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Impact of Climate Change on Maize Grown in the Brazilian Cerrado

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ABSTRACT. ***Crops are subject to instabilities of climatic conditions that affect yield. Maize is very sensitive to factors like temperature, solar radiation and rainfall. The objective of this work was to evaluate, using crop growth models, the effects of climate change on maize grain yield produced under rainfed conditions. Two global circulation models, HadGEM2-ES and MIROC5, coupled to the regional model Eta, were used to generate projections of changes in maximum and minimum air temperature, solar radiation and rainfall for conditions in southeastern Brazil. The CSM-CERES-Maize model was then used to evaluate the effect of climate changes on rainfed maize grain yield. For each combination of global and regional circulation models, two greenhouse gas concentration scenarios were used: RCP4.5 and RCP8.5. The combined use of global circulation and crop growth models allowed us to estimate the expected average grain yield of corn as affected by future climate. The simulated results indicated that, even at best sowing dates, considerable reduction in maize grain yield may occur. Our simulated results also indicated that the largest grain yield reductions may occur for future climate scenarios from 2071 to the end of the 21st century.***

Keywords. Global warming, Corn, Modeling, Yield, Zea mays L.

INTRODUCTION

Maize (*Zea mays* L.) is among the most important grain crops in the world, with a production of approximately 960 million tons per year. Worldwide, the largest maize producers are the United States, China, Brazil and Argentina which together account for 70% of production (FAOSTAT, 2017). Because of its socioeconomic importance, it is highly relevant to advance our understanding on the response of maize to future weather conditions in order to adopt management strategies to mitigate risks of grain yield reduction.

It is well known that anthropogenic activities have significantly increased concentration of greenhouse gas (GHG) in the atmosphere. For example, the Intergovernmental Panel on Climate Change (IPCC, 2014) reports that from 1970 to 2000 the annual average increase in GHG concentrations was around 1.3%. In the following decade, increases in GHG concentrations reached 2.2% per year. As a consequence, the average air temperature could increase to as much as 4ºC, with changes in rainfall amounts and distribution, and on the incident solar radiation. This could bring unprecedented implications to agriculture, which is one of the most climate change-influenced economic activities. However, the effects of these changes are different for each species (Castillo, 2016). In maize, for example, temperature, solar radiation and rainfall, directly affect growth and development, and ultimately grain yield (Maldaner, 2014, Castillo, 2016).

Modeling is a useful approach to study climate change impact in agriculture. For example, recent climate forecast engines provide the opportunity to advance our understanding on the response of maize to future climate conditions (Sales et al., 2015). The Hadley Centre Global Environmental Model, HadGEM2-ES (Collins et al., 2011; Martin et al., 2011) and the Model for Interdisciplinary Research on Climate, MIROC5 (Collins et al., 2011; Martin et al., 2011) are general circulation models (GCMs) that have been used to generate climate projections at a global scale, while Eta (Mesinger et al., 2012) is a regional circulation model (RCM) that has been used to downscale climate projections from GCMs for South America. Crop growth models like those from the Decision Support System for Agrotechnology Transfer, DSSAT (Jones et al., 2003) have been used to assess the response of crops to climate conditions. The combination of GCMs and RCMs with crop growth models has been used to evaluate the effects of climate change on crops growth and yield. For instance, crops and climate models were used to study the response of autumn-sowing wheat to adverse future climate events in Europe (Trnka et al., 2014). Similarly, Chou et al. (2016) used future weather data to evaluate the effects of water stress on maize, soybean, bean, wheat for conditions in Brazil. Van Oort & Zwart (2017) used modeling to investigate the response of rainfed and irrigated upland and lowland rice to climate change in Africa, while Bunn et al. (2015) studied the effect of climate change on coffee across the world.

The objective of this study was to evaluate the effects of climate change on grain yield of rainfed maize using a combination of two GCMs, a RCM and a crop simulation model.

