Climate Change Impacts on Corn and Soybean Production in Iowa

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Introduction:

Iowa is the top corn producing state in the nation and consistently ranks either first or second in soybean production. Consequently, the state plays a major role in national and global food and fiber markets. About ninety percent of the land in the State is utilized for agriculture, dominated by corn and soybean production. Given the heavy dominance of agriculture in general, and Corn and Soybeans in particular, any significant changes in the production of these two crops by exogeneous factors such as climate will not only have an impact on the agricultural sector but beyond. In 2013, almost 90,000 farms in the state employed nearly 92,000 workers. Once farm-supporting industries are taken into account, this number swells to more than 400,000 or 20% of the state's employment (NRDC, 2015). A very small percent of these crops (less than 1%) is used for direct home consumption; however, the indirect cost on food prices through higher feed and animal costs can be significant.

The impact of potential climate change on production and incomes of farmers is well documented in the literature (see for instance, Osei and Jafri, 2016). The principal climate variables of interest are precipitation and temperature. In the broad Midwest region of the United States, between 1910 and 2010, the average air temperature increased by more than 1.5 degrees F (White House Fact Sheet, 2014). The same source reports that across Iowa, even though not showing any increase in total rainfall, the state was marked with a large increase in the number of days of heavy rainfall. The heavy rains can cause soil erosion, loss of nutrients while increasing the costs of drying the fields due to heavy moisture conditions (Gupta, 2017). The increase in precipitation could also increase the infestation of pests and disease and water clogging conditions in clayey soils.

Future crop yields will be strongly influenced by anomalous weather events than by changes in the average temperature or annual precipitation (White House, 2014). Wetter springs could also reduce yields and profits and farmers may switch for late-planted shorter seasonal variations. Consequently, it is the dispersion of climatic variables such as temperature and precipitation and temperature that will play a key role in the future patterns of production and incomes.

The previous discussion on climate variations have only served to raise interest in opposing viewpoints if these variations are due to natural geological forces or of anthropogenic causes. The inconclusive nature of climate change viewpoints notwithstanding, significant resources have been invested in forecasting weather patterns into the future. Daily weather projections are available through the end of the 21st century. What is not clear is the interaction of these projections on food production and farm incomes. The objective of this research is to help fill that void. We use the most widely accredited compilations of climate projections to determine the corresponding impacts on corn and soybean production assuming current market conditions and crop production potential. To obtain these projections, we use a well-tested and calibrated bio-geophysical model, the Agricultural Policy Environmental eXtender (APEX) and a similarly well tested and calibrated farm-economic model. Our results indicate, as expected, that current climate projections will have variable and significant impacts on corn and soybean production and consequently on the incomes of Iowa farmers.

Background:

It is well known that farm production and climate/weather are closely related. Several plant scientists, agronomists and economists have studied this relationship using scientific data and biological theories. For example, a plant physiologist traced how high temperatures in both day and night time will impact plant growth by adding stress to plants, reducing yield potential (Hatfield, 2010). Hatfield further recognized that increase is CO_2 levels promotes weeds and other climate changes such as high humidity levels promotes diseases and insect growth.

In addition, studies in the academic literature has documented that agricultural production is strongly correlated with biophysical attributes of farms as well as weather and management practices (e.g., Machado et al., 2002, Lambert, 2014, Dell et.al 2014). Dell et.al in a survey article evaluated the extent to which climate change has influenced economic outcomes in general including the impacts on the Agricultural sector. The primary approaches applied in evaluating the impact of weather include using weather related inputs such as precipitation rates, temperatures, humidity levels as inputs in a production function. Previous studies used cross-sectional regressions, utilizing panel data and applying a hedonic approach (also adopted by Lambert (2014) which includes weather variables). The main conclusion of these studies confirms that adverse weather negatively impacted U.S. agriculture. Similar results were also observed in studies conducted in other parts of the world such as India, Mexico and Indonesia. Besides, Lambert (2014) also concluded that weather devastations were associated with greater impacts on net Farm Income than on the value of farm products. The role of offsetting price movements, crop insurance payments to farmers' buffers them from revenue losses but results in government payments subsidized by taxpayers. Such payments are typically not available for farmers in third world countries.

The pattern between temperature and agriculture output appears to follow a non-linear relationship. A threshold temperature represents a range which is considered optimal for plant growth. Schlenker and Roberts (2009) examining temperature data and plant growth discovered optimum temperature in output yields ranging from 29 to 32 C. The ideal temperatures varies from one crop to another; for example, for Corn, it is 29 C, for Soybeans, it is 30 C while for Cotton it is 32 C. When temperatures dip below these ranges, output increases moderately (perhaps with less stress on the plant and decrease in soil evaporation). However, even a small increase above the threshold levels significantly reduces output yields. Thus, the relationship between temperature and yields follow a non-linear path.

