC), a Regional Integrated Science Application (RISA) program supported by NOAA and USDA, considerable progress has been made on understanding climate variability in this region, its impacts on the agricultural sector, and decisions that could be improved via use of climate forecasts. We have built strong cooperation with the Cooperative State Extension Services for communicating with farmers in educational programs and for providing routine information to support decision making at the grass roots level. A brief synopsis is given below of characteristics of this program, with emphasis on its relevance to climate information and decision support.

Some Characteristics of the SECC RISA Approach. A major characteristic of the SECC RISA approach is our work with the agricultural Cooperative Extension Service (CES). The CES is part of the land grant university system in each state, and thus has its homes at the University of Florida, University of Georgia, and Auburn University in the states involved in our consortium. The mission of the CES is to provide scientifically based agricultural, human, and natural resources knowledge that citizens use in making decisions that contribute to an improved quality of life. There are Extension offices in each county in our three states. These offices provide information and conduct educational programs on issues of importance to citizens in their communities. Through close contact with end-users of university-based research, Extension faculty in county offices are well positioned to understand their clients' needs, to provide that information to researchers, and to develop appropriate programs for providing information to clients for decision making. Additionally, Extension specialist faculty members are located on the three university campuses to help develop and coordinate extension programs in their areas of expertise.

Considerable work had to be done before our cooperation with Extension was developed. Our project started work with three major thrusts:

- Characterize climate variability in the SE USA, including an assessment of whether there would be any skill in predicting climate variables based on increasing understanding of the ENSO phenomenon. We found that ENSO has a strong effect on climate (rainfall and temperature) in this region, particularly in the Fall and Winter months, with smaller effects in the Spring and Summer months. Thus, a significant amount of the annual variability in climate is predictable in this region.
- Determine the effects of ENSO on agriculture and forestry, focusing mostly in Florida in our early work. In this work, we relied heavily on statistical analysis of historical agricultural production and forest fire records. We also used climate records, categorized by ENSO phase, and weather-sensitive crop simulation models to study how much variability in production could be accounted for by climate variability alone, and whether different management practices could be tailored for specific crops using climate forecasts to benefit farmers. We found that crop yields were significantly correlated with ENSO phase for most commodities. For example, El Niño decreased winter yields of tomato (18% of long-term average), bell pepper (18%), sweet corn (15%) and snap beans (12%). El Niño events increased sugarcane yields following La Niña years, and increased yields of grapefruit (5%) and tangerines (13%) but decreased lime yields in the harvest following El Niño events. Furthermore, ENSO had a significant influence corn and tobacco yields, areas of soybean and cotton harvested, and total values of corn, soybean, peanut and tobacco in Alabama, Florida, Georgia and South Carolina. Results showed that there is almost $500 million difference in value of these four crops associated with ENSO. Crop yields tended to be higher than the trend in the season before, and lower than the trend after El Niño winters. ENSO phases explained an average shift of $212 million (26%) of the long-term average, inflation-adjusted value of field corn production, and $133 million for soybean. We also found high correlation between ENSO phase and forest fires in Florida. Our work with crop models confirmed these correlations, and we demonstrated in various cases how profits could be increased and risks decreased by adjusting management using climate forecasts. Examples are to change planting dates in El Niño years for winter tomato and to not plant winter pastures in North Florida when a La Niña is forecast. This work is continuing for peanut, potato, dairy, and other agricultural systems, with involvement of Extension and farmers.

- Communicate with stakeholders to understand their needs and reactions to possible use of climate forecasts. We conducted a number of *sondeos*, a team survey process developed by one of our team members (P. E. Hildebrand). These *sondeos* were conducted to learn from Extension Agents, farmers, and ranchers about decisions that are made by producers that could potentially benefit from climate information, and whether and how climate information is currently being used. Surveys of extension personnel proved to be particularly effective to determine farmer perspectives and opportunities for using climate prediction within agricultural production. Weather forecasts (1 day to 2 weeks) are already affecting farm management in Florida. The most common decisions that farmers and extension personnel indicated might be adjusted in response to credible climate forecasts were: field preparation, marketing, livestock stocking rates, crop choice or area of each crop, choice of crop varieties, and crop management. Ranchers expressed strong interest in climate forecasts, and indicated that there were several decisions that they might change if they had climate forecasts. Ranchers with stocker steer operations might expand the herd if wet weather (El Niño) and thus good forage production were expected. Cow-calf ranchers could cull cows more heavily in a La Niña year. Farmers producing hay were most interested as climate forecast would allow them to make decisions as to how much hay they can grow, how much fertilizer to use, and how much hay they need to stock. Thus, indirectly it could also affect fertilizer use. Ranchers told us that the warm and dry winters brought by La Niña are unfavorable for planting winter rye as forage. With reliable climate predictions, cattle farmers can decide whether or not it is profitable to plant winter forage that year. Many growers were sensitive to price impacts of increasing globalization, and wanted forecasts for their competitor's regions. While growers of rainfed crops were concerned about climate fluctuations, market variations tended to dominate decisions of high value crops.

