AGROCLIMATIC APTITUDE FOR MAIZE CROP IN REGIONS OF MATO GROSSO STATE, BRAZIL †

[APTITUD AGROCLIMÁTICA PARA EL CULTIVO DE MAÍZ EN REGIONES DEL ESTADO DE MATO GROSSO, BRASIL]

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SUMMARY

Background. The maize crop is strongly influenced by climatic variables such as precipitation and air temperature, directly influencing its adaptation to a specific location and climate. **Objective.** To determine the agroclimatic adaptability of the maize crop for different agricultural regions of the Mato Grosso State, Brazil. **Methodology.** This work was developed at the State University of Mato Grosso (UNEMAT), on the dependences of the Centro Tecnológico de Geoprocessamento e Sensoriamento Remoto (CETEGEO-SR). A study was carried out on the adaptability of maize in the municipalities of Rondonópolis, Cuiabá, Tangará da Serra, Campo Novo do Parecis, Sorriso, and Sinop, in the state of Mato Grosso, Brazil. The climatic variables of precipitation and air temperature, calculated on ten-day periods, were used for each municipality as provided by the Instituto Nacional de Meteorologia (INMET). Based on the climatic requirements of the crop, the adaptability of maize during the year was classified. **Results.** The recommended sowing of the season maize in the municipalities is between the 30th and 33rd ten-day periods and for off-season maize it is between the 1st to 5th ten-day periods, without damage to the development, productivity, and crop harvest. All municipalities are considered suitable for growing maize with the average air temperature. Regarding precipitation, maize is classified as moderated by excess water for cultivation in the spring and summer periods. **Implications.** This study provides knowledge and technical recommendations on the use of water in the maize crop, as well as the correct sowing date and cultivation of this crop for the study region. **Conclusion.** The maize crop is suitable for cultivation in the municipalities studied, with recommended sowing between October to February.
Keywords: Adaptability; climate; precipitation; water balance; *Zea mays* L.

RESUMEN

Antecedentes. El cultivo de maíz está muy influenciado por variables climáticas como la precipitación y la temperatura del aire, lo que influye directamente en su adaptación a una ubicación y clima específicos. **Objetivo.** Determinar la adaptabilidad agroclimática del cultivo de maíz para diferentes regiones agrícolas en el estado de Mato Grosso, Brasil. **Metodología.** El presente trabajo se desarrolló en la Universidad Estatal de Mato Grosso (UNEMAT), en las instalaciones del Centro Tecnológico de Geoprocessamento e Sensoriamento Remoto (CETEGEO-SR). Un estudio sobre la adaptabilidad del cultivo de maíz en los municipios de Rondonópolis, Cuiabá, Tangará da Serra, Campo Novo do Parecis, Sorriso y Sinop, en el estado de Mato Grosso, Brasil fue realizado. Para cada municipio estudiado se utilizaron las variables climáticas precipitación y temperatura del aire, calculadas en períodos de diez días, provistas por el Instituto Nacional de Meteorología (INMET). Con base en los requerimientos climáticos del cultivo, la adaptabilidad del maíz durante el año fue clasificada. **Resultados.** La siembra recomendada del maíz en los municipios es entre los períodos de diez días 30 y 33 y para el maíz fuera de temporada es del periodo de diez días 1 al 5, sin perjuicio del desarrollo, productividad y cosecha del cultivo. Todos los municipios se consideran aptos para el cultivo de maíz en relación con la temperatura media del aire. En cuanto a las precipitaciones, el maíz se clasifica como moderado por exceso de agua para el cultivo en el período de primavera y verano. **Implicaciones.** Este estudio aporta conocimientos y recomendaciones técnicas sobre el uso del agua en el cultivo del maíz, así como la fecha correcta de siembra y cultivo de este cultivo para la región de estudio. **Conclusiones.** El cultivo de maíz es en los municipios estudiados, con siembra recomendada entre octubre y febrero.
Palabras Clave: Adaptabilidad; clima; precipitación; balance hídrico; *Zea mays* L.

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INTRODUCTION

The maize (*Zea mays* L.), among the main plants grown in Brazil, stands out in terms of economic importance, also, it has wide adaptation to Brazilian edaphoclimatic conditions, in addition to achieving high levels of production, even in adverse conditions (Bergamaschi and Matzenauer, 2014). Brazil currently occupies the third position among the largest maize producers in the world, being surpassed only by the United States of America and China, this is due to the fact of the vast Brazilian agricultural area and the appropriate technologies existing in Brazil (FAO, 2015).

Currently, the maize crop represents 41.10% of Brazilian production among all crops, with producers investing more in technology each year, where the Mato Grosso State is among the main producers of this cereal in the country (CONAB, 2020). Also, according to Companhia Nacional de Abastecimento (CONAB), the average productivity in the Mato Grosso State was obtained in the agricultural year 2019/20, considering the total sown area (5.41 million hectares) was 6,392 kg ha^{-1}.

Agroclimatic aptitude is intended to characterize the meteorological parameters that most act on the behavior of plants and, consequently in their extreme conditions, come to harm the growth and development of crops (Medeiros *et al*., 2018). Understanding the behavior of climatic variables in each region helps in activities to be developed, especially in agricultural activities (Medeiros *et al*., 2018). Regions where climatic factors are the main cause of fluctuations in crop productivity, as temperature and precipitation, for example, cannot be controlled or modified on a large scale in an anthropic way (Barbieri *et al*., 2016).

Temperature, precipitation, and local altitude are described as the elements that most determine the productivity of a crop, these characteristics being crucial for the elaboration of agroclimatic zoning (Toledo *et al*., 2009; Maldaner *et al*., 2014), aiming at the exploitation of economically profitable crops and guiding the most appropriate use of a given region for crops that are more adapted so that the determination of agroclimatic suitability represents an ally tool for choosing cultivation areas (Possas *et al*., 2012; Wollmann and Galvani, 2013). The knowledge of the distribution and volume of rainfall, as well as the thermal characteristics, are of fundamental importance for planning agricultural activities in the production of maize crops, such as sowing on an appropriate date, crop treatments, and management of crop systems aiming to avoid water stress on plants and thus decrease productivity (Wagner *et al*., 2013).

Maize crop is considered a very demanding plant about climatic conditions, especially concerning temperature, so that phenology is regulated by the thermal regime. Thermal conditions influence the most diverse vital processes of plants, from germination and emergence by soil temperature, phenological development, and growth of the plant, by both soil and air temperatures (Bergamaschi and Matzenauer, 2014). The thermal requirements of the maize crop vary according to the genotypes, however, few cultivars can grow at temperatures below 10 °C or above 34 °C (Cruz *et al*., 2008), with an ideal average temperature of 24 to 30 °C, with temperatures near and during flowering, between 15 ºC to 30 ºC are ideal (BRASIL, 2020). The water consumption of maize is around 600 mm and can be cultivated in the range between 300 and 5,000 mm, showing good productivity with rainfall above 500 mm during the cycle (Magalhães and Durães, 2006).

