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Article

Impacts of Future Climate Predictions on Second Season Maize in an Agrosystem on a Biome Transition Region in Mato Grosso State

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Abstract

Climate change promotes variations in climatic elements necessary for crop growth and development, such as temperature and rainfall, potentially impacting yields of staple crops. The objective of this study was to assess future climate projections, derived from Intergovernmental Panel on Climate Change, and their impacts on second season maize in a region of Mato Grosso state. Field experiments in the 15/16 season comprising different sowing dates and hybrids maturities in rainfed conditions were used for crop model adjustment and posterior simulation of experiments. Crop simulations comprised historical (1980-2010) and future (2010-2100) time frames combined with local crop management practices. Results showed decreases of 50-89% in grain yields, with the most pessimistic scenarios at the latest sowing date at the end of the century. Decreases in the duration of crop cycle and in the efficiency of water use were observed, indicating the negative impacts of projected higher temperatures and drier conditions in crop development. Results highlight the unfeasibility of practicing late sowing dates in second season for maize in the future, indicating the necessity of adjusting management practices so that the double-cropping production system is possible.

Keywords: *Zea mays L.*, rainfed maize, climate change, Mato Grosso.

Impactos de Predições Climáticas Futuras sobre o Milho de Segunda Safra em Agrossistema em Região de Transição de Bioma no Estado do Mato Grosso

Resumo

As alterações climáticas promovem variações nos elementos climáticos necessários para o crescimento e desenvolvimento das culturas agrícolas, como temperatura e chuvas, potencialmente impactando os níveis de produtividade. O objetivo deste estudo foi avaliar projeções futuras do clima, oriundas do Painel Intergovernamental sobre Mudança do Clima, e seus impactos sobre o milho de segunda safra em uma região do estado de Mato Grosso. Experimentos de campo na safra 15/16, compreendendo diferentes datas de semeadura e maturidade de híbridos em condições de sequeiro, foram utilizados para ajuste do modelo de desenvolvimento de cultura e posterior simulação dos experimentos. As simulações envolveram período histórico (1980-2010) e futuros (2010-2100) combinados com práticas locais de manejo da cultura. Os resultados mostraram decréscimos de 50-89% na produtividade de grãos, com os cenários mais pessimistas na data de semeadura mais tardia no final do século. Decréscimos na duração do ciclo da cultura e na eficiência do uso da água foram observados, indicando os impactos negativos das altas temperaturas e condições mais secas projetadas para o desenvolvimento da cultura. Os resultados evidenciaram a inviabilidade de se praticar as épocas de semeadura mais tardias na segunda safra para o milho em condições futuras, indicando a necessidade de adequação das práticas de manejo para que o sistema de produção de cultivo de culturas em sucessão seja possível.

Palavras-chave: *Zea mays L.*, milho sequeiro, mudanças climáticas, Mato Grosso.

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1. Introduction

Maize is one of the most economically important crops in Brazil. According to the National Company of storage and supply (CONAB, 2017), the crop is projected to provide more than 87 thousands of tons of production in the 2017/18 agricultural season, of which more than 89% coming from Central-Southern portion of the country (which include Midwestern, Southern and Southeastern regions). Mato Grosso, the third largest Brazilian state (IBGE, 2017) and major national agricultural producer, is located in the Midwestern region. In the last agricultural season, it was responsible for more than 57% of Midwestern total production of maize (~45 thousand tones) and responsible for 30% of the country's total production (of ~87 thousand tones). The state also presented a total maize production 79% higher than the second larger producing state, Paraná state (CONAB, 2017).

Due to the overall Brazil's warm climate, a double-cropping system is usually practiced in great part of its territory, including states that goes from Southern (*e.g.* Paraná) all the way to Midwestern (*e.g.* Mato Grosso) political regions. In this context, in which the most common cultivated crops are soybean and maize in the first and second season, respectively, it is of main importance the occurrence of general warm temperatures during the autum-winter, due to the risk of frost and consequent maize yields failure, a condition not found in the southernmost states (Duarte, 2004). In the double-cropping system, the main crop is cultivated in the start of the rainy or first season (around mid September - October) and the second crop is sown right after the main crop's harvest (denoting the beginning of the decline of the rainfall, around late January-March). Mato Grosso state, as well as the whole Midwestern region, has the great majority of its total maize production concentrated in the second cropping season, while soybean figure as the main crop in the first season (CONAB, 2017). The double-cropping agriculture system is intrinsically related to climatic dynamics. In Mato Grosso state, the consistent annual warm temperatures and the contrasting rainfall regime (with annual amount increasing as latitude increases) is a main driver of its agricultural dynamics (Arvor *et al.*, 2014). Thus, on second season, water stress presents great importance concerning agricultural activity. For maize, this can represent water deficiency during the most critical phases, i.e., flowering and grain filling. In this context, the importance of an earlier sowing date is widely acknowledged and even suggested by government initiatives (BRASIL, 2017) in order to avoid as much water stress as possible.

General warming tendencies and greater rainfall variability are already worldwide stated conditions due to climate change (IPCC, 2014). Although most regions in the world will or are already experiencing climate change effects, these changes are spatially and temporally variable (Penereiro *et al.*, 2018); also, some regions are understood as more sensitive, meaning that they will experience changes in a more accentuated manner. Specifically in Brazil, an assessment performed by Torres and Marengo (2014) could identify 'hotspots' where climate change can be more accentuated in a warmer climate. Mato Grosso state, along with Midwestern region and Amazon are some of Brazil's hotspots, indicating, especially, higher surface air temperatures in winter, higher temperature variability in summer and more variable averages and interannual rainfall in winter (Torres and Marengo, 2014). In agriculture, specifically for maize, the increase in temperatures more frequently will surpass the crop optimal temperature, resulting in shorter vegetative and reproductive phases (Lizaso *et al.*, 2018), situation that will be more easily found in warm-climate regions. Interference in processes related to water availability, such as crop evapotranspiration, can impose critical changes in its physiology due to climate conditions, ultimately impacting grain yields. Studies have been showing that for maize, regions with cooler climate may present yield benefits due to warmer temperatures, while the opposite is the predominant effect in regions with warmer climate (Southworth *et al.*, 2000). Assessments of climate impacts on agriculture must rely on simulation studies to be able to make long-term projections. The use of properly parameterized crop models in agricultural crop studies is an indispensable step for understanding future yield constraints related to environment (Boote *et al.*, 2010; Lobell and Asseng, 2017), which can help the formulation of policies to mitigate climate change impacts. Crop models, such as those contained in the Decision Support for Agrotechnology Transfer (DSSAT) (Jones *et al.*, 2003) have been used for few decades to provide information on the interaction of genotype-environment-management, and more recently in the context of climate change impacts on agricultural crops (Rosenzweig *et al.*, 2013).