Changes in precipitation also appear to have an impact on yields. This is true especially for rain-fed crops and also mostly in third-world countries where irrigation systems are neither fully developed nor are sophisticated conservations methods such as drip irrigation available. For example, in Mexico (which typically relies on low and variable rainfall), warmer and dryer conditions results in nutritional and economic disaster. Even with irrigation reservoirs, water can become scarce under dryer conditions (Liverman, 1990). In addition, dry and warmer climates in agricultural regions also accelerate out-migration from these disaster-prone areas (Feng et. al, 2010). Generally, increases in rainfall results in higher yields while decreases produce lower yields (Jayachandran, 2006, Levine and Yang, 2014).

The effects described so far are short term in nature, and some economists have argued that in the long run, adaptation and mitigation techniques such as developing drought-resistant crops and farm practices such as no-till farming could mitigate the impacts of short run fluctuations in weather patterns (Deschena and Greenstone, 2007). Nevertheless, prolonged drought and long run impacts of climate change is likely to have an adverse impact on agriculture output.

Projected increased variabilities in climate are expected to impact agriculture and have significant implications for policy and food security for Iowa and the entire nation, but the specific impacts have not yet been quantified. This paper helps to meet that need. We employ an integrated modeling system comprising APEX (Williams et al., 2000) and Farm-level Economic Model (FEM) to determine the likely future trajectory of corn and soybean production in Iowa contingent upon the most likely medium-term (30-year) global circulation model (GCM) climate projections for Iowa. The results of this study indicate that current counter-cyclical government-funded farm income support programs will be subject to significant stresses if projections of warmer and dryer spring weather patterns materialize.

This paper addresses the extent to which corn and soybean production in the state will be affected by climate projections over the next 30 years. While a number of econometric studies have attempted to assay the causality between weather and crop yield and production, computer simulation models remain the most plausible tools available to the scientific community for assessing the impacts of future climate scenarios on agricultural production and incomes. Computer models such as Agricultural Policy Environmental eXtender (APEX) and Erosion Productivity Impact Calculator (EPIC) have been used for decades to estimate crop yields as functions of weather attributes at reasonable levels of precision. Linkage of such models to economic assessment models and tools enables us to reliably forecast the impacts of anticipated climate changes on farm production and incomes and the viability of rural communities under such prolonged stresses.

Methodology:

Climate impacts crop production directly through its impacts on rates of photosynthesis, evapotranspiration, nutrient cycling and transformations, and timeliness of field operations. In this study, we used an integrated computer modeling system comprising APEX and FEM to estimate the impacts of 30-year climate projections for the period 2016 through 2045 on corn and soybean production in Iowa and consequent impacts on farm incomes and government support programs. The results of the model simulations were used to develop projections of corn and soybean production and farm incomes for the state of Iowa, and to determine implications for farm policy.

<u>Data Sources:</u>

Climate projections were obtained from the National Center for Atmospheric Research's Earth System Grid portal. Climate projections chosen represent three prominent scenarios referred to as representative concentration pathways (RCPs). The specific scenarios included in this study are RCP 26 (the most optimistic projection), RCP 85, the most pessimistic, and RCP 45 (a middle ground. Climate projectiosn were obtained at a one-eighth degree latitude and longitude grid for the entire United States. Data for Iowa represented thousands of grip points and were overlaid on soil and crop cover layers to match weather projections with current crop patterns. Weather data on precipitation, minimum and maximum temperature, solar radiation, and relative humidity were thus developed over a 30-year period from 01/01/2018 through 12/31/2047. Current climate data for the same points covered the period of 01/01/1987 through 12/31/2016. Data on all other biophysical attributes (soil data layers, land cover, and topography) were readily available from previous and ongoing research efforts in northeastern Iowa watersheds. Crop management information and economic input data including input prices and producer prices of corn and soybean were all assumed to be exogenous and to follow current trends.

