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Increased climate risk in Brazilian double cropping agriculture systems: Implications for land use in Northern Brazil

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ABSTRACT

Brazil is currently one of the largest soybean and maize producers in the world. A dramatic increase in total production of these grains was possible due to the implementation of double cropping systems (two crops on the same land in the same agricultural calendar) in places where the wet season is sufficiently long. Although several recent studies have assessed soybean productivity change in South America after climate change, they have not considered important factors such as the decision whether or not to adopt double cropping systems and the incidence of diseases—both of which can influence planting dates. Here, we test five cultivars (expressed by total growing degree days) and 10 planting dates using two crop models and four climate models to assess soybean productivity in Brazil after climate change. Our results indicate that soybean productivity will increase in farms that choose to grow only one crop in the agricultural calendar (planting dates occur usually in November–December). However, the productivity of short-cycle cultivars planted in late September, typically sowed by farmers who chose to grow two crops in the same agricultural calendar, may dramatically decrease. While delaying planting dates of early planted cultivars can offset productivity loss, it may also compromise the possibility to plant a second crop. Furthermore, additional deforestation can lead to increased productivity loss due to further reductions in September and October rainfall. Urgent adaptation strategies are needed to maintain highly productive double cropping systems in Brazil in the advent of climate change.

1. Introduction

Brazil is the second largest soybean producer and the third largest maize producer in the world, contributing with 30% and 7%, respectively, of the global harvest of these crops in 2013. Argentina and Paraguay are also in the top six soybean producers. While global production of these commodities nearly doubled from 1993 to 2013, soybean and maize production in Brazil and Argentina increased three-fold. This enormous increase in production in the last 20 years is even greater than the increase observed in the United States, the main producer of these commodities worldwide (FAO, 2014). One of the main drivers of these dramatic increases in grain production in Brazil has been the extensive adoption of double cropping systems, in which farmers sow a second crop (mainly maize, but cotton is also common) in the same space after soybean has been harvested, optimizing the use of land and resources. Second crop production was not particularly prevalent a decade ago, but by 2014 it represented nearly 58% of the total area of harvested maize (Conab, 2015).

Double cropping systems are favored by high annual rainfall, a long wet season and a low variability of the onset of the wet season (Arvor et al., 2014). In most regions where double cropping has been adopted, the wet season is about 6–7 months long and there is very little margin for error in the timing of sowing and harvesting. For double cropping to be viable, farmers need to ensure that the soybeans are harvested in time for the second crop to mature while climatic conditions are still favorable. Considering that sowing may take as long as two to four weeks for a 10,000 ha soybean ranch in

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central-northern Brazil, farmers who aspire to use double cropping systems typically choose to sow as soon as possible: at the end of the sanitary break, when rainfall conditions are marginally favorable. The sanitary break, adopted by Brazil and Paraguay, is the 2–3 month period where soybean plants are absent from the fields as a measure to control Asian soybean rust (*Phakopsora sp*). The break typically lasts from June 15 to September 15/30 in Brazil. Sowing soybean at the end of the sanitary break carries a relatively high climate risk but a low probability of rust infection, thereby reducing the need to apply fungicides. Moreover, early harvested soybean typically fetches higher market prices.

South American, and especially Brazilian, agricultural production is projected to rise this century in order to meet part of the increasing global demand for food. The FAO estimates that Brazilian soybean and maize production may increase 37% and 13%, respectively, in the next 10 years (OECD/FAO, 2015). Similarly, the Brazilian Ministry of Agriculture, Livestock and Supply (MAPA, from the acronym in Portuguese) estimates that the production of these commodities will increase 33.9% and 26.3%, respectively. To avoid negative environmental consequences, increases in Brazilian food production should ideally not be achieved by a proportional increase in the planted area, and double cropping agriculture systems might play an important role to achieve this objective.

The long-term viability of double cropping systems in Brazil is critically dependent on future climatic conditions. However, recent long-term climate assessments indicate that the wet season in southern Amazonia is becoming shorter (Butt et al., 2011; Costa and Pires, 2010; Fu et al., 2013) due to deforestation and changes in atmospheric composition. Such changes in seasonality may be incompatible with the adoption of double cropping systems (Arvor et al., 2014).