There is a national scarcity of studies on climate change impacts in staple crops, although the probable negative effects on the main crops of the double-cropping system has already been pointed out by few studies (Minuzzi and Lopes, 2015; Pires *et al.*, 2016). Mato Grosso state, due to its location and large extension, houses different biomes and climate patterns, highlighting the importance of assessment of environment-crop management interactions and its impacts in agricultural activity in the climate change context. Tangará da Serra, a municipality located in the South-Central portion of the state is unique according to this point of view: its territory comprises the transition between Cerrado and Amazônia biomes, which influence on local climate conditions, also impacting on crop yields. The main objective of this study was to assess impacts on second season maize development under future climate scenarios in a Brazilian region of Mato Grosso state. This objective was accomplished through the following specific objectives: (i) assessment of local future climate change under different projections of scenarios and future periods; (ii) assessment of the impact of different sowing dates and hybrid maturity on crop development under future climate scenarios.

2. Materials and Methods

2.1. Study area characterization

This study comprised simulations based on field experiments conducted at the experimental area of CETEGO-SR ("Centro Tecnológico de Geoprocessamento e Sensoriamento Remoto aplicado à produção de Biodiesel") located at the State University of Mato Grosso, university campus of Tangará da Serra, in the 2015/2016 cropping season (Barbieri, 2017). The referred municipality (14°37'10" S; 57°29'09" W), located in the South-Central portion of Mato Grosso state, has climate classified as Tropical wet (Aw) (Köppen classification) with annual average temperature of 24.4 °C and total rainfall of 1830 mm, concentrated between October and March (Dallacort *et al.*, 2011). Soil characteristics of the experimental area were obtained for 0-20 cm through soil analysis prior to experiments (Barbieri, 2017). At this local level, the soil is classified as Latossolo Vermelho (EMBRAPA, 2006) or Rhodic ferralsol (FAO classification) (IUSS WORKING GROUP WRB, 2014), with a very clayey texture. The observed soil information was combined with data from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012), wich information are available at ~ 1 km grid cell resolution, to complete information up to 100 cm of soil depth (Table 1). Soil water parameters, i.e., wilting point, field capacity and saturation, were calculated apart from the crop model through pedotransfer functions adapted for Brazilian soil (Tomasella *et al.*, 2000) and also used as input data in the crop model. Maize sowing was performed in different dates, characterizing the second cropping season, an early: 27/01/2016 (S1) and an intermediate-late date: 25/02/2016 (S2). Three hybrids of different maturity were used in each sowing date, an early: AG 7088 (H1), an intermediate: AS 1555 (H2) and a late: DKB 390 (H3) maturity material. Experiments were conducted imposing non-irrigated conditions for the crop. Installation of experiment and crop management was made to provide proper soil correction and fertilization and full control of pests, diseases and weeds.

2.2. Climate data: baseline and projections

Observed daily meteorological information, locally available at the University in the experimental area from an automatic station, comprised seven years of data. The data set consisted of average maximum and minimum temperatures (°C), average solar radiation (MJ m^{-1} day^{-1}), average wind speed (m s^{-1}), average air relative humidity (%) and rainfall (mm). The remaining years to complete the baseline scenario (a thirty years series) was obtained from a high-resolution grid database developed for Brazil (Xavier *et al.*, 2016), with resolution grids of 0.25° x 0.25°, for the same climatic variables. The potential evapotranspiration (ETp) was estimated by FAO 33 method through the crop model. Baseline climate was used to develop future climatic series projections. Future projections were made with the aid of the International Panel on Climate Change (IPCC)'s fifth report (IPCC, 2014). Its fifth report gathers the assessment of several Global Climatic Models (GCMs), currently originated from the Coupled Model Intercomparison Project Phase 5-CMIP5 (Taylor *et al.*, 2012). In this IPCC's report, scenarios of radiative forcing, denominated Representative Concentration Pathways (RCPs) are presented, referring to the trajectories of society and by consequence to the possible scenarios relating to greenhouse gases forcing over time. In the present study two RCPs were used: (i) RCP4.5, considered an intermediate scenario where total emissions are stabilized before the year of 2100 (Smith and Wigley, 2006; Clarke *et al.*, 2007; Wise *et al.*, 2009) and (ii) RCP 8.5, considered a high-emission scenario, characterized by the continuous increase of GHGs emissions over time leading to the highest GHGs concentration levels (Riahi *et al.*, 2007). The development of future daily meteorological data was performed through algorithms routines developed by the Agricultural Model Intercomparison and

Table 1 - Soil parameters used in the simulations for the study region in Tangará da Serra, Mato Grosso state and respective sources. Soil parameter values are indicated by "t" for topsoil (0-30 cm) and by "s" for subsoil (30-100). SLL: wilting point, SDUL: field capacity and SAT: saturation point. Parameters used for estimating soil-water parameters are indicated by (*), added to clay, sand and silt fractions (%), also obtained through observed and HWSD data.

Soil parameter	Value	Source
Texture	Fine	Observed and HWSD
Dominant group (FAO)	Rhodic ferralsols	Observed and HWSD
Texture (t)	Clayey	Observed and HWSD
Texture (s)	Clayey	Observed and HWSD
pH (t)	5.9	Observed
pH (s)	5.7	HWSD
Organic carbon (%) (t)	1.75	Observed
Organic carbon (%) (s)	0.8	HWSD
Bulk density (kg d^{-3}) (t)	1.14	HWSD
Bulk density (kg d^{-3}) (s)	1.16	HWSD
SLL (cm3 cm^{-3}) (t)	0.296	
SLL (cm3 cm^{-3}) (s)	0.266	
SDUL (cm3 cm^{-3}) (t)	0.358	Tomasella (2000)
SDUL (cm3 cm^{-3}) (s)	0.323	
SAT (cm3 cm^{-3}) (t)	0.585	
SAT (cm3 cm^{-3}) (s)	0.529	

Improvement Project (AgMIP) international collaborative group (Rosenzweig *et al.*, 2013), referent to CMIP5. In an attempt to minimize uncertainty, inherent to simulations and to the climatic system, we chose to use an ensemble of GCMs. The choice of models was based on Pinheiro *et al.* (2014) and Silveira *et al.* (2013), which evaluated the performance of GCMs in Brazilian regions. GCMs and their identification can be observed in Table 2. Maximum and minimum temperatures and rainfall were the variables changed through mean and variability changes by the routines using the GCMs, outputting climatic files to be used as input in the crop model simulations. Average values of atmospheric CO_2 concentration was adopted for each set of assessed periods (Table 3), and were also used for characterize future climate projections. The specific sets of years of future climate were: (i) short-term future: 2010-2039; (ii) mid-term future: 2040-2069 and (iii) end of century: 2070-2100; and each time frame assessed for each RCP (4.5 and 8.5).

