

**EFFECTS OF CLIMATE CHANGE ON SOYBEAN: DIFFERENT CROPPING SCENARIOS FOR BRAZIL AND USA****ALICE DA SILVA GUNDIM<sup>1</sup>, ANA CAROLINA FERREIRA FRANÇA<sup>1</sup>, CARLOS ALBERTO QUILOANGO-CHIMARRO<sup>1</sup>, JÉFFERSON DE OLIVEIRA COSTA<sup>2</sup> AND RUBENS DUARTE COELHO<sup>1</sup>**

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**ABSTRACT:** Variations in air temperature, changes in the concentration of atmospheric carbon dioxide (CO<sub>2</sub>), and the volume and distribution of precipitation in response to climate change affect crop development and yield. Thus, research assessing the effects of these changes on crop yield for future scenarios using crop modeling is relevant. The objective of this study was to simulate the effects of climate change on soybean crop development under different cropping scenarios using the DSSAT/CROPGRO-Soybean agricultural model. The seasonal mode configuration was used with edaphoclimatic data from the regions of Rondonópolis, Mato Grosso, Brazil, and Ames, Iowa, United States of America (USA). The daily timescale was adopted for the simulation of plant development; moreover, soil physicochemical parameters and input data of daily meteorological variables were used. The output variables were maximum leaf area index (LAIX), yield (kg ha<sup>-1</sup>), and growing cycle length (in days). Grain yield and growing cycle length were the most affected variables under the climate change scenarios. Remarkably, under future climate conditions, soybean crop productivity tends to increase, most significantly for Ames/USA under irrigated conditions.

**Keywords:** DSSAT, *Glycine max*, modeling.

**IMPACTOS DAS MUDANÇAS CLIMÁTICAS NA CULTURA DA SOJA: DIFERENTES CENÁRIOS DE CULTIVO PARA BRASIL E EUA**

**RESUMO:** Variações na temperatura do ar, mudanças na concentração de dióxido de carbono atmosférico (CO<sub>2</sub>) e o volume e distribuição da precipitação em resposta às mudanças climáticas afetam o desenvolvimento e o rendimento das culturas. Assim, pesquisas avaliando os efeitos dessas mudanças no rendimento das culturas para cenários futuros usando modelagem de culturas são relevantes. O objetivo deste estudo foi simular os efeitos das mudanças climáticas no desenvolvimento da cultura da soja em diferentes cenários de cultivo usando o modelo agrícola DSSAT/CROPGRO-Soybean. A configuração do modo sazonal foi utilizada com dados edafoclimáticos das regiões de Rondonópolis, Mato Grosso, Brasil, e Ames, Iowa, Estados Unidos da América (EUA). A escala de tempo diária foi adotada para a simulação do desenvolvimento da planta; além disso, foram utilizados parâmetros físico-químicos do solo e dados de entrada de variáveis meteorológicas diárias. As variáveis de saída foram índice máximo de área foliar (LAIX), produtividade (kg ha<sup>-1</sup>) e duração do ciclo de cultivo (em dias). A produtividade de grãos e a duração do ciclo vegetativo foram as variáveis mais afetadas nos cenários de mudanças climáticas. Notavelmente, sob condições climáticas futuras, a produtividade da cultura da soja tende a aumentar mais significativamente em Ames/EUA sob condições irrigadas.

**Palavras-chaves:** DSSAT, *Glycine max*, modelagem.

## 1 INTRODUCTION

Agriculture is an anthropic activity that is highly dependent on climatic conditions. The growth, development, and yield of agricultural crops are influenced by variations in air temperature and the volume and distribution of precipitation as well as by changes in the concentration of atmospheric carbon dioxide (CO<sub>2</sub>) (Ramirez-Villegas *et al.*, 2018). Data from the IPCC (2018) show that due to high CO<sub>2</sub> emissions into the atmosphere from intensified human activities, there is likely to be a global temperature increase of between 1.5 and 2 °C. In this context, it is important to develop studies that evaluate the effects of climate change on agricultural production. However, conducting field experiments of this nature is difficult because of labor and financial limitations. Thus, agricultural modeling is a reliable tool for predicting the development of agricultural crops in various future scenarios (Lobell; Burke, 2010).

Mechanistic models, which are based on the physics and physiological processes of plants, represent tools for research and crop management. For example, the Decision Support System for Agrotechnology Transfer (DSSAT) presents a set of models developed for several relevant crops (Jones *et al.*, 2003; Hoogenboom *et al.*, 2019). The CROPGRO-Soybean model stands out for its application in soybean (Dogan; Kirnak; Copur, 2007; Battisti; Sentelhas, 2019). These mechanistic models can be used to simulate and evaluate the future impacts of climate change on crop production by modifying temperature and CO<sub>2</sub> concentration. In this way, it is possible to understand the main modifications in the growth and development of soybean crops and later use this information as a tool to make decisions. Furthermore, it is possible to compare these effects in Brazilian production areas and in the production areas of its main competitors, thus promoting future market analysis (Rosenzweig *et al.*, 2013).