In the maize crop, when there is a period of water deficit, some physiological processes and mechanisms are activated in the plant to alter the lack of water, resulting in changes and reduction of the final production, in the absorption and transport of nutrients, and transpiration, these processes highly dependent on water availability (Santos and Carlesso, 1998). About the water balance for the maize crop, the most sensitive phase to the water deficit is flowering, with a more pronounced negative impact on grain production (Bergamaschi *et al*., 2006). Therefore, knowing the periods of need and water scarcity is essential to delimit areas with a climatic aptitude for the crop under study (Medeiros *et al*., 2018).

Knowledge of the adaptability of maize crop is essential to determine the regions suitable for growing maize within a given location (Francisco *et al*., 2017), thus aiming to reduce productivity losses and increase the return on investments made by producers, making them able to practice financially sustainable agriculture (Nunes *et al*., 2007). In this way, the farmer will be able to outline action strategies aimed at reducing mainly the effects of water deficiency.

Francisco *et al*. (2017) proposed different classes of agroclimatic suitability for maize in the Paraíba State, analyzing the distribution of rainfall, temperature regime, and the probability of water deficit, and highlight the importance of carrying out studies like this taking into account the climatic specificity of each region of the country.

Thus, the present work aimed to determine the agroclimatic adaptability of the maize crop for different agricultural regions of Mato Grosso State, Brazil.

MATERIAL AND METHODS

Experimental site

The present work was developed at the State University of Mato Grosso – UNEMAT, Campus Professor Eugênio Carlos Stieler de Tangará da Serra - MT and, on the dependences of the Centro Tecnológico de Geoprocessamento e Sensoriamento Remoto (CETEGEO-SR), in the same location. The data used were registered in meteorological stations of the Instituto Nacional de Meteorologia (INMET) (INMET, 2020), located in the municipalities of Rondonópolis, Cuiabá, Tangará da Serra, Campo Novo do Parecis, Sorriso and Sinop, in the Mato Grosso State, Brazil (Figure 1), with data from the years 2003 to 2019, that is, a historical series of 17 years of each municipality (Table 1).

According to Köppen, the predominant climate of Mato Grosso State is classified as a mega thermic humid tropical (Aw), where high temperatures are present, with a dry season, which runs from May to September, and a rainy one that goes from October to April, with average annual rainfall between 1,200 to 2,000 mm, with average temperatures over 18 °C in all months (Souza *et al*., 2013). The type of soil in the study regions is classified as Oxisol (Santos *et al*., 2018).

Table 1. Location of the meteorological stations used to determine the agroclimatic suitability of the maize crop, located in the Mato Grosso State – Brazil.

Class of climate	Organization	Municipality	Latitude	Longitude	Altitude (m)
Aw	INMET	Rondonópolis	16° 27’ S	54° 34’ W	284.0
Aw	INMET	Cuiabá	15° 37' S	56° 06' W	151.3
Aw	INMET	Tangará da Serra	14° 39’ S	57° 25’ W	440.0
Aw	INMET	Campo Novo do Parecis	13° 47' S	57° 50' W	570.0
Aw	INMET	Sorriso	12° 33' S	55° 43' W	380.0
Aw	INMET	Sinop	11° 58' S	55° 33' W	371.0

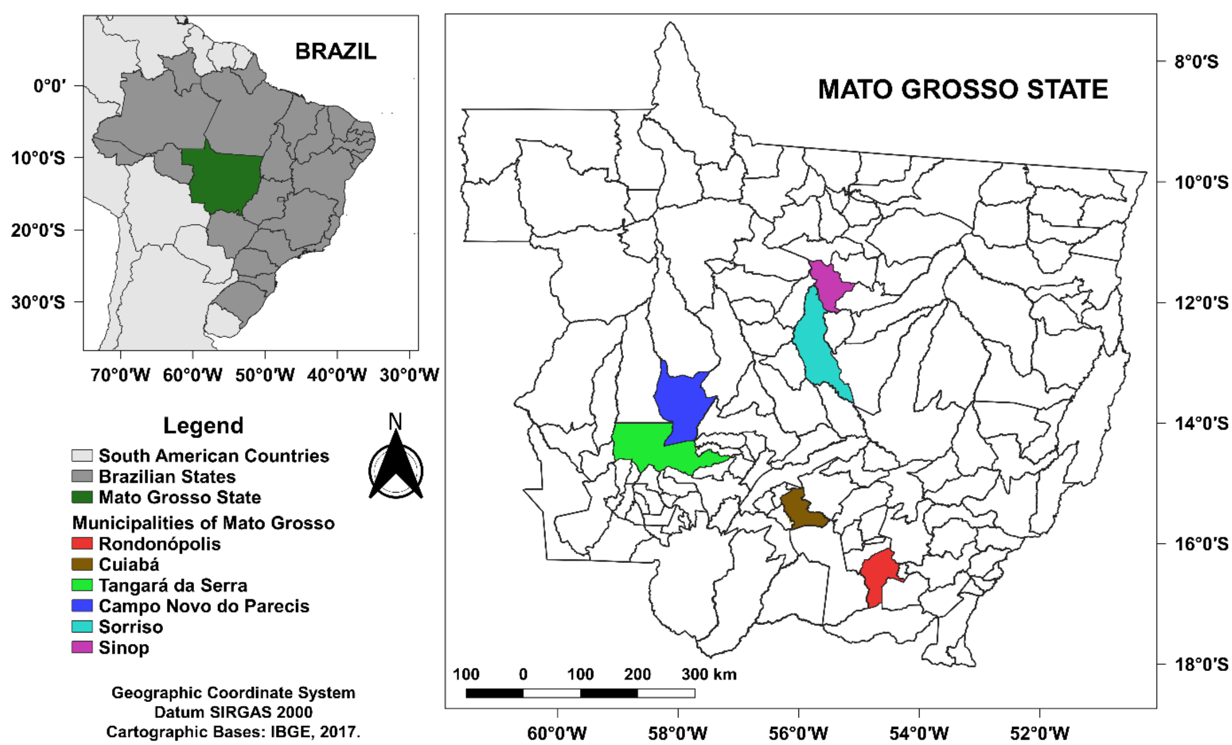


Figure 1. Location of the Mato Grosso State - Brazil, with emphasis on the municipalities studied.

Climatic data, climatic aptitude and adaptability

Data of air temperature and precipitation obtained from INMET were used. For organization, tabulation, verification, and possible corrections, consistency analysis and determination of air temperature and precipitation averages were carried out for December, monthly and annual periods, using the CLIMA software, developed by Instituto Agronômico do Paraná (IAPAR) (Faria *et al*., 2003).

