Climate Change – Impacts on Agriculture and Natural Resources

A. Scope/audience

Climate change has been identified as one of the most significant challenges affecting the mankind today. It is an extremely broad area that includes changes in the physical and chemical climate, the associated impacts on agriculture and food security, and feedbacks. These changes in climate include, but are not limited to, changes in precipitation, temperature, air composition, atmospheric circulations, weather extremes, and solar radiation.

B. Overview & contribution in the past 5 years

Research in climate change, including changes in temperature, precipitation, ultraviolet solar radiation, greenhouse gas emissions, and their effects on crop production has been the focus of many members of the Agronomy department. In the past five years, researchers in the department have collectively had more than 29 collaborative projects with partners across Purdue and national labs (including USDA-NSERL) totaling more than $7.5 million in climate change-related research. The projects resulted in more than 60 refereed publications and the completed or ongoing training of more than 20 graduate students and nine post-doctoral researchers in the past five years. This research has been supported by NSF, USDA CSREES NRICGP, NASA, EPA, NOAA, and DOE and includes activities in climate change <u>monitoring</u> (*in situ*, airborne, and satellite) <u>prediction,</u> <u>impact evaluation</u> (and <u>adaptation and/or mitigation strategies</u> (using genetics and extension/education projects), with some of the projects having extension components through the Indiana State Climate Office and normal extension activities of various faculty and staff. The complexity of climate change in the earth system requires interdisciplinary teams of researchers to develop capabilities to measure, monitor, adapt, and mitigate impacts. A PhD. Program called Earth Systems Science is currently being developed in Agronomy to train future researchers conduct interdisciplinary research in the earth-atmosphere system, including climate change. In addition, the Purdue Climate Change Research Center (PCCRC), has developed extensive capability in the last five years with significant involvement of the Agronomy Department, including partial faculty appointments with Earth and Atmospheric Sciences of three faculty members (Niyogi, Gurney, Zhuang). Research in climate change now ranges from field to watershed, landscape, regional, continental, and global scales, and includes the development of genetic resources expressing traits favorable to qualitative and quantitative crop production under changing climatic conditions, and significant contributions to education. Monitoring inputs and impacts are critical to developing an understanding of the complex processes that contribute to climate change and then to developing capability for predicting future levels of change and developing capability to adapt to and mitigate the impact of climate change. Agronomy is uniquely positioned uniquely to contribute to initiatives in these areas, as well as to education and extension about climate change. Specific projects conducted in the past five years within this area include:

1. Monitoring climate change:
    a. Measurement of greenhouse and nitrogen gases associated with agricultural activities and natural systems
    b. Measurement of the quantity and quality of wetland and other freshwater resources impacted by climate change
    c. Monitoring of regional climate and land use changes from *in situ* and satellite data products
    d. Evaluation the spatial distribution of carbon across the landscape
    e. Evaluation the spatial distribution and variability in flooding across watersheds
2. Predicting climate change:
    a. Assessment of climate variability/change and extreme weather using models and observations
    b. Evaluation of the effects of changes in wind patterns on seed and spore distributions in the United States and Africa
    c. Assessment of the effects of climate change on regional hydrology
    d. Understanding of the potential for carbon sequestration
3. Evaluating impacts of climate change:
    a. Evaluation of the effects of changes in solar radiation, CO_2 levels, and pollution on crop production
    b. Evaluation of the impacts of changes in greenhouse gases on crops and natural vegetation
    c. Evaluation of changes in climate, land use, and water resources on landscape scale processes
    d. Evaluation of the effects of climate on soil resource quality
    e. Evaluation of agricultural intensification and urbanization on regional climate and extreme weather
4. Adaptation and/or mitigation strategies to a changing climate:
    a. Development of genetic resources for the expression of traits favorable to qualitative and quantitative crop production under changing climatic conditions and associated changes in biotic stresses in the Midwestern United States., the entire United States, and Africa
    b. Work with local agencies in developing drought and water shortage plans
    c. Development of best management practices to conserve water, nitrogen, and reduce degradation of air and water quality
5. Education and extension of climate change information:
    a. Development of Earth Systems Science PhD focus in Agronomy
    b. Development of middle school curriculum on climate change for teachers
    c. Expansion of the capabilities, products and dissemination of climate information through the State Climate Office
    d. Development of cyber-infrastructure for climate and environmental information through Web portals

e. Development and dissemination of guidelines for best management practices to minimize soil carbon and nitrogen losses in production agriculture and turf management