2.3. Crop model and simulations

Maize growth and development was simulated by means of the CSM CERES MAIZE, part of the Decision Support System for Agrotechnology Transfer (DSSAT v. 4.7.0.0) software (Jones *et al.*, 2003; Hoogenboom *et al.*, 2017). The model was previously adjusted to local environmental conditions related to phenological events and yield components, resulting in good agreement between simulated and observed (maximum absolute deviation of four days for phenological events and 7% for non-irrigated grain yields) (see Barbieri, 2017 for further information). Considering the optimum crop management at experimental level (no reduction factors from nutrient, pests and diseases), the crop model was used for estimating potential yield in water-limited conditions, (i.e., water-limited yields) (Lobell *et al.*, 2009), capturing exclusively the influence of climate conditions and their interactions with crop development. For both baseline (1980-2010) and future climate (2010-2100) scenarios, the model was run comprising the combination of two sowing dates and three hybrid maturity.

Table 2 - Identification of Global Circulation Models (GCMs) used in the present study for simulating future climate projections in Tangará da Serra, Mato Grosso state..

Model	Origin	Country	Resolution
GISS-E2-R	NASA Goddard Institute for Space Studies	United States	2.0° x 2.5°
CSIRO-MK3-6-0	Commonwealth Scientific and Industrial Research Organisation - Mark 3.6.0	Australia	1.8° x 1.8°
HadGEM2-ES	Hadley Centre Global Environmental Model	United Kingdom	1.8° x 1.2°
inmcm4	Institute for Numerical Mathematics - Coupled Model Version 4	Russia	2.0° x 1.5°
MIROC-ESM	Model for interdisciplinary Research on Climate - Earth System Model	Japan	2.8° x 2.8°
MPI-ESM-LR	Max Planck Institute - Earth System Model - Lower Resolution	Germany	1.8° x 1.8°
CNRM-CM5	Centre Europeen de Recherche Meteorologique - Coupled Model 5	France	1.5° x 1.5°

Assessment of local future climate projections of rainfall and temperatures was performed. The impacts from the variation of these climatic variables through analysis of crop yields, number of days per crop cycle (NDC) (Pires *et al.*, 2016) and water-use efficiency (WUE, an index between yield and water consumptive use) (Souza *et al.*, 2016) was performed for the present study's crop management conditions and assessed time periods.

Data manipulation and visualization were performed by using the R software - version 3.5.2 (R Core Team, 2018) e and by using the tidyverse package (v1.2.1; Wickham, 2017).

3. Results and Discussion

3.1. Baseline climate of Tangará da Serra

In the baseline scenario, the amount of monthly rainfall varied from 10 mm (in July, the driest month) to 210-290 mm (November - March, the rainy season in which the main crop is cultivated) characterizing the Aw climate (Fig. 1). Rainfall variability reached their highest and lowest values during the wet and dry season, respectively, with monthly standard deviation (sd) values of 64-90 mm between November - March, and of 13-25 mm between June - August. Average values of monthly maximum temperatures ranged from 31-34 °C, with sd between 1.9-3.6 °C, while for minimum temperatures the range was between 16-22 °C, with sd between 0.8-2.7 °C during the year.

Main agricultural municipalities in Mato Grosso state are located in the Aw climatic zone, wherein the double cropping system is commonly practiced. On these areas, crops like maize, for an average cycle of 130 days, will be able to profit from rainfall if sown as early as possible in January, which can help mitigate water stress during its critical phases (flowering to beginning of grain filling). Authors have pointed that the accentuated sensibility to water stress in the reproductive stage, added to rainfall variability have contributed to the strong susceptibility of maize to this non biotic factor (Bergamaschi and Matzenauer, 2014), which can be observed in several Brazilian regions. Southeastern (Soler *et al.*, 2007) and warmer portion of Southern regions (Andrea *et al.*, 2018), for example, cultivate maize as a second season crop, with

Table 3 - Average atmospheric CO_2 concentration for the assessed sets of years of baseline, RCP 4.5 and RCP 8.5 scenarios used for future climate projections in Tangará da Serra, Mato Grosso state.

Scenario	Period	Av. $[CO_2]$ (ppm)	Source
Baseline	1980-2010	362	Keeling, C.D. *et al.*, (2005)
RCP 4.5	2010-2039	422	Clarke L. *et al.*, (2007); Smith & Wigley, (2006); Wise *et al.*, (2009) through RCP databse (see http://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=welcome)
	2040-2069	495	
	2070-2100	532	
RCP 8.5	2010-2039	432	Riahi, K. *et al.*, (2007) through RCP database (see http://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=welcome)
	2040-2069	572	
	2070-2100	803	

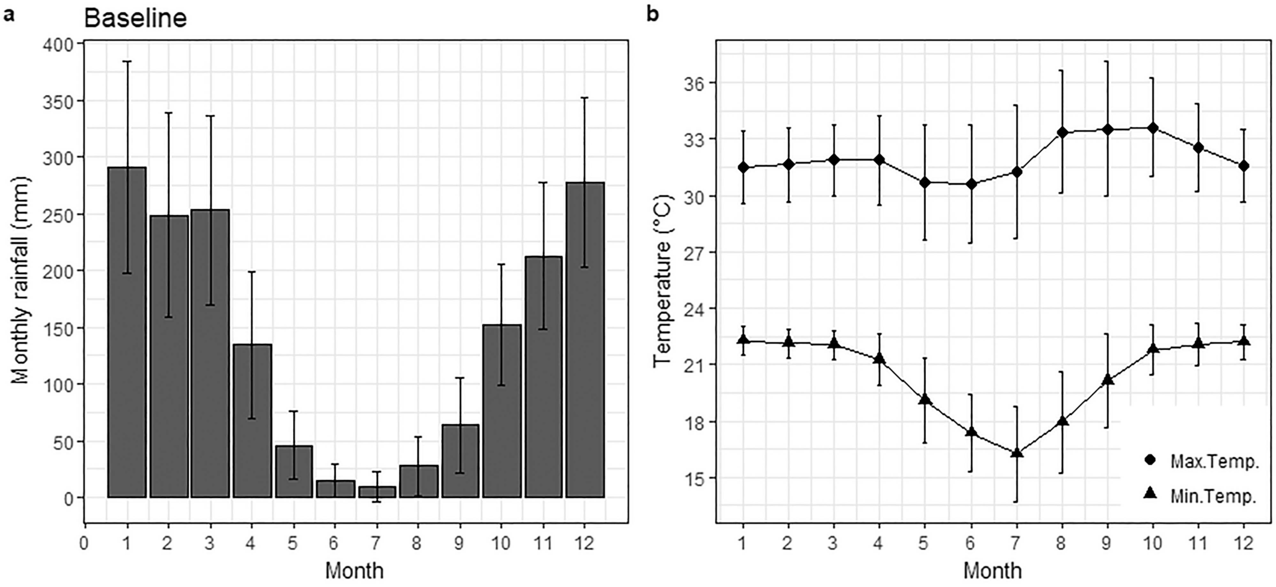

Figure 1 - Monthly averages of rainfall (a) and maximum and minimum temperatures (b) of baseline climate scenario (1980-2010) in Tangará da Serra, Brazil. Bars indicate standard deviation.