Based on water and thermal requirements, a classification of the climatic suitability of the maize crop was organized, defined by six pre-established criteria: C1) full aptitude - corresponds to areas without climatic limitation; C2) moderate ability due to water excess (characterized by indicating areas where water excess may impair growth, development, productivity, harvesting and/or drying of grains) - there will be too much water for the crop; C3) moderate ability due to water deficiency (areas with small and/or moderate water deficiency, hindering the growth and development and the productivity of the crop); C4) moderate aptitude due to thermal deficiency (characterized by indicating areas, where thermal deficiency occurs, hindering the growth and development of the crop and the productivity of the crop); C5) aptitude moderated by thermal excess (areas with small and/or moderate thermal excess hindering the growth and development and productivity of the crop), and; C6) Inapt aptitude (due to high water deficiency, making the vegetative period of the crop unfeasible).

For the six established classes of climatic suitability of maize, they were categorized according to the temperature and precipitation required by the crop during its cycle, being represented by a color scale as can be seen in Table 2.

The water needs of the maize crop in the initial, development, intermediate and final stages are 17.3; 122.0; 231.4, and 50.8 mm, respectively, with a water demand of 421.5 mm for a cycle of 104 days in a Cerrado environment (Murga-Orrillo *et al*., 2016). Barbieri *et al*. (2020) evaluating the maize crop in Tangará da Serra - MT, found water consumption values of 115.96, 159.05, and 60.93 mm for the initial, intermediate, and final phases, respectively, totaling 335.94 mm for the entire cycle of the crop, with a general average of 3.40 mm d^{-1}. With the knowledge of these values, it is possible to determine the adaptability of the maize crop based on the water requirements of the crop.

Following the recommendation for sowing times proposed in the Agricultural Zoning of Climatic Risk (AZCR) for crop and off-season maize in the Mato Grosso State (BRASIL, 2019; BRASIL, 2020), the sowing period lies between September 21 to December 31 for maize 1st season, and between January 1 to February 20 for maize 2nd season. Considering that the average crop cycle is up to 120 days for the studied regions, it was understood as a period of data comparison that goes from the 27th ten-day period of one year to the 12th ten-day period of the following year for the cultivation of maize crop, and between the 1st to 17th ten-day period for maize in off-season cultivation for all sowing and harvest periods.

Table 2. Climatic indicators and classification during the maize cycle for different regions of the Mato Grosso State.

Class	Climatic aptitude	Average air temperature (°C)	Precipitation (mm)
C1	Apt	≥19 to ≤34	≥400 to ≤800
C2	Moderated by water excess	-	≥801
C3	Moderated by water deficiency	-	≥300 to <399
C4	Moderated by thermal deficiency	≥16 to <19	-
C5	Moderated by thermal excess	>34	-
C6	Inapt	<16	<299

Source: Adapted from Magalhães and Durães (2006); Dalmago *et al*. (2009); Cruz *et al*. (2008); Cruz *et al*. (2010); Wagner *et al*. (2011); Francisco *et al*. (2017).

Water balance

The climatological water balance for ten-day periods in the studied regions was calculated from the model proposed by Thornthwaite and Mather (1955), considering the 75 mm available soil water capacity (AWC) for the municipalities of Rondonópolis, Cuiabá, Tangará da Serra, Campo Novo do Parecis, Sorriso and Sinop (Sans *et al*., 2001; Rossato, 2001; Barbieri *et al*., 2017). The calculation of the water balance was performed using a spreadsheet Software Microsoft Excel® developed by Rolim *et al*. (1998).

Statistical analysis

The data obtained were initially analyzed using descriptive statistical techniques, that is, by calculating the mean, median, asymmetry coefficient, and kurtosis coefficient (Ck).

Ten-day period analysis of precipitation and the air temperature was carried out, taking into account the climatic requirements of the maize crop during its cycle and for sowing times in the first and second season harvest periods Mato Grosso State, to determine the periods favorable and unfavorable for the development of crop, analyzing periods with temperatures below or beyond the ideal range and with low or high rainfall.

RESULTS AND DISCUSSION

Climatic data and adaptability

The annual rainfall averages for the municipalities studied are shown in Figure 2. The Sinop region had the highest annual average rainfall, with 1,810.5 mm, while the municipality of Rondonópolis had the lowest annual average with 1,346.9 mm, with rains between October to April as described by Dallacort *et al*. (2011), rainfall variation also observed by Barbieri *et al*. (2016) in different municipalities of Mato Grosso State.

For all the studied regions, the historical average annual rainfall was 1,597.2 mm, a level considered satisfactory for the two possible maize crops in the Mato Grosso State under rainfed cultivation (Fancelli and Dourado-Neto, 2007; Cruz *et al*., 2010). The yield of the maize crop is not only linked to the total amount of water but that there are precipitations distributed throughout its development that meet its physiological needs (Magalhães and Durães, 2006).

For the municipalities studied, the historical average annual rainfall showed a maximum standard deviation of 337.03 mm for the Sorriso region and a minimum of 176.17 mm for the Rondonópolis region. About all the seasons studied, the average annual standard deviation of precipitation was 258.10 mm, showing that there may be variability of rainfall in the state of 16.16% concerning the annual average for the historical period studied.

Regarding the average annual temperature, it varied from 24.65 °C in the municipality of Campo Novo do Parecis to 26.82 °C in the municipality of Cuiabá (Table 3). Regarding the maximum annual temperature, temperatures between 29.34 to 32.13 °C were recorded for Campo Novo do Parecis and Sinop, respectively. As for the annual minimum temperature, historical averages ranged from 20.13 to 22.86 °C for Tangará da Serra and Cuiabá, respectively.

Historical records of the average annual temperature for the municipalities studied showed a maximum standard deviation of 1.56 °C for the region of Rondonópolis and a minimum of 0.71 °C for the municipality of Sinop.

The ideal temperature range for maize cultivation is between 19 and 34 ºC (Cruz *et al*., 2008; Francisco *et al*., 2017). It is observed, in this way, that the average annual air temperature favored the development of the crop throughout the year, in the different regions considered, this not being an obstacle to the sowing of maize, in any of the two harvests for Mato Grosso State (CONAB, 2020).

The reduction of nitrate reductase activity is caused when air temperatures above 35 °C occur, causing a fall in the protein composition of the grain and yield, and night temperatures above 24 °C cause an increase in respiration, thus, the rate of photoassimilates decreases and thus, with a reduction in production (Francisco *et al*., 2017; Francisco and Santos, 2018).

