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Potential individual versus simultaneous climate change effects on soybean (C_3) and maize (C_4) crops: An agrotechnology model based study

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Abstract

Landuse/landcover change induced effects on regional weather and climate patterns and the associated plant response or agricultural productivity are coupled processes. Some of the basic responses to climate change can be detected via changes in radiation (*R*), precipitation (*P*), and temperature (*T*). Past studies indicate that each of these three variables can affect LCLUC response and the agricultural productivity. This study seeks to address the following question: What is the effect of individual versus simultaneous changes in *R*, *P*, and *T* on plant response such as crop yields in a C_3 and a C_4 plant? This question is addressed by conducting model experiments for soybean (C_3) and maize (C_4) crops using the DSSAT: Decision Support System for Agrotechnology Transfer, CROPGRO (soybean), and CERES-Maize (maize) models. These models were configured over an agricultural experiment station in Clayton, NC [35.65°N, 78.5°W]. Observed weather and field conditions corresponding to 1998 were used as the control. In the first set of experiments, the CROPGRO (soybean) and CERES-Maize (maize) responses to individual changes in *R* and *P* (25%, 50%, 75%, 150%) and *T* (±1, ±2 °C) with respect to control were studied. In the second set, *R*, *P*, and *T* were simultaneously changed by 50%, 150%, and ±2 °C, and the interactions and direct effects of individual versus simultaneous variable changes were analyzed. For the model setting and the prescribed environmental changes, results from the first set of experiments indicate: (i) precipitation changes were most sensitive and directly affected yield and water loss due to evapotranspiration; (ii) radiation changes had a non-linear effect and were not as prominent as precipitation changes; (iii) temperature had a limited impact and the response was non-linear; (iv) soybeans and maize responded differently for *R*, *P*, and *T*, with maize being more sensitive. The results from the second set of experiments indicate that simultaneous change analyses do not necessarily agree with those from individual changes, particularly for temperature changes. Our analysis indicates that for the changing climate, precipitation (hydrological), temperature, and radiative feedbacks show a non-linear effect on yield. Study results also indicate that for studying the feedback between the land surface and the atmospheric changes, (i) there is a need for performing simultaneous parameter changes in the response assessment of cropping patterns and crop yield based on ensembles of projected climate change, and (ii) C_3 crops are generally considered more sensitive than C_4; however, the temperature–radiation related changes shown in this study also effected significant changes in C_4 crops. Future studies assessing LCLUC impacts, including

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those from agricultural cropping patterns and other LCULC–climate couplings, should advance beyond the sensitivity mode and consider multivariable, ensemble approaches to identify the vulnerability and feedbacks in estimating climate-related impacts.
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1. Introduction

Alterations in agricultural activity continue to be a major driver of regional landuse/landcover change (LULCC). Feedbacks that occur due to LULCC are noticed in shifts in regional climate patterns, which in turn lead to changes in the vegetation productivity and land surface feedback (Pielke et al., 2002). As discussed in Foley et al. (2005), an increase in the human population and the demand for food and fiber has expanded the croplands, pasturelands, plantations, and urban areas in recent decades. Croplands and pastures presently occupy nearly 40% of the land surface and have become one of the largest landuse categories, rivaling forest cover in extent. The last four decades have also seen a doubling of the world harvest, some of which is due to about a 12% increase in world cropland area, but most is due to cultivar and other environmental, technological, and management factors (Foley et al. (2005)). Thus, changes in the cropping patterns in response to crop cycle, mixed agriculture, environmental and climate change considerations, and agricultural demand continue to be important factors.

Studies of climate change impacts on agriculture initially focused on rising CO_2 levels (Curry et al., 1990). A wide range of literature exists in synthesizing both the negative and the positive effects of CO_2 increase in plants (Curtis and Wang, 1998). Studies such as Hansen et al. (2002) and Pielke et al. (in press) suggest, following their discussion, that additional aspects of climate change (e.g. radiation, temperature, precipitation) need to be studied to assess the impact of climate change, beyond the CO_2 increase, on regional productivity.

Studies such as Mearns et al. (1996, 2003), Rosenzweig and Tubiello (1997), Iglesias et al. (1996), and Izaurralde et al. (2003) indicate that precipitation is a leading factor affecting crop yields. In a study by Ferris et al. (1999), water deficit treatments reduced the overall biomass of soybeans, regardless of CO_2 enrichment. It has become increasingly evident that complex interactions of precipitation occurrence can impact the overall health of crops as well as regional productivity. Consequently LCLUC prediction models use precipitation change as one of the criteria in developing the trajectory of the landuse change.

Similarly, studies that have monitored the influence of changes in radiative forcing on crops have focused on the impact of the increase in ultra-violet radiation (Booker et al., 1992; Fiscus et al., 1994; Miller et al., 1994). Limited attempts have also been made to observe the combined effects of changes in UV–B radiation, temperature, and CO_2 (e.g. Mark and Tevini, 1997). Recent studies (Chameides et al., 1999; Niyogi et al., 2004) analyzed changes in these radiative properties (diffuse radiation) and suggested that radiative dimming may aid crop productivity. The increase in aerosols and clouds created by volcanic eruptions as well as biomass burning are also being recognized as factors that can affect biospheric productivity and structure (Hansen et al., 1999; Gu et al., 2003). The natural and anthropogenic aerosols absorb solar radiation, and this solar absorption within the atmosphere, together with the reflection of solar radiation to space, leads to a reduction in the solar radiation absorbed by the Earth's surface. This would tend to have a redistribution effect on surface heating and change agricultural productivity in certain areas (Pielke et al., in press).

In addition, temperature changes can affect crop productivity (Fiscus et al., 1997). Higher temperatures may increase plant carboxilation and stimulate higher photosynthesis, respiration, and transpiration rates. Meanwhile, flowering may also be partially triggered by higher temperatures, while low temperatures may reduce energy use and increased sugar storage. Reddy et al. (2002) concluded that the rates of plant growth and development would continue to increase in the southern U.S. because of enhanced metabolic rates at higher temperatures, combined with increased carbon availability. Combined changes in radiation and temperatures can produce various effects. For example, an increase in aerosols can typically reduce surface radiation levels, and hence, surface temperatures. If these aerosols are carbon-dominated, they can cause warming, while sulfate aerosols can cause further cooling (Pielke et al., in press; Niyogi et al., in press).

Changes in temperature can also affect air vapor pressure deficits, thus impacting the water use in agricultural landscapes (Kirschbaum, 2004). This coupling affects transpiration and can cause significant shifts in temperature and water loss. These feedbacks contribute to regional changes in precipitation and cloudiness, leading to changes in radiation (Pielke et al., 2003).

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