We realized that if our research on use of climate forecasts was to be effective, results and training on how to use this information need to be widely disseminated to farmers, ranchers, and foresters. Because our early research indicated high potential value of climate forecast use and acceptance, we made a strategic decision to invest heavily in partnering with Extension. Because of the large numbers of agricultural decision makers and their dispersal throughout all counties in each state, the fact that the CES has offices in all of those areas, and the mission of the CES, this strategy made a lot of sense. A summary of the main activities related to our initiative to cooperate more closely with Extension is listed below.

- Obtained approval and programmatic support from Extension administration in Florida for partnership
- Began cooperating with leaders in the Florida Automated Weather Network, an Extension activity, to provide climate information via their web page
- Developed a State Major Program in Extension. This is the primary educational program development mechanism in Extension. It targets county Extension faculty through educational programs, giving them support to produce

information products and educational programs for their clients in their own counties

- Hold In-Service training programs to present Extension Agents information that we have produced thus far and obtain feedback on priorities for additional work
- Develop concepts and initial design for an Agricultural Climate Risk Information and decision support System (ACRIS). We contracted a private firm to design the web-based site, and are working on initial implementation now. The new Extension Specialist (see below) is working with Extension faculty and farmers to evaluate what the site should contain and ways of presenting risk management information to farmers. The ACRIS is being designed specifically for use by Extension, but it will also be open to farmers, ranchers, foresters, and others who need information on climate-related risk to agricultural systems and options for reducing those risks. Support on this component of our work is coming from the Risk Management Agency of USDA as well as from NOAA-OGP.
- Hired a Climate Extension Specialist to coordinate our interface and activities with Extension. This includes getting input from extension faculty in the three states and developing the tools and information needed for the ACRIS.

I am very optimistic about the continuing positive evolution of our working relationship with Extension. We have found that farmers are interested in climate during the next few months, and that there are many possibilities for using climate forecasts beyond what we would have thought of in our research efforts and beyond what we may be able to quantify. We have also learned that Extension Agents will pick up on this knowledge, produce recommendation products, and disseminate them to farmers. The examples of this process in Florida were originated via educational programs aimed at Extension and included follow-up work by the Extension Agents and one or more RISA team member. I have found, through a number of interactions with Extension and with farmers, that farmers understand uncertainties, and appreciate the fact that we emphasize the shifts in probabilities of outcomes as opposed to deterministic predictions of either climate or agricultural production.

How Can We Better Link Climate Variability & Climate Change for Societal Benefit?

Agriculture is beginning to respond to this new knowledge about climate variability in different parts of the world, in developing and developed countries. The different programs that NOAA has initiated and supported on climate variability and forecast research and its application to benefit societies are beginning to have an impact at the grass roots level. Our work in the SE USA is only one example of many in which stakeholders are being engaged in dialogues with researchers and extension on climate variability and use of uncertain climate forecasts. What strikes me is the opportunity that we now have to put into practice our research on climate variability via an existing institution (Extension) that has a mission complementary to ours. A lot of work still remains before climate forecast information is routinely used throughout agriculture for making decisions aimed at reducing risks climate-related risks. However, I am optimistic that this type of cooperation will continue to evolve for mutual benefit to all.

What about climate change? My conclusion is that initiatives to engage agriculture in discussions about adaptation to climate change would not be met with much interest unless the discussion is couched in the context of climate variability. Considerable effort was needed to develop interest in the agricultural sector on seasonal to annual climate variability. And, these efforts still need considerable attention and support to make sure that climate forecast use is sustainable. A reasonable strategy is to build on the efforts in which farmers and their advisors are beginning to understand and make use of seasonal climate forecasts and risks associated with their decisions. Ultimately, the impacts of climate change on agriculture will hinge on seasonal and annual climate variability and how societies learn how to adapt to it. Thus, perhaps we can think of two aspects to this problem. First, by learning more about climate variability and how to use it in agricultural decision-making, we are preparing our agricultural sector to better deal with climate conditions that may occur in the future. Secondly, when discussing climate change with those in agriculture, it would be advantageous to discuss it relative to climate variability. I believe that this would mean more to farmers than stating average projected temperature increases. For example, if farmers know how to adjust management for warmer, drier years now, it would be meaningful to inform them that climate change will likely mean more seasons that are warm and dry when compared with current climate conditions. We have not yet done this in our discussions with farmers. But, it is a logical extension of what we are currently discussing with farmers, which would help them better relate to how climate change might impact them and provide a basis for more meaningful dialogues on climate change.