METHODS

General characteristics of the simulated region

This research was developed as a case study for conditions at the county of Sete Lagoas, Brazil (19 ° 30 'S, 44 ° 12' W and altitude 739 m).

The climate of the region, according to Köeppen and Geiger (Alvares et al., 2013), is classified as Cwa. The annual average temperature is 20.9°C, while the maximum reaches 28.2°C and the minimum 15.6°C. The average annual precipitation is 1362 mm, with a well-defined rainy season between December and February, concentrating 55% of the rainfall volume (Ferreira & Souza, 2011). The soil of the experimental area is Cerrado biome Ferralsol, with a very clayey texture (Panoso et al., 2002).

Future climate

The future climatic conditions used in this study were obtained using the GCMs HadGEM2-ES (Collins et al., 2011; Martin et al., 2011) and MIROC5 (Watanabe et al., 2011) coupled to the RCM Eta (Mesinger et al., 2012). Two scenarios of atmospheric GHG concentrations (IPCC, 2014), based on Representative Concentration Pathways (RCPs) 4.5 (RCP4.5) and 8.5 (RCP8.5), were used to model future climate. The concentration of GHGs in the RCP4.5 reach a pick around 2040, but then decline, while emissions in the latter increase throughout the 21st century. Because the global circulation models provide biased representations of the weather time series, corrections were performed according to the procedure described in Teutschbein and Seiber (2012).

Simulation scenarios

Four scenarios of weather conditions were used: a) current weather (41-yr period, 1964-2004), b) future short-term (2008-2040), c) future mid-term (2041-2070), and future long-term (2071-2098). Then, outputs from the GCMs and the RCM were used to run the CSM-CERES-Maize model v4.6.1.0 (Hoogenboom et al., 2015) of the Decision Support System for Agrotechnology Transfer, DSSAT (Jones et al., 2003). The model was set to run weekly sowing dates for rainfed maize; from August 1 to July 24, totaling 52 dates. The maize hybrid DKB390PRO, previously parameterized and evaluated by Andrade et al. (2016), was used. Information from a representative soil profile of the Brazilian Cerrado ecosystem at 0-0.05 m, 0.05-0.20 m, 0.20-0.40 m, 0.40-0.70 and 0.70 to 1.00 m were used as input to the model (Table 1). Management information included row spacing, plant population, and fertilization strategy. Simulated results were used for analysis and evaluation of the effect of climate change on maize growth and grain yield.

Table 1. Soil characteristics used as input in the crop growth model.

Layer	Permanent Wilting Point	Field Capacity	Saturation	pH in water	Bulk Density
(m)	(m^3 m^{-3})				(kg m^{-3})
0-0.05	0.191	0.300	0.611	6.09	910
0.05-0.20	0.249	0.362	0.551	5.95	1050
0.20-0.40	0.234	0.359	0.583	5.93	970
0.40-0.70	0.229	0.354	0.605	5.60	930
0.70-1.0	0.168	0.276	0.604	5.49	910

RESULTS AND DISCUSSION

Considerable differences were observed in temperature and rainfall for the future weather scenarios; the most evident changes are in rainfall amounts. For all GHG concentration scenarios and time periods, maximum and minimum temperature tended to increase while rainfall tended to decrease, compared to current weather (Table 2).

Table 2. Average past and future weather conditions during the growing season (from month to month) for two circulation models and two scenarios of greenhouse gas concentrations.

