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AN ECONOMIC ANALYSIS OF CLIMATE CHANGE ON COTTON PRODUCTION ACROSS THE U.S. COTTON BELT: PRELIMINARY RESULTS

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Abstract

Increases in average ambient temperature and CO_2 levels, as predicted by researchers studying climate change, may potentially affect agricultural production levels and the suitability of regions for specific crop production. The crop simulation model, GOSSYM, was used to examine the impact of changes in these two variables on yield and irrigation requirements of cotton produced at nine locations across the U.S. cotton belt: Shafter, CA; Maricopa, AZ; Artesia, NM; Lubbock TX, Corpus Christi, TX; Portageville, MO; Stoneville, MS, Meridianville, AL, and Florence SC. Average net returns were calculated for each location, under two potential climate regimes, one based on historic weather patterns and one based on patterns predicted by a regional climate model (Mearns, 2000). Under each regime, the interaction of five changes in average temperature and five changes in carbon dioxide level were evaluated. The ranges chosen for changes in temperature and CO_2 levels reflect conditions from the pre-industrial era to the limit of accepted scientific predictions for climate change.

While results were specific for each location, some general trends are that, *ceteris paribus*, as CO_2 level increased, production improved and net returns increased. However, yield and net returns results under the regional climate model's predictions of future climate generally had lower magnitude yield and net returns than those under present climate at all levels of atmospheric CO_2 and temperature deviation. Thus future climate conditions had a negative effect on yield and net returns at most locations. No clear trend emerged on the effects of temperature increases on yield and net returns.

Introduction

The Earth's dynamic climate system is affected by natural processes of diverse spatial and temporal scale and by anthropogenic activities. It has been shown that levels of greenhouse gases (mainly CO_2, but also CH_4, N_2O, O_3, water vapor, and chlorofluorocarbons) in the atmosphere have increased over approximately the last century and a half due to emissions (Intergovermental Panel on Climate Change). Increases in levels of greenhouse gases have resulted in a positive radiative forcing effect, leading to increased global average air temperature – the phenomenon most often referred to as climate change. Through a number of feedback mechanisms, climate change actually involves changes in both mean and variability of weather parameters (Mearns *et al*.). Studies have been conducted to examine the effects of climate change on environmental processes (Baker and Allen; Drake; Intergovermental Panel on Climate Change; Watterson *et al*.; Woodward *et al*.), including numerous works on climate change effects pertaining to agricultural production (Adams *et al*.; Buan *et al*.; Conroy *et al*.; Easterling *et al*.; Mearns, 1996; Riha *et al*.; Rosenzweig and Hillel; Saariko; Thompson). As the focus with climate change research is frequently on future conditions and effects, crop simulation modeling is often used to evaluate potential yield impacts (Brown and Rosenberg; Wang and Erda). In general, many studies predict adverse affects on crop yields in the absence of management adaptation. However, the net effect of climate change on crop production depends on interactions of weather parameters (such as atmospheric CO_2 and temperature), geography, soil type, management practices, and cultivar properties. This study will examine the economic impact of climate change on U.S. cotton production, using the GOSSYM simulation model for nine U.S. locations over a number of years, with interactions of CO_2 and temperature changes. This paper reports preliminary results on yield and net returns for the various locations.

Materials and Methods

GOSSYM is a mechanistic cotton growth model that simulates daily progression of cotton physiology, growth, development, and yield, based on input data for geography, daily weather, soil type and hydrology, management practices, and cultivar properties was used in this study (Baker *et al*.; Hodges et al., 1998). Nine cotton-producing locations across the U.S. are included in the study. From west to east, these locations are: Shafter, CA, Maricopa, AZ, Artesia, NM, Lubbock, TX, Corpus Christi, TX, Portageville, MO, Stoneville, MS, Meridianville, AL, and Florence, SC. For each location, daily weather data consisting of maximum and minimum temperature, solar radiation, precipitation, and wind speed was used as input for the model, along with soil physical and hydrologic characteristics of a typical soil type of that area, and the timing and frequency of selected management practices such as application of growth hormone and defoliant. For more detail on weather, soils, and management practices for each location, refer to Richardson. Availability of historical weather data varied by location, ranging from 7 years (Meridianville, AL) to 30 years (Stoneville, MS). Production of a mid-season upland variety of cotton was simulated at all locations.