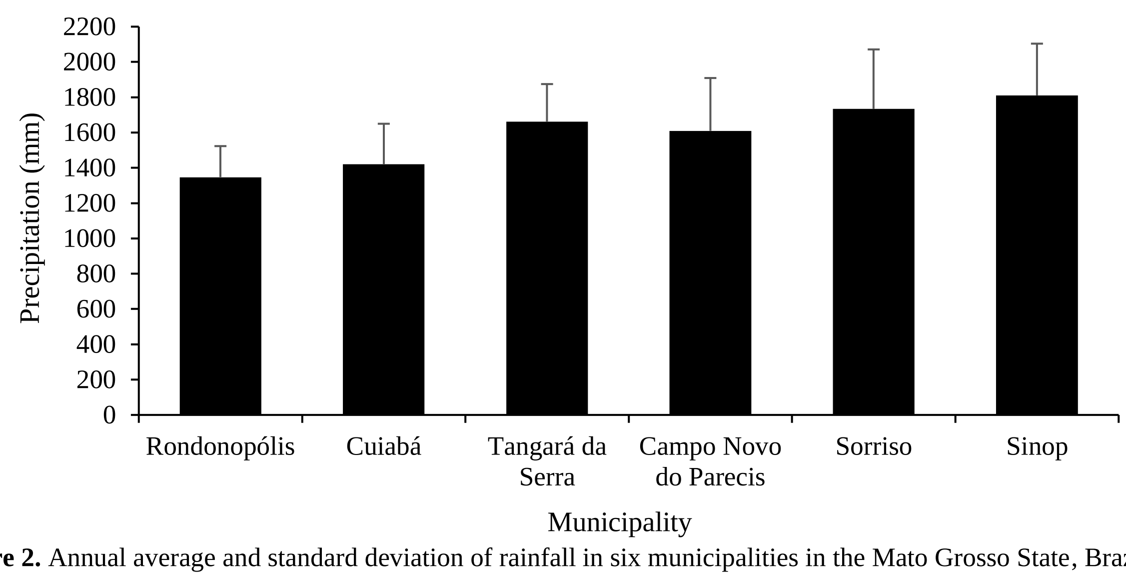


Figure 2. Annual average and standard deviation of rainfall in six municipalities in the Mato Grosso State, Brazil.

Table 3. Annual average and standard deviation of air temperature in six municipalities in the Mato Grosso State.

Municipality	Temperature (°C)		
	Maximum	Average	Minimum
Rondonópolis	31.09±1.47	25.84±1.56	21.55±2.28
Cuiabá	31.52±1.32	26.82±1.45	22.86±1.98
Tangará da Serra	31.15±1.43	24.74±1.03	20.13±1.70
Campo Novo do Parecis	29.34±1.32	24.65±0.94	20.87±1.39
Sorriso	31.31±1.51	25.93±0.80	21.59±1.25
Sinop	32.13±1.38	26.28±0.71	21.76±1.31

When comparing average with median, there is a low variation between the values of rainfall, which makes them close to normal, a fact also is proven by the value of the asymmetry coefficient, presenting positive asymmetry in three municipalities and negative in the other three, however values close to 0 (symmetry), which is a good parameter for annual rainfall assessment (Table 4). About the kurtosis coefficient (Ck), the average precipitation values for most of the studied municipalities had a platykurtic distribution (Ck < 0), with only the municipalities of Rondonópolis and Tangará da Serra showing a leptokurtic distribution (Ck > 0).

Comparing the average with the median for the historical values of average air temperature, there is also a low variation between the values, which makes them close to normal (asymmetry coefficient close to 0), which is a good parameter for the annual assessment of average temperatures (Table 4). The Ck values also reveal a platykurtic distribution for three southernmost municipalities (Rondonópolis, Cuiabá and Tangará da Serra), and a leptokurtic distribution for the other three studied municipalities (Campo Novo do Parecis, Sorriso and Sinop), but distributions close to normal for all municipalities (Ck = 0, mesokurtic). According to Carvalho *et al*. (2002) the asymmetry and kurtosis values varying from 0 and 3, respectively, indicate the normality of the data, which can be observed in this study.

The ten-day periods distribution of rainfall for the municipalities studied indicates that the regions have similar characteristics concerning the distribution of rainfall during the year (Figure 3), a fact also evidenced by Marco *et al*. (2014) for different regions studied in the Mato Grosso State. The regions under study have two well-defined seasons, a dry one that runs from May to September, and a rainy one that runs from October to April, with a characteristic climatic condition in the Midwest region of Brazil, where the Cerrado predominates (Sette, 2005; EMBRAPA, 2012), behavior also observed in municipalities of Mato Grosso State (Dallacort *et al*., 2011; Barbieri *et al*., 2016).

For the municipality of Rondonópolis, it can be observed that the highest rainfall concentrations were registered in the 1st, 2nd, 3rd and 34th ten-day periods, which respectively presented 85.49; 81.62; 102.58, and 85.79 mm. The least rainy period corresponds from the 16th to the 26th ranging from 0.91 to 9.29 mm. The municipality of Cuiabá has the highest rainfall from the 10th to the 15th with precipitation between 13.26 to 94.16 mm and the lowest between the 16th to the 26th, varying between 0.17 and 11.16 mm. The highest rainfall was recorded in the 10th and 5th ten-day periods with 94.16 and 84.55 mm, respectively. In Tangará da Serra there is an increase in precipitation starting from the 10th to the 36th, remaining stable from the 1st to the 4th, and decreasing from the 5th to the 15th. The greatest precipitations were found in the 1st, 2nd, 5th, and 36 with 95.52; 99.47; 117.30, and 99.47 mm, respectively.

In Campo Novo do Parecis, rainfall growth starts from the 25th to the 5th and decreases at the 6th and 7th, starts to grow again on the 8th, and then decreases to the 16th ten-day periods. The greatest precipitations were found in the 1st, 3rd, 4th, and 5th ten-day periods with 94.29; 110.69; 100.98, and 98.82 mm, respectively. The least rainy period is from 10 to 24 days, ranging from 0.14 to 5.29 mm. In Sorriso, the growth is from 24th to 4th after decreasing until the 10th ten-day period. The 10th, 5th, 35th, and 36th ten-day periods were the ones with the highest rainfall with 113.52; 118.18; 95.61, and 111.61 mm, respectively. The least rainy period corresponded between the 16 to 23 days, ranging from 0.01 to 4.42 mm. In Sinop, there is an increase in precipitation from the 26th to the 9th ten-day periods and then decreases from the 10th until the 12th ten-day periods. The least rainy period was between 10 to 25 days, ranging from 0.09 to 6.39 mm.