Model/ Scenario	Period	Rainfall[a]	Rainfall Change[a]	Maximum Temperature[b]	Maximum Temperature Change	Minimum Temperature[c]	Minimum Temperature Change
		(mm)	(%)	(°C)			
HadGEM2-ES RCP4.5	Past (1964-2004)	570	-	28.9	-	17.1	-
	Future short-term (2007-2040)	378	-34	31.9	+3.0	18.6	+1.6
	Future mid-term (2041-2070)	415	-27	32.1	+3.3	19.4	+2.3
	Future long-term (2071-2098)	389	-32	32.8	+3.9	19.8	+2.7
HadGEM2-ES RCP8.5	Past (1964-2004)	570	-	28.9	-	17.1	-
	Future short-term (2007-2040)	319	-44	32.6	+3.7	18.6	+1.5
	Future mid-term (2041-2070)	369	-35	33.7	+4.9	20.4	+3.3
	Future long-term (2071-2098)	275	-52	36.5	+7.7	22.1	+5.0
MIROC5 RCP4.5	Past (1964-2004)	595	-	28.9	-	17.1	-
	Future short-term (2007-2040)	435	-27	30.0	+1.2	18.0	+0.8
	Future mid-term (2041-2070)	454	-24	30.6	+1.7	18.6	+1.5
	Future long-term (2071-2098)	414	-30	31.2	+2.3	19.0	+1.9
MIROC5 RCP8.5	Past (1964-2004)	595	-	28.9	-	17.1	-
	Future short-term (2007-2040)	435	-27	30.3	+3.0	18.2	-
	Future mid-term (2041-2070)	480	-19	31.1	+3.3	19.3	+1.6
	Future long-term (2071-2098)	424	-29	32.8	+3.9	20.5	+2.3

[a] In-season accumulated rainfall
[b] In-season daily average maximum air temperature;
[c] In-season daily average minimum air temperature

Under RCP4.5, the HadGEM2-ES model predicted increases of 3.0; 3.3 and 3.9°C in the average maximum temperature for the periods 2008-2040, 2041-2070 and 2071-2098, respectively, while for the average minimum temperature that increase was 1.6; 2.3 and 2.7°C, for the same periods. The projections also indicated that under RCP8.5, the increase in the average maximum and minimum temperature will be even more severe from 2071 to 2098. According to MIROC5, under RCP4.5, increases in average daily maximum temperature will be 1.2; 1.7 and 2.3°C, while increases in the average daily minimum temperature will be 0.8; 1.5 and 1.9°C for the short-, mid- and long-term scenarios, respectively. Under RCP8.5, average maximum daily temperature will increase 1.4; 2.3 and 3.9°C, while average daily minimum temperature for the same period will increase 1.1; 2.1 and 3.4°C. Our results are in agreement with those of Bender (2017), who found that the increase in both maximum and minimum daily average temperature will reach 2.25ºC for RCP4.5, while for the scenario RCP8.5 the average maximum and minimum daily temperature will rise up to 4.61°C and 4.45°C, respectively.

Future rainfall projections from the HadGEM2-ES model call for decreases of 34, 27 and 32% with RCP4.5, and 44, 35 and 52% with RCP8.5 as compared to the past time period, for short-, mid- and long-term, respectively. Future rainfall projections using the MIROC5 indicated rainfall decrease of 27, 24 and 30% with RCP4.5 and 27, 19 and 29% with RCP8.5 as compared to the past period, for short-, mid- and long-term, respectively (Table 2).

As compared to the past time period, the maize grain yield is expected to reduce in all scenarios (Figure 1). Considering the best sowing date and scenarios derived using HadGEM2-ES, the average crop yield ranged from 4,157 to 4,614 kg ha^{-1} for the RCP4.5, and from 1,954 to 3,954 kg ha^{-1} for the RCP8.5. As for the MIROC5 circulation model, maize grain yield ranged from 6,133 to 6,950 kg ha^{-1}, for the RCP4.5, and from 5,317 to 6,897 kg ha^{-1}, for the RCP8.5 (Table 3). These results are lower than the 8,430 kg ha^{-1} simulated for rainfed maize production in Sete Lagoas, Brazil using current weather and the CSM-CERES-Maize model (Tigges et al., 2016).