Research has spanned the scales of field, watershed, landscape, regional (Indiana, Midwest, Africa, India, Arctic, Brazil), to global. Given the breadth of expertise at multiple scales, the department is particularly well positioned to work across scales for the scaling up of results from field-scale experiments to the down-scaling of regional and global models.

C. Current challenges

To a large extent, weather (temperature, light, and water) determines people's ability to grow enough to feed themselves and their animals. Climate change results in changes in weather patterns, and feedbacks in turn impact climate. Such changes are induced in part by increases in greenhouse gases and thus challenge the continued use of currently accepted agricultural practices. The United States Climate Change Science Program "Synthesis and Assessment Product 4.3 (SAP 4.3): The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States." (http://www.climatescience.gov/Library/sap/sap4-3/default.php) describes aspects of climate change that appear to be already affecting U.S. water resources, agriculture, land resources, and biodiversity. They include:

1. More rapid maturation of grain and oilseed crops
2. Greater risk of crop failures, particularly if precipitation decreases or becomes more variable
3. More rapid growth of weeds, northward migration of weed species, and greater resistance of weeds to herbicide applications
4. Higher precipitation and streamflow with decreased drought severity and duration, over the 20th century (the West and Southwest, however, are notable exceptions, and increased drought conditions)
5. Reduced mountain snowpack and earlier spring snowmelt runoff in the Western United States
6. Invasion by exotic grass species into arid lands causing an increased fire frequency. Rivers and riparian systems in arid lands will be negatively impacted.
7. Increased growing season length by 10 to 14 days compared to the last 19 years across the temperate latitudes.

Specifically for Indiana, temperature change over the last century is limited to regions of higher urban growth, while the precipitation changes similarly do not show dramatic deviations from historical climatology. However, there has been a statistically significant increase in the growing season duration and the intensity, spatial extent and duration of hydrological extremes such as droughts and flooding. While greater changes in climate have occurred in other parts of the United States than in Indiana, the inter-related issues of supply and demand for food and fiber necessarily impacts the Midwest. Further, when considered at the continental or global scales, the problem necessitates the attention of the Purdue Agronomy Department.

D. Fundamental issues for next 10 years

Short- or long-term fluctuations in weather and climate variability and climate change can have extreme impacts on agricultural production, potentially reducing crop yields and forcing farmers to adopt new agricultural practices in response to altered conditions. Climate change over the long-term, in particular global warming, could affect agriculture in a number of ways — the majority of which would threaten food security for the world's most vulnerable people. It is expected that:

1. Predictability of weather and climate will decrease, making planning of farm operations more difficult
2. Climate variability will increase, shifting climatic and agro-ecological zones forcing farmers to adapt, as well as threatening natural vegetation
3. The current imbalance of food production between cool and temperate regions and tropical and subtropical regions could increase
4. Pests and vector-borne diseases will spread into new areas
5. Forage production will likely extend into late fall and early spring, decreasing need for winter season forage reserves.

E. Projects that Purdue and especially Agronomy can develop to address these issues

The Agronomy department is best positioned for thrusts in multi-scale monitoring and assessment and development of adaptation strategies. The strong credibility of extension provides a clear path for the transfer of useful information to the public. Major projects could potentially include subcomponents in a number of the previously defined categories. Research in many of these areas is already underway.