All regions showed rainfall rates higher than those required by the crop, during the 27th and 12th ten-day periods in which the cultivation of maize is understood. During this period the historical amount precipitated in the municipalities was 1261.18 mm in Rondonópolis, 1308.41 mm in Cuiabá, 1597.67 mm in Tangará da Serra, 1515.30 mm in Campo Novo do Parecis, 1655.24 mm in Sorriso, and 1764.61 mm in Sinop.

Table 4. Descriptive statistics for the historical series studied of the annual rainfall values and average air temperature in six municipalities in the Mato Grosso State.

Municipality	Precipitation				Average air temperature			
	Average	Median	Asymmetry	Kurtosis	Average	Median	Asymmetry	Kurtosis
	(mm)		(dimensionless)		(°C)		(dimensionless)	
Rondonópolis	1346.99	1327.30	-0.64	0.80	25.84	26.20	-0.48	-0.83
Cuiabá	1420.22	1467.80	-0.47	-1.23	26.82	27.12	-0.56	-0.84
Tangará da Serra	1661.39	1678.35	0.88	0.55	24.74	24.79	-0.10	-0.64
Campo Novo do Parecis	1609.71	1633.40	0.12	-1.11	24.65	24.67	0.27	0.19
Sorriso	1734.13	1786.90	-0.08	-1.47	25.93	25.72	1.14	0.54
Sinop	1810.47	1788.50	0.20	-1.23	26.28	26.12	0.95	0.42

Even though sowing is carried out in the last period recommended in the region for maize harvest (December 31), the historical rainfall indexes were excellent about those recommended for the crop during its cycle, with 712.96 mm; 801.15 mm; 665.82 mm; 614.01 mm; 719.89 mm and 735.35 mm for the municipalities of Rondonópolis, Cuiabá, Tangará da Serra, Campo Novo do Parecis, Sorriso and Sinop, respectively.

About off-season maize, all municipalities presented satisfactory levels of precipitation concerning the period of maize cultivation in this second crop condition. Even if the sowing is carried out in the last period recommended in the region for off-season maize (February 20), the historical rainfall indexes were satisfactory to those recommended for the crop during its cycle, with 457.18 mm; 498.29 mm; 459.42 mm; 500.22 mm and 526.91 mm for the municipalities of Cuiabá, Tangará da Serra, Campo Novo do Parecis, Sorriso and Sinop, respectively. Only the municipality of Rondonópolis presented moderate water restriction with 343.95 mm if sowing was carried out on the last recommended date (February 20), however, if the sowing is advanced it can be cultivated without any water restriction in the municipality.

The municipalities of Rondonópolis, Tangará da Serra, Sorriso, and Sinop were characterized by the three rainiest months in December, January, and February, except for Cuiabá and Campo Novo do Parecis where the three rainiest months were in January, February and March. The historical average of ten-day periods precipitation in these three rainiest months was 78.06 mm for the municipality of Rondonópolis, 76.03 mm in Cuiabá, 95.22 mm in Tangará da Serra, 88.46 mm in Campo Novo do Parecis, 96.59 mm in Sorriso and 102.86 mm in Sinop (Figure 3).

The rainfall averages in the municipalities analyzed showed a reduction until April, is possible to observe some ten-day periods that show irregular rains and that the driest months were May, June, July, and August for all the regions, being possible to observe ten-day periods averages below 10 mm. Maize is not tolerant of long periods of drought, depending on at least 400 mm of water during its development cycle, but above 300 mm it already shows satisfactory productivity (Cruz *et al*., 2008; Francisco *et al*., 2017).

Thus, taking into account the two sowing seasons (1st harvest and 2nd harvest) and the duration of the average maize cycle, which is around 120 days (Minuzzi and Lopes, 2015; BRASIL, 2020), it is not possible to find water deficiency in the 1st harvest, a period in which the maize is sown from September to December, in none of the ten-day periods in which the maize is cultivated, observing a satisfactory amount and good regularity of the rains between October to March (Figure 3). However, in this sowing period, the risk of rain at the time of harvest is greater, which can compromise grain production and quality (Simão *et al*., 2018). In the 2nd harvest, when the maize is sown between January and February, there is a good regularity of rainfall that meets the maize crop and with low rainfall in May and June, favoring the harvest without compromising the quality of the grains.

The precipitation averages found in the studied cities are considered optimal for the cultivation of maize since they meet the water requirements for the crop, with an optimum amount for the development of maize (Murga-Orrillo *et al*., 2016; Barbieri *et al*., 2020), however, the second crop period is the most recommended, optimizing the sowing season and obtaining 2 harvests per year in this region of the country (Sacks *et al*., 2010; Kappes, 2013). The greatest water demand for maize crops covers the period from pre-flowering to grain filling (Silva *et al*., 2006). Therefore, the planting season is directly linked to the gain of high yields in the off-season maize cultivation in Mato Grosso, with greater risks of failure occurring in later seasons (Dallacort *et al*., 2011).