The objective of this study was to simulate the impacts of climate change on soybean crop development under different crop scenarios using the DSSAT/CROPGRO-Soybean Agricultural Model.

## 2 MATERIAL AND METHODS

The soybean simulations were performed using the DSSAT/CROPGRO Soybean model. The seasonal mode was used with soil and climate data from Rondonópolis (16°27'S, 54°38'W, MT, Brazil) and Ames (42°01'N, 93°37'W, Iowa, USA). These regions were chosen because they are the largest soybean producers in Brazil and the USA.

A daily timescale was adopted to simulate plant development. The soil physicochemical parameters and daily meteorological variables were also assessed. The input variables for the climate were the maximum, minimum, and dew air temperature (°C), rainfall (mm), solar radiation (MJ m<sup>-2</sup>), and wind speed (m s<sup>-1</sup>). Meteorological data series were obtained from the NASA POWER website for the years 1985–2015 (30-year historical series).

The soil profiles required for the simulation in both countries refer to data from experiments available on the DSSAT platform. The representative soil profile for the USA was the soil named Ritchie 6/12/97 Loam (IUBF970110), obtained from an experiment conducted in Ames City. For Brazil, the soil of Terra Roxa Estruturada (LE00850001) was selected.

For Rondonópolis, the sowing date adopted was 11/15/1985 according to the CONAB (Soja, 2022) calendar, and the cultivar selected from the program database was maturity group (MG) 8, which is commonly used in this region (Alliprandini *et al.*, 2009). Following the same setting parameters, the sowing date for Ames was 05/01/1985, and the cultivar selected was MG 3 (Mourtzinis; Conley, 2017). For both regions, the plant population was 300,000 plants ha<sup>-1</sup>, with a spacing of 0.45 meters.

The parameters used for the simulations were the water condition (irrigated or rainfed), and for the future conditions were modified: air temperature (increase for minimum and maximum temperature of 2 °C) and CO<sub>2</sub> concentration (increase in CO<sub>2</sub> of 526 ppm).

The experiment consisted of eight treatments, as detailed in Table 1.

The output variables were maximum leaf area index (LAIX), yield ( $\text{kg ha}^{-1}$ ), and

growing cycle length (in days). Finally, boxplot graphs were generated in RStudio.

**Table 1.** Treatments adopted in the experiment with their respective simulation characteristics.

Treatments	Water condition	City / Country	Soil type	Weather condition
1	Irrigated	Rondonópolis / Brazil	LE00850001	Present
2	Rainfed	Rondonópolis / Brazil	LE00850001	Present
3	Irrigated	Ames / United States	IUBF970110	Present
4	Rainfed	Ames / United States	IUBF970110	Present
5	Irrigated	Rondonópolis / Brazil	LE00850001	Future
6	Rainfed	Rondonópolis / Brazil	LE00850001	Future
7	Irrigated	Ames / United States	IUBF970110	Future
8	Rainfed	Ames / United States	IUBF970110	Future

### 3 RESULTS AND DISCUSSION

#### 3.1 Meteorological parameters of the simulations

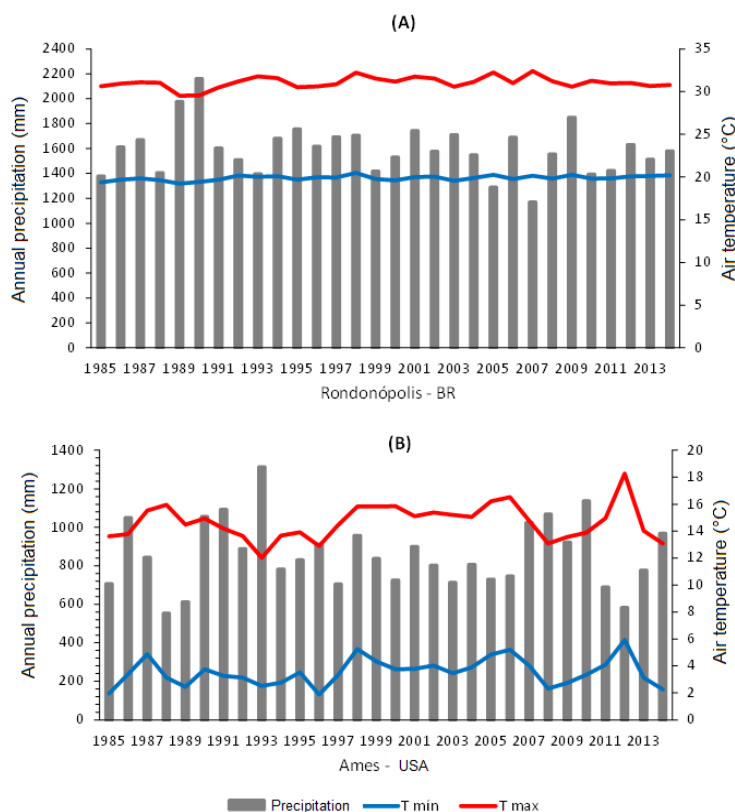
For Rondonópolis, the highest annual averages of maximum and minimum temperatures were recorded in 2005 at 32.39 °C and 20.25 °C, respectively. The lowest annual averages of maximum and minimum temperatures were recorded in 1990 at 29.53 °C and 1985 at 19.37 °C, respectively (Figure 1A). For precipitation, there was low annual variation in the rainfall regime, in which the maximum recorded was in 1990 with 2159 mm of rain. The lowest rainfall recorded was in 2007, at 1169 mm. This municipality recorded a rainfall accumulation of more than 1000 mm throughout the simulated period.