At each location, two climate scenarios were tested. The first scenario is described by historical weather datasets, and is referred to as the "present" scenario. The second, called the "future" scenario, is based on weather datasets generated by modifying historical weather datasets to incorporate projected monthly mean future changes in weather parameters (average maximum and minimum air temperature, solar radiation, precipitation, and wind speed) produced by the RegCMs regional climate change model from the National Center for Atmospheric Research (Mearns 2000). Because of their higher spatial resolution over smaller geographic area, regional climate change model has e been shown to provide more useful data output for use in site-specific crop simulation models than the coarser scale general circulation models used to predict global climate change patterns (Doherty *et al.*). A sample future change data set generated by the RegCMs model for the Stoneville, MS location is shown in Table 1. Under each of the two climate scenarios, several further conditions were imposed, including deviations from historical temperature maximum and minimum by –2, 0, 2, 4, and 6 degrees Celsius, and CO_2 levels of 200, 400, 600, 800, and 1000 ppm. These ranges of deviations were chosen to illustrate potential conditions from pre-industrial times through the next century, in line with published studies (Intergovernmental Panel on Climate Change; Karl *et al.*) Another analytical division was introduced with rainfed versus irrigated production. Under rainfed conditions, the only water received by the growing plants in the simulations is what is available through precipitation and soil moisture. Thus changes in drought stress that occurred with changing climate conditions were also captured in the GOSSYM simulations of rainfed production. In the irrigated simulations, ¾" of water is automatically delivered to the plants when the daily drought stress index falls below a critical threshold. With results for both rainfed and irrigated production, under both present and future climate scenarios (2x2), as well as the interaction of temperature and CO_2 deviations (5x5), a total of 100 sets of results were produced at each location. Average yield and net returns were obtained for each set (Tables 2 and 3).

Upland cotton production enterprise budgets published by the relevant state Cooperative Extension Agencies were the source for much of the economic data used in the modeling effort (http://www.cottoninc.com/ag_cotton_budgets/homepage). Prices quoted in the published budgets were all updated to year 2003 prices, using the index for farm inputs published by the National Agricultural Statistics Service of the USDA (http://www.usda.gov/nass/graphics/data/paid.txt). Variable costs included costs of materials (pesticide, fertilizer, growth regulator and defoliant), custom costs (air application of chemicals, scouting, hauling, ginning), labor, machinery operating costs (fuel, lubrication, repairs; includes irrigation equipment), irrigation water costs (in some locations), and estimated interest on operating loans. Fixed costs included annual machinery and vehicle costs, as a function of replacement costs and interest on machinery investment.

Net returns were calculated using the following formula:

$$NR = PY - WX - F \ ,$$

where *NR* is net returns in dollars per acre, *P* is price of cotton lint in dollars per pound, *Y* is yield of cotton lint in pounds per acre, *W* is price of variable inputs in dollars per acre, *X* is quantity of variable inputs per acre, and *F* is the cost of fixed inputs to production, in dollars per acre. The price for cotton lint was obtained from the USDA National Agricultural Statistics Service (http://risk.cotton.org/prices/asp), and is the average upland cotton price received by U.S. farmers in 2003 ($0.5024/lb). Revenue from cotton seed was not included in this analysis.

Results

As the economic model utilized is a simple one, and assumes full sale of all cotton yield, the results for net returns closely track the GOSSYM results for yield Presentation of results is divided into several categories for ease of reporting.

The Effects of Atmospheric CO_2

At all locations, under rainfed conditions, for both present and future weather patterns, yield and net returns increased as the level of CO_2 increased. This agrees with previous studies of cotton production under changing climatic conditions (Reddy *et al*, 2002). Under irrigated conditions, yield and net returns also increased, however, at all locations except Portageville MO, yield and net returns at the upper levels of CO_2 concentration tended to cluster together at higher levels of yield and net returns.