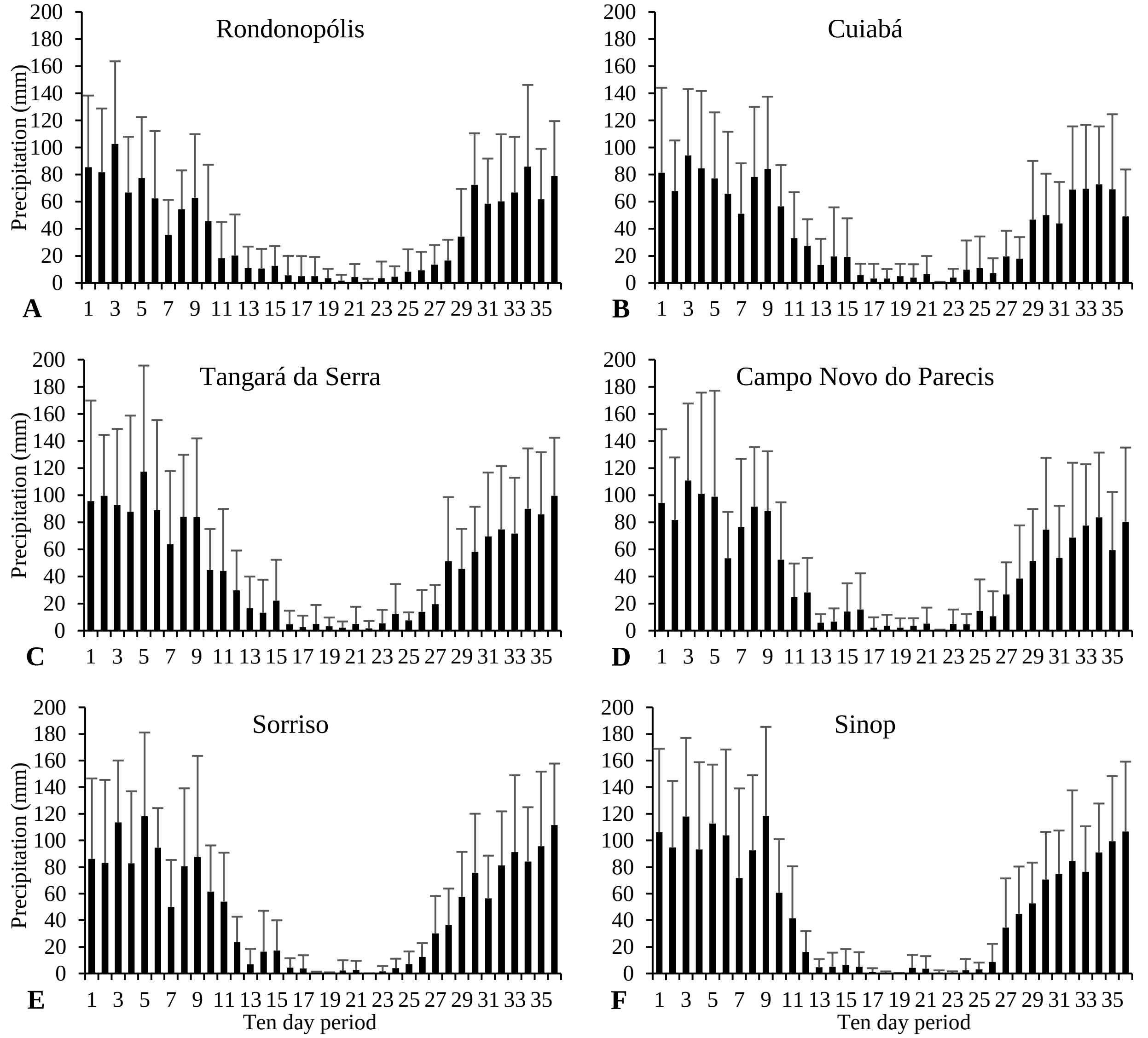


Figure 3. Rainfall distribution and standard deviation at ten-day periods for the municipalities of Rondonópolis (A), Cuiabá (B), Tangará da Serra (C), Campo Novo do Parecis (D), Sorriso (E) and Sinop (F), Mato Grosso State, Brazil.

About the regime of ten-day periods of air temperature in the regions under study, there are no wide ranges of variation of the ten-day periods between averages from the warmest to the coldest months, however, it is in the months of the dry season (winter in the region) that the lowest air temperature values in the cities studied (Figure 4).

In Rondonópolis, the month with the highest average air temperature recorded was October with a ten-day periods average of 27.93 °C, on the other hand, the month of July had the lowest air temperatures with a ten-day periods average of 23.17 °C (Figure 4A). Cuiabá recorded an air temperature of 28.74 °C in October and 24.30 °C in July, Tangará da Serra recorded an air temperature of 26.49 °C in September and 23.24 °C in July, Campo Novo do Parecis recorded an air temperature of 26.50 °C in September and 23.15 °C in June, Sorriso recorded an air temperature of 27.72 °C in September and 25.17 °C in July and Sinop recorded an air temperature of 27.82 °C in September and 25.40 °C in July, for months with higher and lower average values of ten-day periods air temperature, respectively (Figures 4B to 4F).

The highest temperature averages are found in October and November for the region, ranging from 23 to 27.88 °C (Ramos *et al.*, 2017), values like those found in the studied months and years of this work. Souza *et al.* (2013) found mean air temperature values of 25.11 °C in Rondonópolis, 26.84 °C in Cuiabá, and similar mean air temperature values for other municipalities of Mato Grosso State.

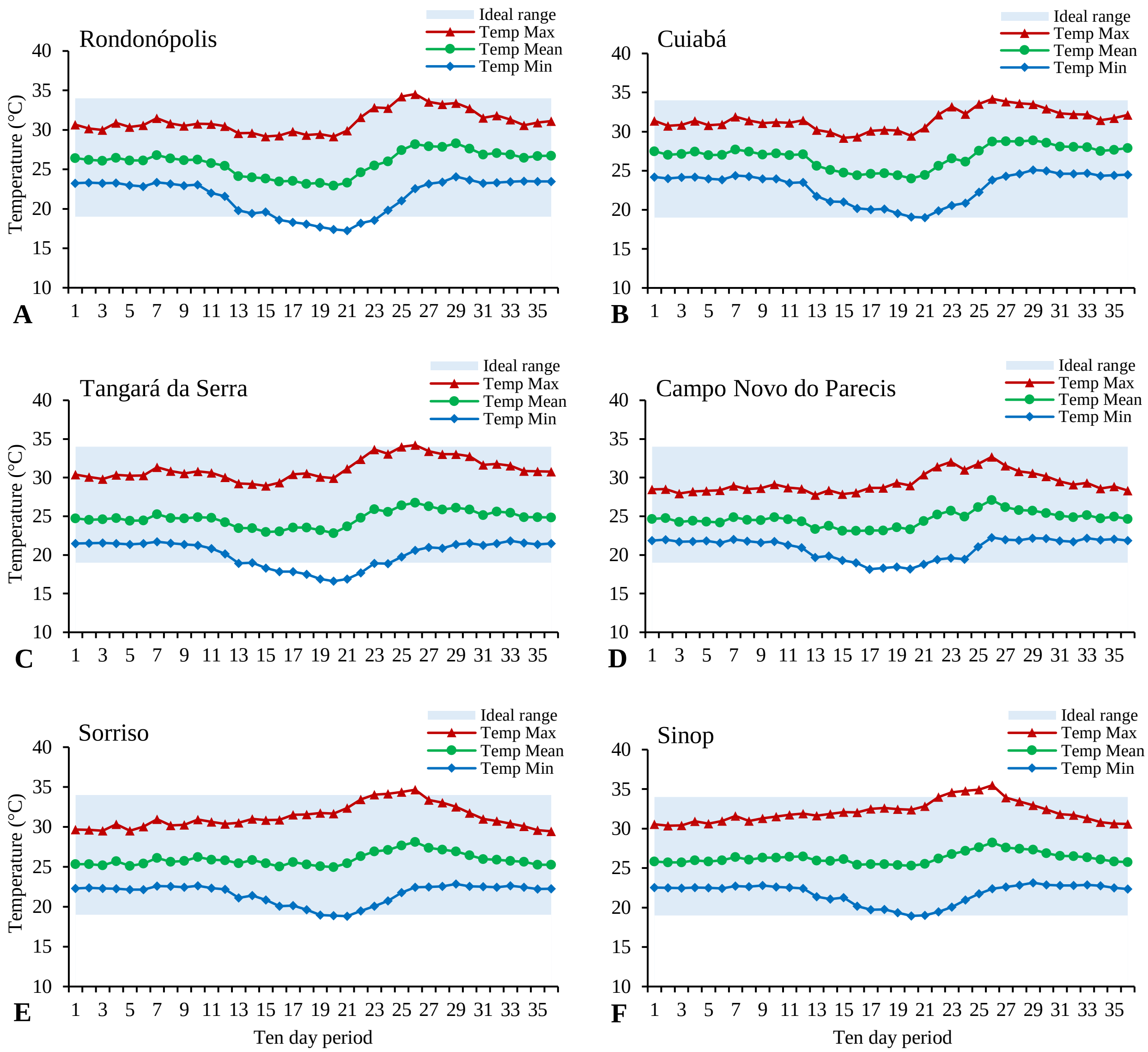


Figure 4. Distribution of air temperature and ideal temperature range for the cultivation of maize (19 to 34 °C) at ten-day periods for the municipalities of Rondonópolis (A), Cuiabá (B), Tangará da Serra (C), Campo Novo do Parecis (D), Sorriso (E) and Sinop (F), Mato Grosso State, Brazil.