Modeling System:

For this paper, two calibrated computer simulation models were used to project future corn and soybean production in Iowa in response to plausible climate patterns. Both models were calibrated using historical weather and agricultural production data and farm cost and returns summaries. APEX, a well-established biophysical model, was then used to simulate crop production levels under future climate patterns over the course of 30 years. The crop productivity data obtained from the APEX simulations were then be used as input in the FEM (Osei et al., 2000; Osei et al., 2012), an annual economic simulation model for agricultural operations, to estimate the farm income and cost implications of the crop and livestock production levels indicated by the APEX model. FEM and APEX have been linked in previous work and have been used in numerous simulations (Osei et al., 2008). FEM is an annual economic simulation model that includes numerous subroutines and algorithms for simulating farm economics.

The two computer simulation models were calibrated and used for the present study. FEM was used to determine the impacts of baseline and drought scenarios on farm incomes, costs, and net income. The APEX model was used to estimate crop yields and selected edge-of-field water quality metrics, namely sediment, total nitrogen and total phosphorus in surface and subsurface flow. APEX and FEM have been linked in a previous effort to enable seamless transfer of data between the two models (Osei et al., 2008). In this study the two models were applied in fully linked mode (Figure 1) to enable transfer of biophysical parameters to the economic simulation model. The two models were calibrated separately prior to their use in the simulations.

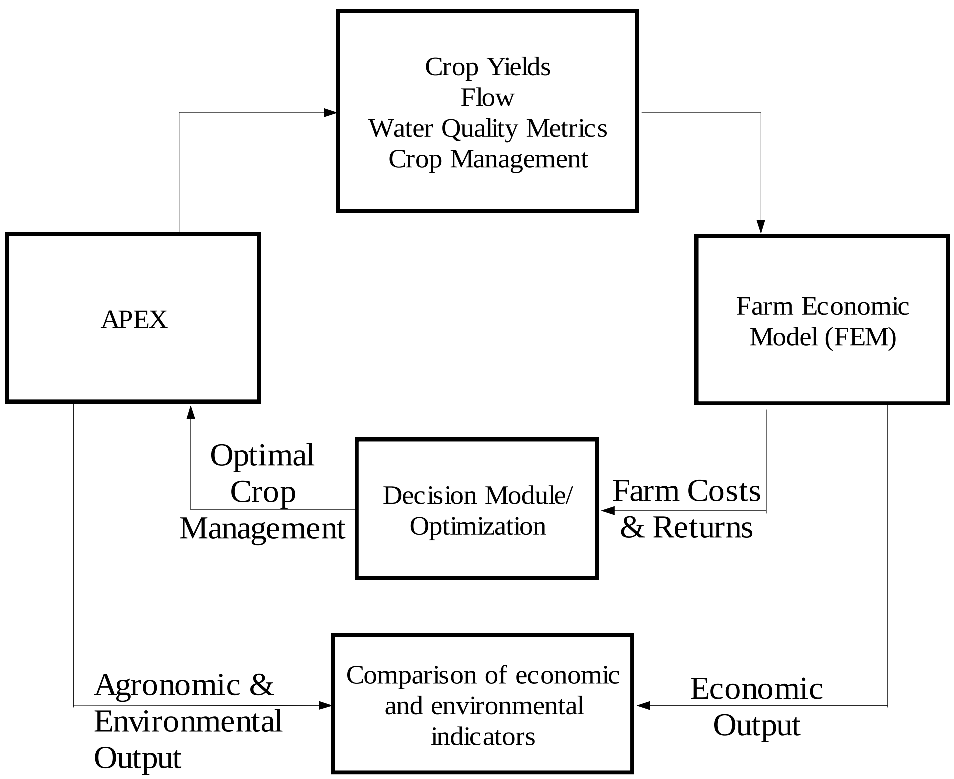

Figure 1. Schematic of FEM and APEX linkage for scenario simulation and analysis

FEM is a whole-farm simulation model that is used to simulate farm-level economic impacts in response to alternative agricultural policy and practice scenarios. FEM operates on annual time step and can be executed for extended periods of 30 years or more. Key categories of input data required to simulate a farm in FEM include type of livestock system, manure management methods, cropping systems and cultural practices, facilities and equipment, field attributes, input and output prices, and other external factors. Economic outputs generated by FEM include total revenue, total cost, net farm returns, livestock rations, crop and livestock sales, costs of individual production components (crop and livestock enterprise costs, fertilizer expenses, labor costs, etc.), debt payment, and owner's equity (Osei et al., 2000).

Prior to the simulations performed in this paper, FEM was calibrated against current (2013 and 2014) farm custom rates tabulated for many states in the continental U.S. Estimated costs of planting, tillage, nutrient, and chemical application operations and harvesting costs from the FEM model were all found to be consistent with corresponding custom rates data reported for recent years. A comparison of FEM output to selected custom rates data is shown in Table 1.