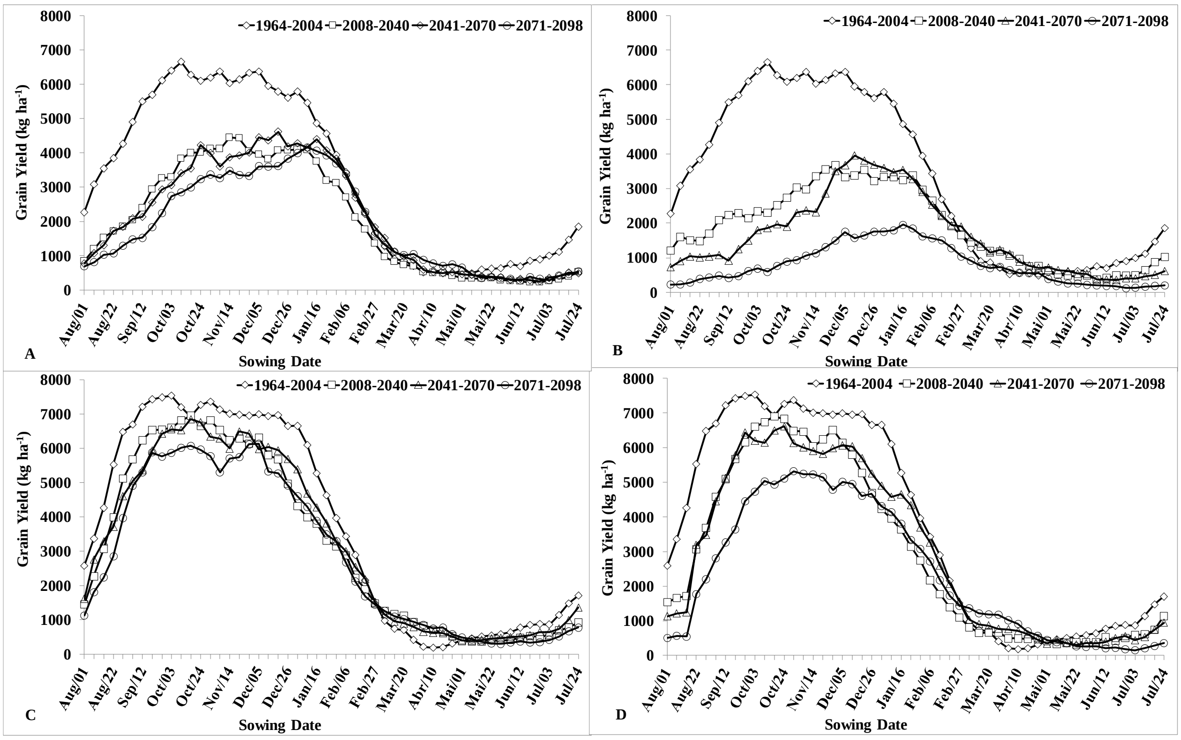

Figure 1. Average simulated maize yield using future weather data from two GCMs and two scenarios of atmospheric greenhouse gas concentrations. (A) HadGEM2-ES RCP4.5; (B) HadGEM2-ES RCP8.5; (C) MIROC5 RCP4.5 and MIROC5

In all future scenarios and time periods, a shorter growing season was observed because of increases in air temperature (Table 3). The growing season was reduced as much as 18 and 24 days when data from the HadGEM2-ES model under the RCP4.5 and the RCP8.5 scenarios were used, respectively. When outputs from the MIROC5 were used, the growing season was reduced as much as 12 and 16 days under the RCP4.5 and RCP8.5 scenarios, respectively. This reduction is associated to thermal units, the main drivers of development of maize, which reduces the maize plant time and ability to accumulate and translocate photoassimilates to the grain, thus reducing grain yield (Cruz et al., 2011). This effect has been described by Wagner et al. (2011), who evaluated the development of maize for conditions in southern Brazil, associating short growing seasons to increases in air temperature. Air temperature increases also contribute to reductions of net photosynthetic rate due to increased respiration that affects the biomass and grain productivity. According to Fancelli (2000), high night air temperature implies an excessive energy consumption due to increases in cell respiration, causing a lower balance of photoassimilates and promoting a significant reduction in crop yield.