The temperature has been presented as the most important climatic element to predict the phenological events of the maize crop if there is no water deficiency (Wagner *et al*., 2011). When calculating the thermal sum of the maize crop, the base temperature is generally below 10 °C (Renato *et al*., 2013). Most maize hybrids have thermal requirements that can vary affecting physiological processes such as germination and growth, but few can develop at temperatures below 10 °C (Silva *et al*., 2006; Wagner *et al*., 2011). Estimates of the upper threshold or maximum temperature for maize are in the range of 19 to 34 °C (NeSmith and Ritchie, 1992; Wagner *et al*., 2011).

The ten-day period averages of minimum and maximum temperatures recorded in the municipalities were within the optimum range for the development of maize (between 19 and 34 °C) (Cruz *et al*., 2008; Francisco *et al*., 2017), and the average optimum temperature is between 25 to 30 °C (Francisco *et al*., 2017), thus, the temperatures observed in the study municipalities are suitable for the cultivation of this crop in the State.

Regarding the ten-day periods' temperature average, the studied municipalities have little oscillation between the lowest and the highest temperature, that is, they have a small thermal amplitude between them, and in all places, this variable is within the appropriate levels for the development of the maize crop, so all the municipalities were able satisfaction of the maize growth thermal requirements.

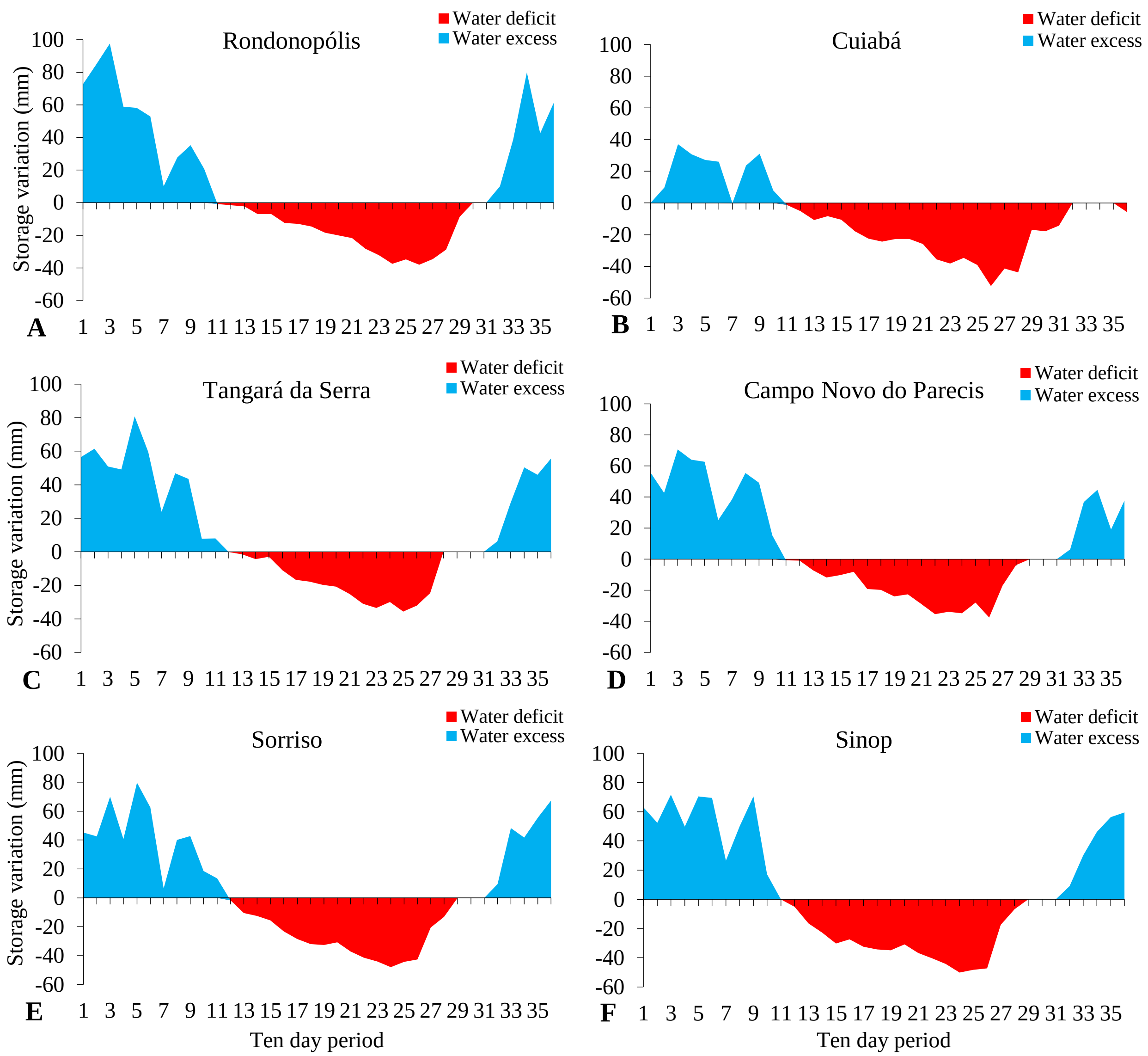
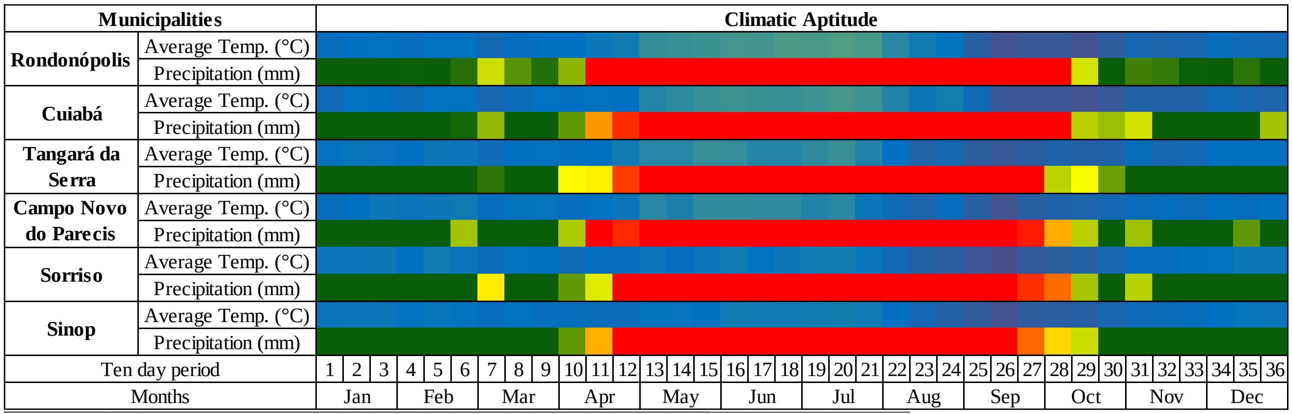