rainfall pattern (concerning most months of the year) similar to the assessed region. Thus, sowing dates performed from late February until beginning of March have greater possibilities to suffer from water deficit, penalizing crop yields. This condition, due to rainfall patterns, is a reality in many Brazilian regions, whether in subtropical climate, under historical and current climate conditions (Soler *et al.*, 2007); or in warmer climate types of other regions including Midwestern, under historical or current climate conditions (Heinemann *et al.*, 2009; Penereiro *et al.*, 2018) as also under future climate projections (Torres and Marengo, 2014; Pires *et al.*, 2016). Possible delays in sowing second season maize, as pointed by periodic reports of state agriculture (IMEA, 2017), can be originated from current or previous crop (summer crop) cultivation and its calendar of operations. In this context, unfavorable environment conditions, such as insufficient or excess of soil moisture can delay and even make it impossible to carry out operations.

3.2. Climate projections for Tangará da Serra

Projections of future climate can be observed in Figs. 2 and 3 through the absolute differences of temperatures and rainfall from baseline scenario. The projections presented in this study are consistent with an overall tendency of increases in maximum and minimum temperatures and altered rainfall patterns and amounts (IPCC, 2014). In terms of monthly rainfall, RCP 8.5 emission scenario presented greater absolute variability: during January - June, average monthly deviation from baseline varied between -20 to 4% (near future); -13 to 13% (mid future) and -13 to 4% (end of century). During July -

December, these values ranged between -17 to 0%; -25 to 11% and -44 to 0%, respectively. In RCP 4.5, monthly rainfall (January - June) deviated from baseline as follows: -13 to 7% (near future), -13 to 4% (mid future) and -13 to 2% (end of century); during July - December these same values ranged between -11 to 36%, -22 to 7% and -34 to 3%, respectively. Rainfall decreases were most accentuated during September - October in all future scenarios (Figs. 2 and 3). Rainfall future projections are always more subject to uncertainties than temperature, probably due to the more variable nature of this climatic variable. Kent *et al.* (2015) present in detail several facts concerning the uncertainties on projecting seasonal precipitation in the tropics, and point to the strong contribution of dynamic processes as result of spatial shifts in convective mass flux, and that is where efforts to understand uncertainties should be directed. Knutti and Sedlácek (2013) assessed the evolution from CMIP3 to CMIP5 climate models in climate change context, and found an overall consistency and robustness across generations of models, although the complexity of more moderns models tend to increase. As these authors point, climate models are continuing evolving, and these uncertainties should not prevent their use as an aid in decision-making.

Maximum and minimum temperatures deviations from baseline were represented only by increases in all scenarios. RCP 8.5 presented the most accentuated increases in all time periods, for both maximum and minimum temperatures; variability of average maximum temperature from baseline during January - June ranged between 1-5% (near future), 6-10% (mid future) and 12-16% (end of century). During July - December these values varied between 2-6%; 7-12% and 13-20%, respectively. Average minimum temperature deviations in this RCP during January - June varied between 5-9% (near future), 10-18% (mid future) and 19-33% (end of century), while for July - December these values varied between 5-8%, 13-19% and 22-34%, respectively. For RCP 4.5, average maximum temperature deviation from baseline varied between 1-4% (near future), 4-7% (mid future) and 6-9% (end of century) for January - June, and between 1-7%, 4-11% and 6-12%, respectively, for July - December. Average minimum temperature deviations in this RCP during January - June varied between 4-8% (near future), 8-14% (mid future) and 10-18% (end of century), while for July - December these values varied between 5-9%, 9-15% and 12-18%, respectively.

The assessed future projections of climate could negatively impact the state and national grain production. National maize production (of which the state is responsible for ~40% of second season maize production, according to CONAB (2017), could be undermined if no efforts to alleviate water and temperature constraints are performed. This general reduction tendency can be found in studies that assessed the impacts of climate change, in Brazil, particularly for maize as also other grain crops, even in Southern regions of Brazil, with climate cooler than Midwestern (Streck and Alberto, 2006; Streck *et al.*, 2010). While temperature constraints will be more difficult to solve due to impossibility of manipulating environment for this particular climate variable at large and commercial scale, water constraints could be more easily

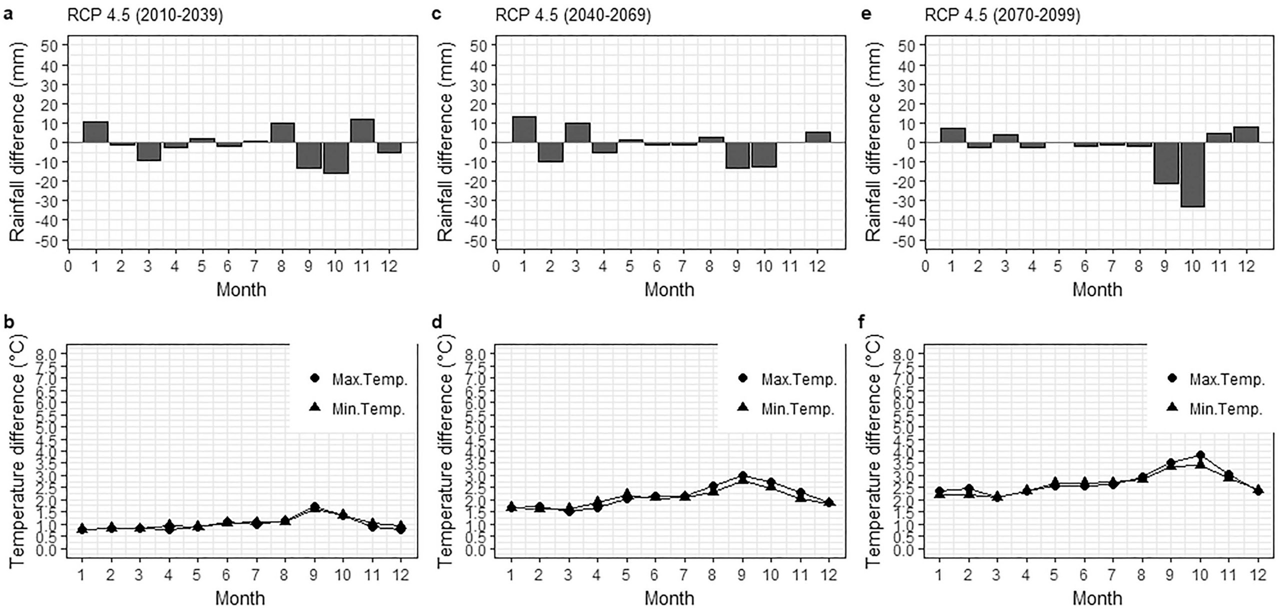

Figure 2 - Monthly rainfall (a,c,e) and maximum and minimum temperatures (b,d,f) absolute differences from baseline climate scenario generated for RCP 4.5 at short-term future (a,b), medium-term future (c,d) and end of the century (e,f) in Tangará da Serra, Mato Grosso state.