Global warming will affect rainfall amounts and distribution and air temperature, which in turn will contribute to reductions on maize grain yield. It is expected that the accumulated average rainfall during the growing season will decrease (Table 2) thus, future maize production in Sete Lagoas, Brazil will be limited water and high air temperature. For instance, Souza et al. (2016) found that reductions in rainfall led to considerable losses in rainfed maize grain yield under the conditions of Sete Lagoas, Brazil. Research results have showed that water availability is the main factor influencing the productivity of rainfed maize in Brazil (Bergamaschi et al., 2004). Our study supports such findings and indicate that rainfall amounts during the growing season (from 275 to 480 mm) will be lower than the average maize water requirements of 600 mm (Magalhães, 2006) (Table 2).

Table 3. Best sowing date, average yield and change in yield in relation to the yield of the past time period for two circulation models and two scenarios of greenhouse gas emission.

Model/Scenario	Period	Best Sowing Date[a]	Duration of Growing Season	Change in the Average Duration of Growing Season	Average Yield[b]	Average Yield Change[c]
		(day/month)	(day)		(kg ha^{-1})	(%)
HadGEM RCP4.5	Past (1964-2004)	10/10	134	-	6650	-
	Future short-term (2007-2040)	14/11	116	18	4443	-33.2
	Future mid-term (2041-2070)	19/12	116	18	4614	-30.6
	Future long-term (2071-2098)	09/01	117	17	4157	-37.5
HadGEM RCP8.5	Past (1964-2004)	10/10	134	-	6650	-
	Future short-term (2007-2040)	23/01	111	23	3676	-44.7
	Future mid-term (2041-2070)	16/01	111	23	3954	-40.5
	Future long-term (2071-2098)	16/01	110	24	1954	-70.6
MIROC 4.5	Past (1964-2004)	03/10	135	-	7533	-
	Future short-term (2007-2040)	24/10	124	11	6950	-7.7
	Future mid-term (2041-2070)	07/11	124	11	6850	-9.1
	Future long-term (2071-2098)	31/10	123	12	6133	-18.6
MIROC 8.5	Past (1964-2004)	03/10	135	-	7533	-
	Future short-term (2007-2040)	17/10	119	16	6897	-8.4
	Future mid-term (2041-2070)	24/10	119	16	6618	-12.1
	Future long-term (2071-2098)	31/10	120	15	5317	-29.4

[a] Sowing date that allowed the highest average yield;
[b] Average yield of the best sowing date;
[c] Change in the average yield in relation to the average yield of the past time period.

The projections of the MIROC5 model indicated less maize grain yield reductions as compared to the HadGEM2-ES model (Table 2, Figure 1). Accordingly, reductions are expected to be 19% for RCP4.5 and of 29% for RCP8.5. The smallest average yield was obtained for the period 2071 to 2098 using the HadGEM2-ES model under the RCP8.5. For the period 2071 to 2098 that presented the highest yield drop, the HadGEM2-ES model predicted a rainfall reduction of 32 and 52%, for the emission scenarios RCP4.5 and RCP8.5, respectively. As for the MIROC5 model, a 30 decrease in rainfall of is expected.

CONCLUSIONS

For all future climate scenarios, reductions in maize grain yield are expected. Simulated maize grain yield using future climate data from MIROC5 GCM showed less maize grain reduction (19% and 29% for RCP4.5 and RCP8.5, respectively) than HadGEM2-ES (37% and 71% for RCP4.5 and RCP8.5, respectively).

Reductions in maize grain yield due to the increase in air temperature and decrease in rainfall may range from 38% to 71%, for optimistic (RCP4.5) and pessimistic (RCP8.5) scenarios, respectively.

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