The state of Iowa recorded for the annual averages of maximum and minimum temperature higher in the year 2006 with 18.27 °C and 5.93 °C, respectively, and lower averages in the year 2011 with 12 °C and

2.44 °C, respectively (Figure 1B). The rainfall records show great variation in the rainfall regime in the state, where in 1988 and 1993, the lowest and highest rainfall of the series occurred at 552 mm and 1312 mm, respectively. However, the rainfall pattern of the region was less than 1000 mm in most of the analyzed years.

The differences observed in the volume of rainfall between the countries over the years analyzed stem from the climatic regions in which they are located. In Brazil, the predominant climate is tropical, hot with high temperatures and humidity, and in the United States, it is temperate with a predominantly subtropical climate. These factors influenced the growth and development of soybean crops in both countries, generating differences in the leaf area index and productivity simulated for the conditions of management with water limitation (rainfed) and without water limitation (potential) throughout the simulated period.

**Figure 1.** Annual averages of maximum and minimum air temperature and rainfall during the simulated period for the soybean cycle in Brazil (A) and the United States (B), 1985-2014.



### 3.2 Simulated leaf area index

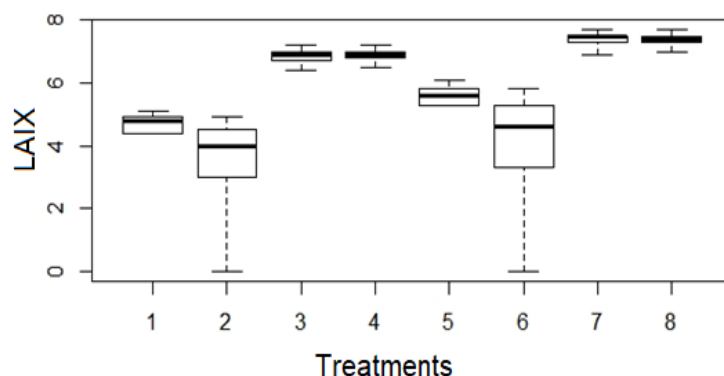
The variation in LAI (maximum leaf area index, LAIX) in the treatments over the simulated period is shown in Figure 2. Similar behavior between treatments T1 (Rondonópolis-potential-current) and T5 (Rondonópolis-potential-future), with maximum LAI higher than the rainfed condition was observed. As expected, soybean development was better under management conditions without water limitation, largely because of the climatic conditions (Figure 1A). The same was observed for treatments T3 (Ames-potential-current) and T7 (Ames-potential-future). The treatments under rainfed conditions (T2, T4, T6, and T8) presented lower maximum IAF than those without water limitation, since plants under adverse environmental conditions tend to decrease their leaf area as a physiological response to these

conditions (Zhao *et al.*, 2021). This is more notable in soybean than in other species because this crop requires a large supply of water during its cycle, which is greatly affected by the rainfall regime.

In the future, both Brazil and the USA will experience an increase in LAIX under both potential and rainfed conditions. This increase can be attributed to the increase in atmospheric CO<sub>2</sub> concentration, which stimulates enhanced biomass production in plants. This effect occurs because CO<sub>2</sub> is the primary substrate for photosynthesis (Flexas; Medrano, 2002).

The treatments in Ames showed lower variability of LAIX for both current and future climates, with LAIX values between 6 and 7, when compared to the treatments in Rondonópolis, with LAIX values between 4 and 5. The difference in LAIX between countries could be because different sowing dates were used because of the different MG.