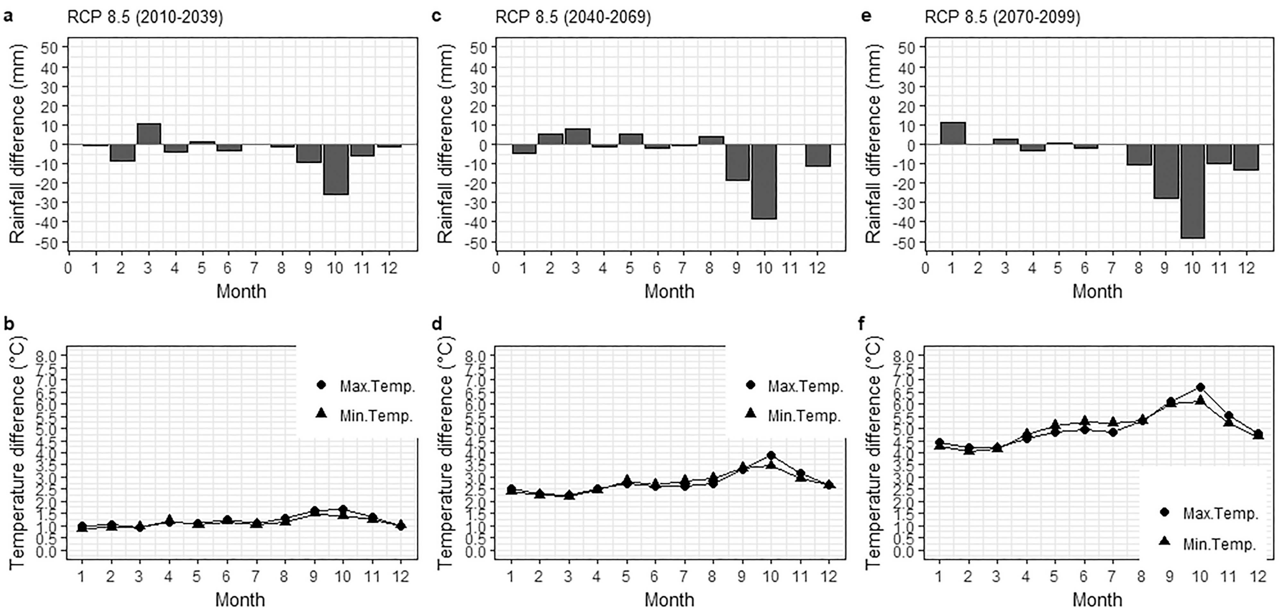

Figure 3 - Monthly rainfall (a,c,e) and maximum and minimum temperatures (b,d,f) absolute differences from baseline climate scenario generated for RCP 8.5 at short-term future (a,b), medium-term future (c,d) and end of the century (e,f) in Tangará da Serra, Mato Grosso state.

addressed when considering the possibility of changing sowing dates or utilizing irrigation.

3.3. Impacts on second season maize in Tangará da Serra

The evolution of simulated maize yields across baseline and future emission scenarios, summarized as average yields of three hybrid maturities within each of two sowing dates can be observed in Fig. 4. Temperature and rainfall projections were responsible for an overall decrease trend of second season maize yields for all assessed scenarios when compared to baseline, varying in magnitude for the RCPs and sowing dates. These results are consistent with studies assessing impact of climate change in maize yields in warm climate environments that typically have double cropping agriculture systems (Minuzzi and Lopes, 2015; Pires *et al.*, 2016). While it was possible to observe an overall clear separation between projection of yields at the earliest and latest assessed sowing dates, results also indicated an increasing differentiation between RCP 4.5 and

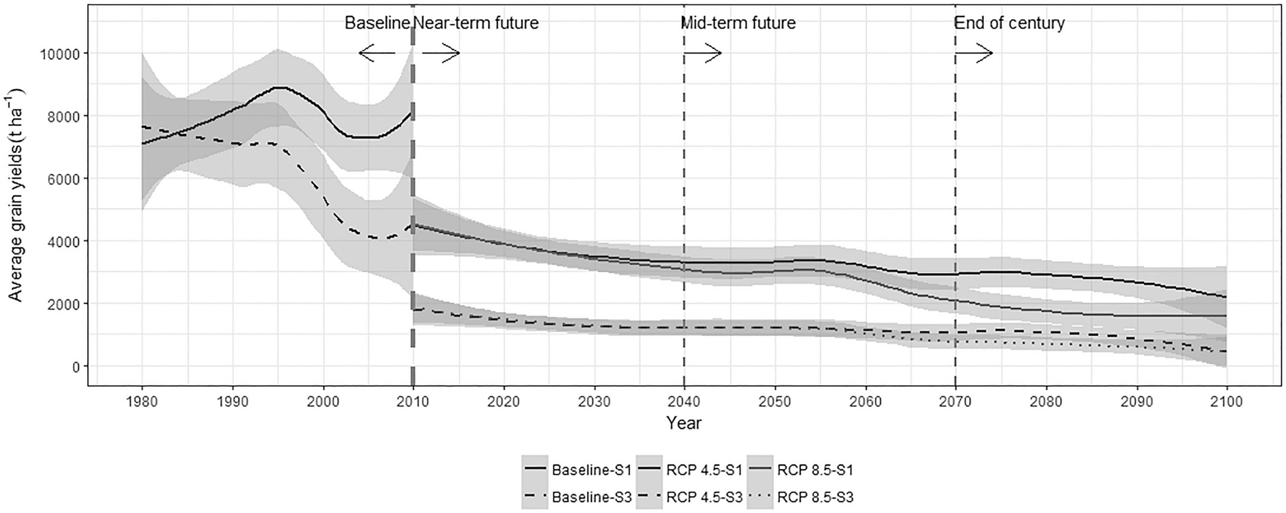

Figure 4 - Variability of maize grain yields in two different sowing dates (early and late) in the baseline (1980-2010) and in sets of future climate scenarios of emissions (RCP 4.5 and RCP 8.5): near-term future (2010-2039); mid-term future (2040-2069) and end of century (2070-2100) of second season rainfed maize in Tangará da Serra, Mato Grosso state. Lines show a local regression for an average value of the three hybrid maturity for each sowing date.