1. Monitoring climate change:
    a. Development of and utilization of measurement methods to evaluate greenhouse gas emissions resulting from changes in agricultural cropping systems.
    b. Incorporation of land use/land cover mapping and monitoring methods based on remote sensing and geographic information systems (GIS)
    c. Integration of *in situ*, airborne, and satellite based monitoring systems for measuring long-term response of agricultural lands to regional and global change
    d. Research in the development of an easy and reliable means to accurately ascertain the mineral and carbon state of agricultural lands, particularly over large areas.
    e. Developing satellite data assimilation techniques to monitor crop systems and hydrological state over agricultural and urban landscapes

2. Predicting climate change
   a. Research in the areas of understanding how climate change (long-term trends) interacts with climate variability at regional and sub-regional scales
   b. Understanding the role of nonradiative forcings, particularly including agricultural intensification, on climate change
   c. Forecasting associated land surface changes and resulting changes in the weather, regional climate, water availability and quality.
   d. Developing soil and water resource status prediction model validations through multi-scale measurement scheme in suitability complex terrains.

3. Evaluating impacts of climate change:
   a. Research in the area of predicting impacts of changes in management practices on soil quality and water availability and quality based on *in-situ* and remote sensing measurements and models.
   b. Research in the effects of droughts on hydrologic and chemical/pesticide flow due to changes in soil structure.
   c. Research in area of climate change on agricultural productivity in the Midwest and in Asia and Africa

4. Adaptation and mitigation strategies to a changing climate:
   a. Integration of models with existing monitoring efforts and plant developmental databases to provide cost-effective strategies that both enhance knowledge of regional climate change impacts and provide management options.
   b. Food production systems for changing (drier/warmer or wetter/cooler climates) climates with especial consideration in Asia and Africa.
   c. Research in the area of genetics x environment are needed to better understand the implications of genetic manipulation on plant response in the environment.
   d. Research in the quick selection in breeding programs for potential new varieties of corn, soybean, wheat, sorghum with resistance to anticipated increases in pest and disease damage.
   e. Research in the production or sequestration of greenhouse gases relative to changing agricultural management practices.
   f. Development of strategies for conserving soil resources and providing carbon credits to farmers (carbon farming).

Education and extension of climate change information
Further development and marketing of the Earth Systems Science PhD program.
Further development of middle school curriculum on climate change for teachers
Development of climate services and decision support systems and portals for climate and agricultural decision making
Development of Weather and Climate project materials for 4-H

Further development of extension materials and presentations to describe best management practices.

Funding for research in this area typically comes from NSF, NASA, NSF, USDA, and DOE, and in some instances from trusts and foundations such as the Showalter Trust and Packard Foundation.

F. The science team (expertise needed)

The Agronomy department has significant basic capabilities for understanding processes and interactions of climate change in the soil/plant/atmosphere system as is evidenced by the research already under way or completed in the department. We have expertise in land surface process modeling, remote sensing and GIS, monitoring land use and cropping systems, monitoring greenhouse and other relevant gas exchanges between the land surface and the atmosphere, understanding feedbacks of climate change on water resources quality and quantity, the impact of changing climate on crop (maize, soybean, wheat) quality and quantity, and the impact on microbial processes. The department's strength in breeding and molecular genetics has an untapped capability to optimize long-term production under changing climate through the expression of new trait combinations. Geographically, the department has significant experience and capabilities through work in the Midwestern United States, desert savanna ecosystems of Africa, as well as the Arctic, Amazon, and Indian monsoon region. While models and techniques can be applied to a number of regions, a regional focus is a strong priority for developing multidisciplinary research projects for major funding initiatives focused on development and dissemination of best management practices and decision support systems for production systems. The focus of our vision is initially the Midwest, but will ultimately include severely stressed regions of the world such as sub-Sahel and Sahel Africa. Expertise in the department includes the capability for the:

1. Development of cropping systems to minimize weed problems (especially if glysulphanate becomes less effective) and disease problems associated with the introduction and spread of new pathogens.
2. Development and dissemination of best management practices for severely stressed regions of the world such as sub-Sahel and Sahel Africa to mitigate impacts of climate change (including increased weed and disease impacts).
3. Development of forage and crop production and turf management systems to take advantage of longer growing seasons, more extreme weather conditions, and
4. Understanding the changes and susceptibility to changes in hydrology/ water availability at landscape and larger scales.
5. Development of decision support systems for agricultural decision making in the Midwest under changing climate

6. Integration of climate and weather variability in the modeling of agricultural processes for effective prediction of impacts would substantially enhance the ability of the department to develop major initiatives.