Table 1. Comparison of custom rates and FEM model output ($/acre).

		FEM Model Output	
Field operation	*Custom rate*	*Fixed Cost*	*Total*
Moldboard plow	18.68	13.37	19.79
Tandem Disk	13.46	7.36	15.13
Chisel Plow	14.32	7.35	16.33
Field Cultivator	11.36	2.88	11.76
Offset Disk	14.4	5.96	16.23
Rotary Hoe	7.56	4.89	8.06
Row Crop Cultivator	10.42	4.99	11.68
Bulk Fertilizer Spreader	6.61	1.14	5.69

APEX (Williams et al., 2000) is a comprehensive field-scale model that was developed in the 1980s to assess the effects of management strategies on crop growth, livestock grazing, and water quality. APEX is designed for whole farm or small watershed analyses and can also be used for applications such as filter strip impacts on nutrient losses from manure application fields that require the configuration of at least two sub-areas. Various components of the model include weather, hydrology, soil temperature, erosion-sedimentation, nutrient and carbon cycling, tillage, dairy management practices, crop management and growth, pesticide and nutrient movement, and costs and returns of various management practices.

APEX is a modified version of the Erosion Productivity Impact Calculator (EPIC) model that has been used widely to simulate alternative management scenarios such as variations in manure and fertilizer application rates, tillage options, and adoption of other cultural and structural management practices. APEX operates on a daily time step and can be applied for a wide range of soil, landscape, climate, crop rotation, and management practice combinations. It can be executed for a single field or used for a wide range of multi-filed configurations including whole farms or small watersheds. APEX is detailed enough to simulate precise management practices such as filter strip impacts on nutrients losses from waste application fields. The main APEX components are weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, management practices, crop management and growth, and pesticide and nutrient fate and transport. Choice of simulated cropping system, manure and/or fertilizer nutrient characteristics, tillage practices, soil layer properties, and other characteristics are input for each simulated subarea. Key outputs include crop yields, edge-of-field nutrient and sediment losses, and other water and nutrient balance indicators.

APEX was calibrated against annual county-level crop yield data assembled by the USDA National Agricultural Statistics Service (USDA-NASS) and available on the USDA-NASS web site. The model is included in USDA's web-based Nutrient Tracking Tool (Saleh et al., 2011) and has been calibrated extensively by many other authors for use to assess edge-of-field water quality impacts across a wide variety of agricultural lands in the U.S. and other nations (Gassman et al., 2010).

Data Sources:

A number of data sources were used for this study. Many of the following datasets are incorporated into the web-based NTT tool. Others were assembled specifically for this study.

Various Geographic Information Systems (GIS) data layers were overlaid in order to determine the distribution of corn and soybean growing areas in Iowa.

Cropland data layer (CDL): A four-year GIS history of cropland cover for the entire United States was obtained from the USDA-NRCS data server. The cropland data used for this study covered the time period of 2010 through 2013. The CDL data is available at a 30-meter level of precision. However, to reduce the number of computations required, the CDL data layer was scaled up to a 900-meter level of precision for use in this study.

SSURGO soils data: The USDA-NRCS SSURGO soils data for each survey area have been assembled and uploaded onto the NTT server. For this study, the SSURGO data layer was overlaid on the CDL data in order to determine the soil types applicable to corn and soybean production fields in Iowa. A total of over 5,000 unique soils were identified as corn and/or soybean growing areas within the State of Iowa for 2015.

Weather data: Precipitation, minimum and maximum temperature, solar radiation, and other key weather variables were obtained from the USDA Parameter-elevation Regressions on Independent Slopes Model (PRISM) database. The weather data are available on the NTT server and were used for the present simulations. The PRISM data used for this study are available at a 4-kilometer resolution for the continental U.S. The simulations presented here were performed with a 30-year history of weather data from 1987 through 2016 to adequately reflect typical weather patterns in Iowa.

Input and output prices: Additional data sources included wheat grain and forage prices, prices of various beef cattle, forage supplements, farm equipment, and crop chemical inputs. All crop chemical price data were obtained from USDA's Agricultural Prices Summary database. Equipment prices were based on current retail prices of the same types of equipment, tractors and other farm machinery.