RCP 8.5 as future scenarios advanced in time. In the early sowing date (baseline average of 7.8 t ha^{-1}), decreases were found reaching an average of ~3.5 t ha^{-1} (-55%, for both RCPs) in near future; of 3.2 t ha^{-1} (-59%, RCP 4.5) and 2.9 t ha^{-1} (-63%, RCP 8.5) in mid future and of 2.9 t ha^{-1} (-63%, RCP 4.5) and 1.7 t ha^{-1} t ha^{-1} (-78%, RCP 8.5) in the end of century. At the late sowing date (baseline average of 6.1 t ha^{-1}) average yields presented a even more accentuated and continuous decrease, to averages of ~1.2 t ha^{-1} (-80%, for both RCPs) in the near future; of 1.1 t ha^{-1} (-82%, for both RCPs) in mid future and of 1.1 t ha^{-1} (-82%, RCP 4.5) and 0.7 t ha^{-1} t ha^{-1} (-88%, RCP 8.5) in the end of the century.

Simulated yields for future climate projections were also assessed detailed for each hybrid maturity and specific sowing date (Fig. 5). For comparison purposes, average yields from baseline are also presented for each sowing date. In the baseline scenario, average yields (and standard deviation) ranged between 6.7-9.3 (1.5-2.2) t ha^{-1} and between 5.3-6.9 (2.0-2.7) t ha^{-1} for the early and late sowing dates, respectively, between hybrids. In the RCP 4.5 scenario, in the near-term future, average yields (sd) ranged between 3.1-4.0 (1.3-1.8) t ha^{-1} and between 1.1-1.3 (0.7-0.9) t ha^{-1} for the early and late sowing dates, respectively, between hybrids. In the mid-term future, same values ranged between 2.8-3.5 (1.2-1.6) t ha^{-1} and between 1.0-1.2 (0.6-0.8) t ha^{-1}. At the end of the century the values ranged between 2.6-3.2 (1.1-1.4) t ha^{-1} and between 1.0-1.2 (0.6-0.7) t ha^{-1} for the early and late sowing dates, respectively, between hybrids. In the RCP 8.5 scenario, in the near-term future, average yields (sd) ranged between 3.1-4.0 (1.2-1.7) t ha^{-1} and between 1.1-1.3 (0.7-0.9) t ha^{-1} for the early and late sowing dates, respectively, between hybrids. In the mid-term future, same values ranged between 2.5-3.2 (1.0-1.4) t ha^{-1} and between 1.0-1.2 (0.6-0.8) t ha^{-1}. At the end of the century the values ranged between 1.5-1.9 (0.7-0.9) t ha^{-1} and between 0.6-0.7 (0.4-0.5) t ha^{-1} for the early and late sowing dates, respectively, between hybrids. As time progress, absolute average of yields and their variability decreases. With most accentuated decreases in RCP 8.5 and at the late sowing date in which yields could reach < 0.1 t ha^{-1}. Although these values may seem extreme, they reflect estimates in a context where no management actions are taken to alleviate the issues, i.e., continue with the same crop management practices. The late maturity hybrid also presented slightly superior average values in all future climate projections. This may be due to the greater number of days the crop stays on field and may profit of some additional water and radiation input (Bassu *et al.*, 2014). When compared with its baseline reference (hybrid and sowing date), decreases in grain yields in RCP 4.5 reached a maximum of 57 and 83% in the near-term future; 62 and 83% in the mid-future; 65 and 84% in the end of century for early and late sowing dates, respectively. For RCP 8.5 those values were of 58 and 82%; 66 and 84%; 79 and 89%, respectively.

Simulated yields for baseline climate scenario corroborate the widespread knowledge that the later second season maize is sown, the lower are their yields due to water stress (BRASIL, 2014), also pointed by several studies (Heinemann *et al.*, 2009). Although irrigation represent a logical technical solution, this management practice is hardly considered in studies concerning the water issues in second season maize through the state of Mato Grosso and mainly all Midwestern (Heinemann *et al.*, 2009;

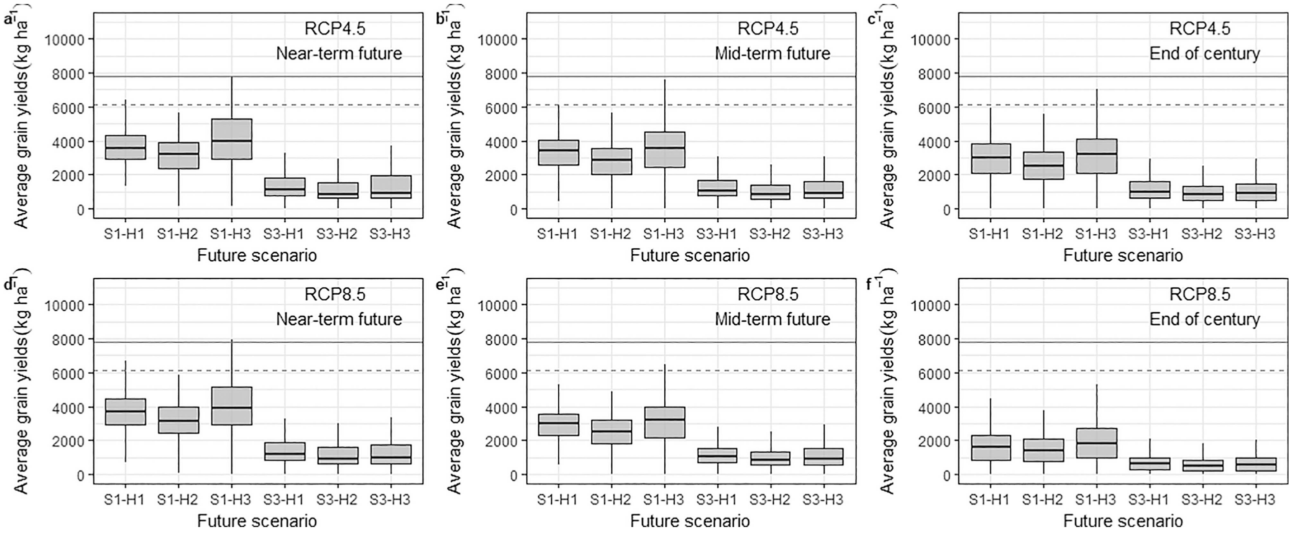

Figure 5 - Variability between the combination of three maize hybrids (H1: early, H2: normal and H3: late maturity) grain yield in two sowing dates (S1, S2) in future climate scenarios for second season rainfed maize in Tangará da Serra, Mato Grosso state. (a), (b) and (c) indicate, respectively, near-term, mid-term and end of century for the RCP 4.5 emission scenario. (d), (e) and (f) indicate, respectively, near-term, mid-term and end of century for the RCP 8.5 emission scenario. Solid and dashed lines indicate the average yields of three hybrids within S1 and S2 sowing dates of baseline scenario, respectively.