Previous modeling studies of the impacts of climate change on crop productivity often oversimplify the complex reality of croplands (Rotter et al., 2011). For example, studies of soybean productivity in South America after climate change typically consider either fixed (Justino et al., 2013; Oliveira et al., 2013; Rosenzweig et al., 2014) or optimum planting dates (Rosenzweig et al., 2014) and the use of only a single crop in the same agricultural calendar. Critically, they have neglected the influence of plant infection, oversimplifying the representation of soybean cultivars and plantings dates that Brazilian farmers currently adopt and, by extension, their likely adaptation to climate change. Even more recent studies, while overcoming some of the previous limitations, have not incorporated the use of double cropping systems (e.g. Oliveira et al., 2013; Rosenzweig et al., 2014). A more realistic model of Brazilian agriculture needs to incorporate realistic representations of cropping systems, planting dates and cultivars, all of which are influenced by economic (e.g. profit) and biophysical (e.g. climate, disease) factors.

Here, we use two gridded crop models and four climate models to assess how regional and global climate change may affect soybean productivity until 2050 under the following realistic management options:

(i) farmers choose to plant short-cycle soybean cultivars immediately after the end of the sanitary break in order to grow two crops in the same agricultural calendar;
(ii) farmers choose to sow soybeans only under favorable climate conditions to obtain the highest productivity (one crop per agricultural calendar).

Although our focus is soybean productivity in Brazil, we also briefly discuss how the productivity of this commodity may change in Argentina and Paraguay. The results presented here can contribute to the development of effective solutions to mitigate the negative effects of climate change in soybean productivity and to maintain high levels of production in the region.

2. Methods

2.1. Gridded crop models description

We use two mechanistic gridded crop models (GCR) to evaluate the change in soybean productivity after climate change (therefore reducing the uncertainty related to model induced bias): the Light-Use Efficiency Model—LUE (Costa et al., 2009; Oliveira et al., 2013) and the Integrated Model of Land Surface Processes (INLAND, Costa et al., manuscript in preparation). Even though the phenological processes in both models are a function of temperature (accumulated growing degree-days), they differ in complexity.

The simplest GCR is the LUE model, where carbon assimilation is simulated using the concept of light-use efficiency. The intensity of radiation, limited by temperature and the availability of soil water, determines soybean daily dry matter net production. Total carbon assimilation is allocated to leaf, stem, root or grains depending on the phenological stage. Soybean productivity is estimated based on the percentage of dry matter allocated to grains. The model operates in a daily time-step, and is fully described by Oliveira et al. (2013).

The most complex crop model of our GCR ensemble is INLAND, a fifth-generation land surface model that simulates the exchanges of energy, water, carbon and momentum in the soil-vegetation-atmosphere system, canopy physiology (photosynthesis, stomatal conductance and respiration) and terrestrial carbon balance (net primary productivity, soil respiration and organic matter decomposition). Processes are organized in a hierarchical framework and operate in time-steps of 60-min. This model is an evolution of Agro-IBIS (Integrated Biosphere Simulator) (Kucharik and Twine, 2007) and has been developed as part of the Brazilian Earth System Model project, aiming to better represent Brazilian biomes (as Amazon and Cerrado) and processes (fire, flooding and agriculture). We use version 2.0, which includes the representation of four crops in addition to 12 natural plant functional types.

Both models were run for the entire South America, with a grid resolution of $1^\circ \times 1^\circ$ ($\sim$110 km × 110 km).

2.2. Experiment design

2.2.1. Planting dates and cultivars

In each individual simulation in this work (sets of simulations are described in Section 2.2.2) we simulated 10 planting dates (09/15, 09/25, 10/05, 10/15, 10/25, 11/05, 11/15, 11/25, 12/05 and 12/15) and 5 cultivars, that vary according to the accumulation of growing degree-days (GDD) needed to achieve physiological maturity – from the earliest to the latest cultivar: 1500, 1600, 1700, 1800 and 1900 GDD (base temperature 10 °C), with typical total cycle duration from 100 to 130 days. Therefore, for every model/scenario we have 50 possible configurations of planting dates and cultivars for each pixel. We then focus our analysis on two specific cases:

- **ESOY**: Short-cycle soybean cultivar (average cycle duration of 100 days) planted early right after the sanitary break (September 25th), to represent farmers who choose to harvest soybean in time to plant a second crop in the same agricultural calendar;
- **HSOY**: Highly productive soybeans, representing farmers who choose to plant only one crop in the same agricultural calendar, and therefore can sow soybean under the most favorable climate conditions. In this case, planting dates and cultivars at each pixel are the ones that lead to highest yields among all of the 50 simulated configurations.