Partners for climate model downscaling include faculty and staff in the PCCRC at Purdue, and researchers at Indiana University and Iowa State University. Additional capabilities in remote sensing of soil moisture and land/surface process interactions and in integration of climate and weather variability in the modeling of agricultural processes for effective prediction of impacts would substantially enhance the ability of the department to develop major initiatives.

This Grand Challenge links with the other Grand Challenges for Agronomy:

1. The Adaptation Strategies research links with the "Harvesting of genetics to isolate economically important traits" and "Bio-feedstock" Grand Challenges.
2. The Adaptation Strategies and Monitoring and Impact Assessment research links with the "Landscape-scale management for sustainable plant production and ecosystems" Grand Challenge.
3. The Prediction and Adaptation research links with the "Bio-feedstock" Grand Challenge.
4. The Impact Assessment research links with the "Persistent Pollutants in the environment and impacts of ecosystem and human health" Grand Challenge.
5. The focus on Africa links with the "International Agriculture research and engagement" Grand Challenge.

G. Time frame

Time frame for this thrust should be at least 10 years. Initial efforts (first three years) will be to develop a team-based 'fully integrated' (by a significant subset of scale, discipline and agriculture-climate interactions) project in the Midwest and conduct preliminary assessments of needs and further establishment of relationships through small multidisciplinary (but not fully integrated) demonstration projects in Africa.

H. Evaluation of success

The department is generally well-positioned for successful engagement of the research opportunities in this area. The breadth of the needs is so great that defining success (or failure) will be very difficult. Faculty are already showing success in the field but that success is not as an integrated and coordinated effort that can be identified by outside funding agencies as 'the place to go' to move forward in understanding and dealing with anticipated agriculture/climate interactions in the arena of changing climate. Department success will be identifiable through the successful completion of 'fully integrated' studies.

I. Dissemination of information to decision makers/scientific community/public

The department hosts the Indiana State Climate Office which interfaces with the state and national decision makers. Extension routinely disseminates information on best management practices. In addition, faculty members are already engaged in various capacities through their role in advisory committees, invited testimonies, and media experts to disseminate in formation at national and international forums discussing climate change.

J. Resources needed

Effective interdisciplinary activities will be greatly enhanced with the provision of shared space to enhance collaborations between student and faculty. At present, individual faculty and students are conducting important research without significant interaction. This lack of interaction both restricts the scope of research and the training of students working on research projects. Additional faculty hires in remote sensing of soil moisture and land surface/vegetation interactions, and the integration of climate and weather variability in the modeling of agricultural processes for effective prediction of impacts are critically needed to provide fundamental capability in the department to develop major initiatives.

Sustained resources for operation of the State Climate Office, the Laboratory for Applications of Remote Sensing, and the Purdue Terrestrial Observatory, to work with the PCCRC and the Center for the Environment, and to provide extensive computational infrastructure to access, develop, and sustain modeling, data storage, and information dissemination will greatly enhance research. Seed funding to develop international collaborative activities would help the department move beyond the natural Midwestern research strength and enhance graduate student experiences. In addition, the provision of research assistantships/ fellowships to develop collaborative student education experiences within the context of the Earth Systems Science PhD program would assist in the rapid establishment of the efforts initiated in the Midwest.

K. Conclusions/recommendations/vision for the future

It is proposed that the next major step include a two-pronged effort involving the development of a team-based fully integrated (by a significant subset of scale, discipline and agriculture-climate interactions) project in the Midwest leveraging existing capabilities and active research. Assessments of needs and further development of relationships of faculty in the department with known partners in Africa followed by a few small multidisciplinary (but not fully integrated) demonstration projects in Africa.

References:

1: U.S. Climate Change Science Program "Synthesis and Assessment Product 4.3 (SAP 4.3): The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States." (http://www.climatescience.gov/Library/sap/sap4-3/default.php)