Minuzzi and Lopes, 2015; Pires *et al.*, 2016). The state presents less than 5% of national irrigated area (IBGE, 2018); this is a region characterized by large extension properties, which has, in general, soybean as main crop on the rainy season. In major part of national territory this is the predominant condition wherein the rainfall period concentrates in one part of the year (4-5 months) and double cropping is practiced. In the projected future climate scenarios the importance of earlier sowing date of second season maize became accentuated; a late sowing date could even be disregarded from being practiced. Results from Pires *et al.* (2016) also show the increases of risk in double cropping systems (soybean-maize succession) due to future water deficit in major soybean producing regions in Brazil, including MT state. Despite the focus of Pires *et al.* (2016) has been on the first season crop, soybean, their results showed that while soybean yields may even increase with delay in sowing, maize as second crop will be negatively affected. Present results agrees and complement information from Pires *et al.* (2016), the presented rainfall decreases in September-October may affect soybean sowing by the deficiency of soil moisture, pushing it forwards in the agricultural calendar, which ultimately will affect maize cropping systems by delay in its sowing. Such water constraints could be alleviated by the use of irrigation practices, for example, however this is not a common practice in maize in Brazil, especially in the Midwestern region, wherein the crop is usually associated with extensive properties. By separately considering the possibility of solving water supply in the second season, regions with Am climate type could represent better conditions for crops such as maize in second cropping season, since its bulk rainfall is concentrated at the first half of the year, when the crop is under growth and development.

In terms of temperatures, the projected scenarios also impose difficulties for cultivating maize. The warmer condition of days and especially nights (i.e., increase in minimum temperatures), which is already a factor by which maize has lower biophysical limits of maize yield in second (when compared to first) season in Brazil (Farinelli *et al.*, 2003), will become even more accentuated in the future. Generally, the increase of temperatures and number of days with higher-than-average daily and night temperatures, act specifically on maize physiology by accelerating the end of its cycle and completing phenological phases by earlier than usual achievement of thermal sum (Lizaso *et al.*, 2018). Bassu *et al.* (2014), in an overview over multi-model responses to maize yields under CO_2 and temperature changes in different regions worldwide (one of them in Midwestern Brazil), indicated temperature increases as the main factor altering maize yields in future climate, situation more aggravated in tropical regions.

In terms of CO_2, experimental studies have shown that its higher concentration in the atmosphere may enhance overall plant growth and water use efficiency; although this effect is expected to be more intense on C_3 plants and the possibility of this positive contribution from CO $_2$is also expected to be attenuated by higher temperatures. McGrath and Lobell (2011) point to the tendency of more intense CO_2 fertilization effect for both C3 and C4 plants, in different intensities, when grown in drought compared with non-water limited conditions. In detail, increases in CO_2 concentrations reduces stomatal activity in both C_3 and C_4 plants (20-40%) and can lead to a greater soil water conservation when crops are under soil water deficit (Hatfield *et al.*, 2011), an apparent advantage. However, reduction in crop evapotranspiration caused by changes in CO_2 concentrations will be mediated by temperature; there is evidence that although WUE can increase in such conditions, its values decline when temperature increases (Hatfield *et al.*, 2011). Thus, as pointed by the latter authors, it is acknowledged that full combined effects of increasing CO_2 concentrations and temperature in water-limited conditions is still subject to understanding on how crops do respond to interactions between these climatic elements and should continue to be evaluated in future experimental and modeling studies. In maize, the isolated effect of doubled CO_2 is relatively low (general ~4% change of grain yield) when compared to other staple crops due to its metabolic pathway (C4), as presented by Hatfield *et al.* (2011).

Summarization of average absolute values and relative differences (%) concerning the average of number of days per crop cycle (NDC) and water use efficiency (WUE) between baseline and future climate scenarios for both assessed RCPs can be observed in Table 4. From the mid-century on, for both RCPs, decreases on the NDC and WUE were more accentuated at the late sowing date, highlighting the negative impacts, related to water and temperature, due to the delaying maize growth and development during the agricultural drier season of the year.

In the baseline scenario, NDC ranged between 123-130 and between 128-135 days for the early and late sowing dates, respectively, between hybrids (shortest and longest lengths for the early and late maturity hybrid, respectively). Relative differences of RCPs presented increasing deviations from baseline, reaching highest variability at the end of the century in RCP 8.5, thus the shortest cycles (~100 days for the early maturity hybrid). Evapotranspiration in RCPs were higher than on baseline due mainly to warmer conditions, however, during the thirty-year periods through the century, evapotranspiration remained practically stable. Due to the continuous decrease of yields, WUE also presented decrease of values, reaching its lowest values in the end of the century, and more accentuated for RCP 8.5. WUE, determined for the entire crop season, indicated the amount of commercial output obtained by the consumptive use of water, in this case grains and evapotranspiration, respectively, as kg grain ha^{-1} mm^{-1}. In the baseline scenario, WUE values

Table 4 - Absolute values (and variation, %) in grain yield (t ha^{-1}), number of days per crop cycle (NDC, in days) and water use efficiency (WUE, in kg ha^{-1} per mm of actual evapotranspiration) between baseline (1980-2010) and future (2010-2100) climate scenarios, RCP 4.5 and RCP 8.5, considering two sowing dates and three hybrid maturity of second season rainfed maize in Tangará da Serra, Mato Grosso state.