**Figure 2.** Maximum leaf area index (LAIX) of soybean crop for different scenarios simulated in DSSAT/CROPGRO-Soybean.



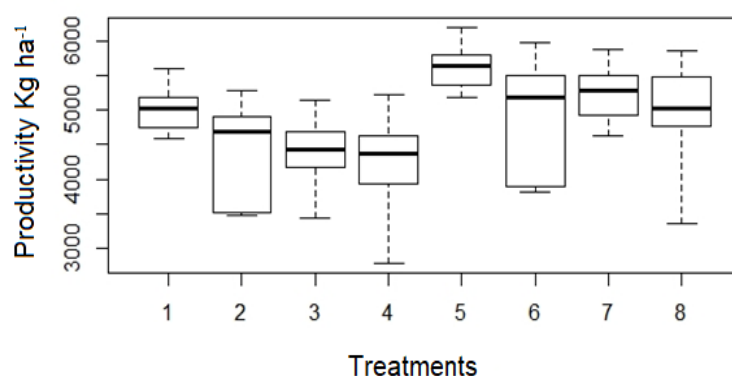
### 3.3 Simulated productivity

For both regions, in the future condition, there were similar productivity gains, being more expressive for T7 (Ames-potential-future) at around 23% in relation to the current scenario (T3) (Ames-potential-current) (Figure 3). According to Zhu, Portis and Long (2004), productivity gains for C3 crops can increase by up to 30% with increasing CO<sub>2</sub> levels.

An increase in temperature can have a negative effect on the biochemical processes of plants, affecting growth, photosynthesis, and

productivity under normal CO<sub>2</sub> concentrations. However, in the future, changes in CO<sub>2</sub> concentration could favor soybean productivity, even with an increase in temperature (Long *et al.*, 2004). This behavior can be explained by the photosynthetic metabolism of C3 plants, in which the concentration of CO<sub>2</sub> in the Rubisco enzyme is proportional to the concentration of this gas in the atmosphere (Flexas; Medrano, 2002). Thus, in the future, the main factor that will modulate grain yield is the increase in CO<sub>2</sub> and not temperature.

**Figure 3.** Productivity of soybean crop for different scenarios simulated in DSSAT/CROPGRO-Soybean.



### 3.4 Duration of the simulated growing cycle

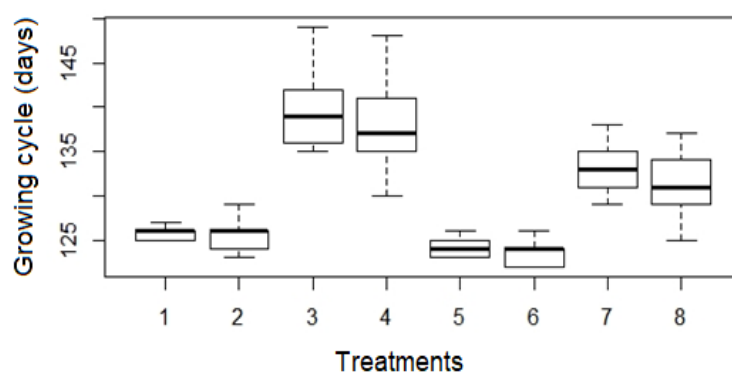
No differences were observed between the rainfed treatments (T1, T3, T5, and T7) and those without water limitation (T2, T4, T6, and T8) (Figure 4). This shows that water deficit did not cause changes in the crop cycle, which is consistent with the results of a previous study conducted by Gava *et al.* (2016).

When comparing the data between the different locations, the cycle was shorter in Rondonópolis (125 days), whereas in Ames, the median was higher (135 days). This could be because the cultivar used in Rondonópolis was GM 8, which was later than the GM 3 cultivar used in Ames. This difference can be attributed to the lower average temperature in Ames (Figure 1B), which results in a slower accumulation of degree-days.

The future cycle in Rondonópolis (T5 and T6) did not show any change compared to the current climate (T1 and T2), whereas in Ames, the duration of the future crop cycle (T7 and T8) was considerably shorter than that in the current scenario (T3 and T4). This could be because late cultivars such as GM 8 used in Rondonópolis have a lower correlation of their development with air temperature, whereas

early cultivars such as GM 3 used in Ames are more influenced by air temperature. Therefore, the response to the increase in temperature simulated in the future climate scenario was more evident in the scenario with the earliest MG. Tao *et al.* (2008) in a study with soybean submitted to climate change scenarios for China, with increased temperature and CO<sub>2</sub>, reported also a decrease in the crop cycle.

**Figure 4.** Duration of the soybean growing cycle for different scenarios simulated in DSSAT/CROPGRO-Soybean.



## 4 CONCLUSIONS

The main effects of climate change on soybean crops, considering the simulated crop scenarios, will be on productivity and the growth cycle. In contrast, LAIX will not change significantly. The simulated treatments under future climate conditions resulted in increased soybean yields, with this increase being more significant for Ames/US under irrigated conditions.

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