Figure 5. Climatological water balance at ten-day periods for the municipalities of Rondonópolis (A), Cuiabá (B), Tangará da Serra (C), Campo Novo do Parecis (D), Sorriso (E) and Sinop (F), Mato Grosso State, Brazil.

Water balance

When analyzing the distribution of the water balance for the six municipalities during the year, in all regions there are ten-day periods with water deficit and surplus (Figure 5). The municipality of Cuiabá was the only one among those studied that did not exhibit similar behavior among those studied, with no water deficit or excess between the 32nd and 34th ten-day periods and with a water deficit occurring in 2 last ten-day periods of the year, unlike what happened in other municipalities.

The municipality of Rondonópolis presented water deficiency between the 11th to the 29th ten-day periods; Cuiabá presented water deficiency between the 11th and the 36th ten-day periods; Campo Novo do Parecis between the 11th to the 28th ten-day periods and the municipalities of Tangará da Serra, Sorriso and Sinop presented water deficiency between the 12th to the 28th ten-day periods (Figures 5A to 5F). It was also found that the ten-day period with the greatest water deficiency was 26th for the municipalities of Rondonópolis, Cuiabá and Campo Novo do Parecis, showing a deficit for the period of 38.1, 52.5, and 37.6 mm, respectively. In Tangará da Serra, the 25th ten-day period shown the greatest water deficiency with 35.7 mm. For the municipalities of Sorriso and Sinop, the 24th ten-day periods were those with the greatest water deficiency, with 48 and 50.1 mm, respectively (Figure 5).



Classes	Climatic aptitude	Average air temperature (°C)	Precipitation (mm)
C1	Apt	≥ 19 to ≤ 34	≥ 400 to ≤ 800
C2	Moderated by water excess	-	≥ 801
C3	Moderated by water deficiency	-	≥ 300 to < 399
C4	Moderated by thermal deficiency	≥ 16 to < 19	-
C5	Moderated by thermal excess	> 34	-
C6	Inapt	< 16	< 299

Figure 6. Monthly and ten-day periods classification of climate suitability for maize crop for different regions of the Mato Grosso State, Brazil.

Based on the water balance, it can be observed that for the study regions, sowing between April and the first ten-day period of October, the water deficiency averages were between 15.7 mm (Rondonópolis), 14.6 mm (Tangará da Serra), 15.6 mm (Campo Novo do Parecis), 21.8 mm (Sorriso) and 23.9 mm (Sinop), this period is considered unfit for maize cultivation for these municipalities, due to prolonged periods of low precipitation, which extend from April to September, requiring the use of irrigation systems for growing maize during this period. The municipality of Cuiabá, on the other hand, had an average water deficit of 20.2 mm between April and October, but with moderate water deficiency even in November and December due to mild water deficiency.

The municipality of Cuiabá showed a water surplus between January and March, the recommended period for sowing (between January 1 and February 20), that is, from the first to the fifth ten-day period. All other regions analyzed showed a water surplus between October and March when sowing is carried out between October and February, thus there is no water deficit throughout the maize crop cycle, at any time of sowing between the 1st to 5th ten-day periods (January 1 to February 20) and 30th to 36th ten-day periods (October 20 to December 31) (Figure 5).

All the municipalities studied were considered Class C2 (moderated by excess water) for the cultivation of maize both for cultivation in the 1st harvest and for the cultivation in the period of the 2nd harvest (Figure 6), period between the 10th to the 36th and 1st to 9th ten-day periods, with some ten-day periods between this period presenting themselves as class C1 and class C3, such as the 31th and 32th ten-days periods for the municipality of Rondonópolis and the 7th ten-day period for the municipality of Sorriso (Figure 6). Even though these municipalities are considered as moderate cultivation due to excess water (Class C2) for the 1st and 2nd crop cultivation, the maize crop does not suffer major losses in its production, so the Mato Grosso State is one of the main producing states of this crop, reaping record productivity yields, standing out on the world stage in the production of this commodity (FAO, 2015; CONAB, 2020).

Climatic aptitude

The maize cultivation in the Mato Grosso State is inapt due to water deficiency (Class C6) between the second ten-day period of April (11th ten-day period) and the end of the second ten-day period of October (29th ten-day period), with recommended sowing in this period with the use of irrigation systems (Figure 6).

Regarding thermal requirements, all municipalities are considered suitable for maize cultivation, with no thermal deficiency or excess in the study regions, being classified as class C1 in all ten-day periods (Figure 6). In general, the season of best growth for the maize crop, in the studied regions, corresponds to the humid period during spring and summer (October to February), which provides great water availability to the soil, due to rainfall and less probability occurrence of five or more dry days and air temperatures ideal for germination and crop development.

New work needs to be done due to the importance of how the climate influences crops and in them, they must demonstrate the importance of water availability and ideal temperature for the development of crops (Villela *et al*., 2015).

CONCLUSIONS

Based on the water requirements of the crop, the implantation of maize is suitable for all the municipalities studied, with the best sowing time observed between the end of October and the end of November for the period of the 1st harvest (30th to the 33rd ten-day periods), and sowing no later than February 20 (5th ten-day period) for the sowing of 2nd crop season, when the high thermal availability recommends the shortest crop time in the field, minimizing climatic risks of crop failure. For the thermal requirements of the crop, all regions can be considered suitable for the cultivation of maize for both the first and the second harvest in the municipalities studied. Water balances were decisive for the definition of the climatic aptitude of maize in the municipalities studied in the Mato Grosso State.

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Data availability. Data are available with the corresponding author (diegodanielmt@gmail.com) upon reasonable request.

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