	Management scenario		Emission scenario	Variable (difference from baseline %)						
	Sowing date	Hybrid maturity		Yield	NDC	WUE		Yield	NDC	WUE
Near-term (2010-2039)	S1	H1	RCP 4.5	3.6 (-0.51)	118 (-0.04)	5.3 (-0.73)	RCP 8.5	3.7 (-0.50)	117 (-0.05)	5.4 (-0.72)
		H2		3.1 (-0.54)	121 (-0.05)	4.6 (-0.74)		3.1 (-0.54)	120 (-0.06)	4.5 (-0.74)
		H3		4.0 (-0.57)	125 (-0.05)	5.8 (-0.76)		4.0 (-0.58)	123 (-0.05)	5.7 (-0.76)
	S2	H1		1.3 (-0.78)	117 (-0.09)	2.7 (-0.86)		1.3 (-0.78)	117 (-0.09)	2.7 (-0.86)
		H2		1.1 (-0.79)	121 (-0.08)	2.2 (-0.87)		1.1 (-0.79)	121 (-0.08)	2.3 (-0.86)
		H3		1.2 (-0.83)	123 (-0.09)	2.4 (-0.89)		1.2 (-0.82)	123 (-0.09)	2.5 (-0.88)
Mid-term (2040-2069)	S1	H1		3.3 (-0.55)	113 (-0.08)	4.9 (-0.75)		2.9 (-0.60)	110 (-0.11)	4.3 (-0.78)
		H2		2.8 (-0.58)	116 (-0.09)	4.1 (-0.77)		2.5 (-0.63)	113 (-0.11)	3.7 (-0.79)
		H3		3.5 (-0.62)	119 (-0.08)	5.2 (-0.78)		3.2 (-0.66)	116 (-0.11)	4.7 (-0.81)
	S2	H1		1.2 (-0.79)	112 (-0.13)	2.5 (-0.87)		1.2 (-0.80)	110 (-0.14)	2.4 (-0.87)
		H2		1.0 (-0.81)	116 (-0.12)	2.1 (-0.88)		1.0 (-0.81)	113 (-0.14)	2.0 (-0.88)
		H3		1.1 (-0.83)	119 (-0.12)	2.3 (-0.89)		1.1 (-0.84)	116 (-0.14)	2.2 (-0.90)
End of century (2070-2100)	S1	H1		3.0 (-0.59)	111 (-0.10)	4.4 (-0.77)		1.6 (-0.78)	101 (-0.18)	2.5 (-0.87)
		H2		2.6 (-0.62)	113 (-0.11)	3.8 (-0.78)		1.5 (-0.78)	104 (-0.18)	2.2 (-0.87)
		H3		3.2 (-0.65)	116 (-0.11)	4.8 (-0.80)		1.9 (-0.79)	106 (-0.18)	2.9 (-0.88)
	S2	H1		1.2 (-0.80)	110 (-0.14)	2.4 (-0.87)		0.8 (-0.87)	99 (-0.23)	1.6 (-0.92)
		H2		1.0 (-0.82)	113 (-0.14)	2.0 (-0.88)		0.6 (-0.88)	101 (-0.23)	1.3 (-0.92)
		H3		1.1 (-0.84)	115 (-0.15)	2.2 (-0.90)		0.7 (-0.89)	104 (-0.23)	1.5 (-0.93)

were closer to upper limits of this range, between 17.7-24 kg ha^{-1} mm^{-1} and between 16.6-21.4 kg ha^{-1} mm^{-1} for the early and late sowing dates, respectively, between hybrids. In the projected future those values decreased by 73-89% and 72-88% in the near future for both RCPs, reaching 77-90% and 87-93% decreases for RCP 4.5 and 8.5, respectively, in the end of the century.

Bassu *et al.* (2014) highlighted a common trend among several crop models of decreasing the duration of crop cycle, and consequently crop biomass and yields in maize with the increase of temperatures in warm-climate locations, physiologically based on the temperature-response trait of maize. These results are also found in Brazil for a variety of regions (Minuzzi and Lopes, 2015); even when there is an apparent positive effect of decreased risk by frost at some sowing dates in Southern Brazil due to warmer climate, scenarios that provided higher relative increases of this variable also leads to the shortening of the cycle (Streck *et al.*, 2010). The decrease of crop cycle length affects crop development mainly due to the imposition of lower water and radiation intake, which ultimately affects CO_2 assimilation. Howell (1990) presented the climate-specific linear relationship between transpiration and crop biomass, when there is no nutritional deficiency, which is the condition of the simulations of this study. Perry (2011) pointed that the shorter the maize growth cycle becomes, the lower the water supply, crop transpiration and water demand by the plant. Thus, in the present study a continuously decreasing WUE, also named water productivity (Perry, 2011) was observed, with the lowest values found for the late sowing date at the end of the century. Minuzzi and Lopes (2015) point to the relationship between cycle duration and WUE; although in its analysis there was a tendency of decrease of yields and increase of WUE, this was due to the non water-limited conditions in the simulations. While baseline WUE are inside the range reported by FAO (Sadras *et al.*, 2007) of 6-23 kg ha^{-1} mm^{-1} for rainfed systems, the decrease in all future projections, of at least 70% is strongly linked by crop cycle duration and yield decreases. While Minuzzi and Lopes, (2015), Bassu *et al.* (2014), did not present sowing date and hybrid maturity variation in its assessment of impact of climate change on maize in Midwestern Brazil, in this study we found the strong evidence of the unfeasibility of late sowing dates on second season maize, suggesting the necessity of shifting to early dates and/or imposing other management practices, such as irrigation. Also, although late maturity hybrids may profit from better resource use (i.e., through longer period in the field), as suggested by Bassu *et al.* (2014), we found that due to less favorable climate conditions in the projected future, a shift to early sowing date will probably be most determinant in achieving higher yields, since the most accentuated yield decreases were due to sowing dates.

In terms of uncertainties regarding crop modeling studies, for C4 crops like maize, great part of these can be linked to model parameterization related to increases in temperatures and CO_2 (Bassu *et al.*, 2014). Specifically for CERES-MAIZE, main uncertainties are related to the possible underestimation of yields and crop transpiration due to increase of temperatures and increases in CO_2, respectively (Boote *et al.*, 2010). While overall model uncertainties may be mitigated by using an ensemble of crop models (Asseng *et al.*, 2013; Bassu *et al.*, 2014), uncertainties on crop responses due to combination of variables climatic elements are heavily dependent on good quality experimental data. Future research should contemplate ensemble of crop models and other regions in Mato Grosso state.

4. Conclusions

For the assessed region, located in the South-Central portion of Mato Grosso state, although some positive rainfall variability was found, most of the future projections found were negative in relation to the baseline, indicating less amount of annual water income in local rainfed agricultural systems. In terms of temperature, all the evaluated models and scenarios pointed only to increases, especially concerning daily minimum temperatures, indicating projections for a warmer future. More extreme projections were always found for the end of the century, especially for RCP 8.5, with the most accentuated estimates.

Projections for maize growth and development at second agricultural season showed predominantly less favorable results when compared to baseline historical scenario. In response to a warmer and overall drier climate, crop cycle length will decrease leading to lower water and radiation uptake, and ultimately lower crop yields, reaching lowest values by the end of the century.

The results highlight the importance of prioritizing earlier sowing dates on second agricultural season as climate continuously keeps changing, as a manner to mitigate the decrease of maize growth and development due to less favorable temperature and rainfall conditions. Adaptation measures concerning climate change will have to comprise the shift of sowing dates to as early as possible, the use of irrigation practices, and/or the development of heat and drought-tolerant genetic materials. Such adaptation will be definitive in the continuity of double-cropping systems, such as soybean-maize succession, common in Central Brazil.

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CONAB http://www.conab.gov.br/conteudos.php?a=1252&t=2

FAO/IIASA/ISRIC/ISS-CAS/JRC http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/

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IBGE (Levantamento Sistemático da Produção Agrícola LSPA) https://www.ibge.gov.br/estatisticas-novoportal/economicas/agricultura-e-pecuaria/9201-levantamento-sistematico-da-producao-agricola.html?=&t=o-que-e

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IPCC http://www.ipcc.ch/report/ar5/syr/

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