The Effects of Temperature

It was difficult to distinguish a general trend in effect of temperature deviation on yield and net returns. In some locations, under rainfed (Shafter CA, Artesia NM, Lubbock TX, Stoneville MS, Meridianville AL, and Florence SC) and irrigated (Maricopa AZ) present climate conditions, yield and net returns declined as the temperature deviation increased. Net returns also declined with an increase in temperature deviation under future climate conditions for both rainfed (Maricopa AZ, Lubbock TX, Corpus Christi TX, Stoneville MS) and irrigated (Shafter CA, Maricopa AZ) production areas. These findings conform to previous research that found higher summer temperatures correlated with smaller bolls and lower yields (Reddy *et* *al*., 2000). However, an increase in yield and net returns accompanied an increase in temperature deviation under irrigated, present climate conditions in Shafter CA and Portageville MO, and under rainfed, future climate conditions in Shafter CA, Artesia NM, Portageville MO, Meridianville AL, and Florence SC. No temperature response in net returns was discernable under present climate, rainfed conditions at Maricopa AZ, Corpus Christi TX, and Portageville MO, or under present climate, irrigated conditions at Artesia NM, Lubbock TX, Corpus Christi TX, Stoneville MS, Meridianville AL, and Florence SC, or under future climate, irrigated conditions at Artesia NM, Lubbock TX, Corpus Christi TX, Stoneville MS, Meridianville AL, and Florence SC.

The Effects of Future Climate

Holding rainfed or irrigated as constant, simulations of cotton production in future climate generally had lower magnitude yield and net returns than those under present climate, at all levels of temperature deviation and atmospheric CO_2. Thus, future climate conditions had a negative effect on yield and net returns at most locations. Exceptions to this general trend were irrigated production at Corpus Christi TX, Florence SC, and Shafter CA, and rainfed production at Artesia NM.

Discussion

While there was a discernible upward trend in the results of yield and net returns for the effect of increased atmospheric CO_2 level, and a downward trend for the results of the changes in five weather parameters that are contained in "future" climate, the effects of rising temperature were not straightforward. This finding agrees with results from controlled-environment studies (Reddy *et al*, 1996, 1997) and simulation studies (Doherty *et al.*), which found that the interaction of changing climate variables with certain feedback mechanisms (for example, changes in water and nutrient utilization rates) can lead to varying yield responses under a range of climate scenarios. In other words, biophysical and climatic specifics of a locality play a major role in yield response to climate change. As best stated by Doherty *et al*., "response of cotton yields to future climate change will vary with environmental conditions, including soil types and baseline climate."

These preliminary results are a base from which to investigate further the effects of climate change on the profitability of cotton production across the U.S. cotton belt. Towards this end, a number of analytical possibilities exist. The GOSSYM simulations included fertilization and management practices for high production without link to economic optimality. In the irrigated scenarios, the simulation also employed an idealized distribution of water, where irrigation began as soon as plants were in danger of water stress. Therefore, water stress was probably less than what might be found under normal seasonal field conditions. An investigation of economically optimal management and irrigation strategies under climate change for the nine different locations presented here is a possibility for further study. The economic analysis presented here also assumed current water pricing, which, for much of the cotton belt, is either cheap or nearly free, except for pumping costs. Under warming conditions predicted with climate change, it would be reasonable to anticipate that water scarcity may increase in some localities and that the price of water might increase. The effect of water price increases on irrigation practices, yield, and net returns is also a possibility for further study. Another useful investigation would be the potential of other more northern locations for cotton production under climate change. In the most northern location in this study, Portageville MO, increases in CO_2 led to increased yields and net returns from cotton production. However yields and net returns were reduced at this location under future climate scenarios as predicted by the regional climate change model, when compared with present climate patterns.

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Table 1. Monthly mean future projected changes in maximum and minimum air temperature (Tmax, Tmin), solar radiation (Irad), precipitation (PPT), and windspeed (WIND) for Stoneville MS, according to the RegCMs Regional Climate Change Model (National Center for Atmospheric Research, Boulder CO)*.

Month	**T_{max} °C**	**T_{min} °C**	**I_{rad} (ratio)**	**PPT (ratio)**	**WIND (ratio)**
January	2.16	3.23	0.98	0.68	0.94
February	5.05	5.44	0.93	0.82	1.02
March	5.21	7.09	0.93	2.05	0.99
April	4.71	6.24	0.94	1.66	0.87
May	3.27	3.60	0.97	1.26	0.81
June	5.87	4.77	1.03	0.95	0.87
July	5.68	4.58	1.07	0.70	1.11
August	5.16	4.33	1.05	0.86	1.05
September	5.37	4.87	1.02	0.72	0.92
October	3.22	2.59	1.06	1.05	1.00
November	5.49	4.88	1.13	0.92	0.99
December	3.53	3.41	1.01	1.41	0.90
Average	4.56	4.59	1.01	1.09	0.96

* Maximum and minimum air temperature data (T_{max} and T_{min}) are given as °C change from present, and the solar radiation, precipitation, and windspeed data (I_{rad}, PPT, and WIND) are given as ratios relative to the present.