Climate Projections: Climate projections were obtained from the National Center for Atmospheric Research's Earth System Grid portal. Climate projections chosen represent a middle ground, an approximate average of a best case lower emissions scenario and an opposite scenario wherein the current greenhouse gas emissions trajectory is maintained. The climate data used for this study included data on precipitation, minimum temperature, and maximum temperature for the period of 2006 through 2099. Specific climate projections used were downscaled Coupled Model Intercomparison Project (CMIP 5) weather projections from NCAR and the Lawrence Livermore National Laboratory at 1/8th degree Latitude and Longitude grid for the entire conterminous United States. The data were obtained from the Bureau of Land Reclamation server at a one-eighth degree latitude and longitude grid for the entire continental United States. Grid points were then associated with each land area simulated simply by proximity.

Weather data on precipitation, minimum and maximum temperature were extracted from the database for the 30-year period from 01/01/2018 through 12/31/2047. Data on all other biophysical attributes (soil data layers, land cover, and topography) were readily available from previous and ongoing research efforts in the Southern Great Plains. Crop and livestock management information and economic input data including input prices and producer prices of crop and livestock commodities were all assumed to be exogenous and to follow current trends. Furthermore, crop productivity was assumed to remain static at current levels.

Climate Scenarios:

Climate projections exist for the continental United States through the 21st century. Predominantly used projections are based on one of three scenarios depending on assumptions about GHG emissions. Each climate change scenario is based on a representative concentration pathway (RCP) that represents a trajectory of GHG concentrations anticipated in response to corresponding mitigation assumptions. Four RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were adopted by the Intergovernmental Panel on Climate Change (IPCC) and have been widely used in climate projections. The nomenclature of the RCPs correspond to projected radiative forcing by 2100 under these scenarios as compared to the preindustrial era. The radiative forcing values are expressed in Watts per square meter (Wm^{-2}). Of the four, the following are the three scenarios considered for this study:

RCP 26: This scenario corresponds to a radiative forcing of 2.6 Wm^{-2} as compared to the pre-industrial era and is projected to result in a 1°C increase in mean global temperatures by the 2046 to 2065 period. This represents the most optimistic scenario among the four, for reducing global warming.

RCP 45: This scenario corresponds to a radiative forcing value of 4.5 Wm^{-2} as compared to the pre-industrial era and is projected to result in a 1.4°C increase in mean global temperatures by the 2046 to 2065 period.

RCP 85: This scenario corresponds to a radiative forcing value of 8.5 Wm^{-2} as compared to the pre-industrial era and is projected to result in a 2.0°C increase in mean global temperatures by the 2046 to 2065 period. This represents the most pessimistic scenario among the four, for reducing global warming.

Corn and soybeans were simulated on all applicable soils on which that crop was grown, based on the 2015 CDL data. These two crops collectively account for a significant component of total farmland in Iowa.

Each major soil type applicable to each crop was simulated for the projected weather scenarios. The results were compared to a status quo baseline that entailed current climate patterns. Crop production and farm economic impacts are presented in this paper, aggregated across all simulation within each county, and across the entire state.

Results and Implications:

Results from model simulations (Table 2) indicate that current medium-term (30-year) climate projections for Iowa will result in moderately significant reductions in corn yield within the state, but only minor impacts on soybean yields, with variations between counties largely proportional to average precipitation levels and inversely proportional to variability in daily precipitation during the growing season. Farm production and incomes are also likely to experience greater variability due to anticipated increases in the frequency of extreme weather events. The consequent implications are that farm incomes before government payments will be lower on average, and the frequency and magnitude of government income support payments will increase. The results of this paper suggest that mitigation strategies need to be developed to assist farmers in addressing income risks associated with prolonged weather extremes. Previous work involving winter wheat production in Texas suggests that winter crop production may actually benefit from warmer climate patterns. Farmers may be well served to consider diversifying their enterprises by incorporating winter cash crops if trends in temperature increase adequately enough to make that viable.

Table 2: Simulated impacts of projected climate change on corn and soybean yields

	Crop yields (bu/ac)		Percentage changes	
Scenario	Corn	Soybeans	Corn	Soybeans
Historical	168.6	45.2	-----	-----
RCP26	150.0	44.5	-11.1	-1.7
RCP45	150.4	44.1	-10.8	-2.5
RCP85	150.4	43.9	-10.8	-2.8

Conclusions:

While climate change science is highly debatable, it is insightful to evaluate the potential implications of projected changes in climate patterns on agricultural production and farm incomes. This paper used the generally accepted climate model projections currently available to determine the implications of these projections on corn and soybean production in Iowa. The limited results shown here suggest a moderate decline in the production of both cash crops in Iowa. Impacts on individual counties or regions may be more or less marked depending on the projected changes in weather patterns. Additional results will highlight regional differences and will also look at the impacts of other climate change scenarios on farm production and income.

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