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Crotalaria Sowing Times Intercropped with Off-Season Maize in the Variability of Soil Temperature and Moisture

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Abstract

The thermal regime and the dynamics of soil moisture affect crop yield. Therefore, there is a need to understand the extent to which the intercropping system modifies the variability of soil temperature and moisture conditions for optimal growth and yield of the maize crop. This study aimed to evaluate the influence of different sowing times of crotalaria in an intercropping system with irrigated and non-irrigated off-season maize in the variability of soil temperature and moisture. The experiment consisted of twelve treatments, consisting of different cropping systems (intercropping): maize in a single crop (MS); sowing of crotalaria simultaneous with maize (MCS); sowing of crotalaria with maize in the VE stage (MCVE); sowing of crotalaria with maize in stage V2 (MCV2); sowing of crotalaria with maize in stage V4 (MCV4); sowing of crotalaria with maize in stage V6 (MCV6), in irrigated and non-irrigated systems. Soil temperature was monitored at depths of 10, 20, 30 and 40 cm, and soil moisture was monitored at a depth of 20 cm using "K-type" thermocouple sensors and time domain reflectometry (TDR) probes, which were all connected to a Datalogger and programmed to store the collected data at 15-minute intervals. Irrigation was carried out with a uniformity coefficient greater than 80% and a water depth of 10.38 mm h^{-1} with a sprinkler system. The intercropping of maize with crotalaria provides the soil with a smaller range of soil temperature, with higher values in the system without irrigation compared to the irrigated system. Soil moisture was lower in the single maize treatment, as it increased soil water evaporation compared to the intercropping treatments. In the irrigated system, the soil moisture was higher at 0.010 m^3 m^{-3} in relation to the system without irrigation. The irrigated system obtained better results for maize yield than the non-irrigated system.

Keywords: irrigation, time domain reflectometry, thermocouple sensors, *Crotalaria spectabilis* Roth., *Zea mays* L.

1. Introduction

The use of soil conservation systems is becoming more frequent in different regions of Brazil, as these systems offer advantages to the environment, as well as increased crop yield (Coser et al., 2016). Among the conservation activities, intercropping is an important and well-known agricultural resource practiced in all growing regions, mainly in the Brazilian Midwest.

The intercrop consists of the simultaneous cultivation of two or more crops in the same area, not necessarily planted or sown at the same time (Santos et al., 2018b). Within the intercropping of agricultural crops, the maize crop (*Zea mays* L.) is commonly intercropped with legumes such as crotalaria (*Crotalaria spectabilis* Roth.), as it has numerous benefits and advantages, especially for the main crop, maize (Souza et al., 2019).

The benefits of using an intercrop are numerous, including the supply of nitrogen fixed by the legume, increased revenue, high efficiency in the use of water and soil nutrients, improvement in soil structure because of the root system of different crops, increased productivity of the subsequent crop, high efficiency of light use, decreased pest infestation, increased soil organic matter content and increased grain yield (Chieza et al., 2017; Patel e Dhillon, 2017; Arf et al., 2018; Gerlach et al., 2019).

Another significant benefit is the ground cover provided by intercropping crops, which has been used to conserve soil water, reduce soil evaporation, and regulate soil temperature, especially in regions where irrigation is not available (Cortez et al., 2015). Thus, continuous monitoring of soil moisture and temperature is very important, especially to understand the dynamics of these factors in the soil and how they can influence plants.

One of the main factors that regulate soil temperature is its degree of coverage (Cortez et al., 2015), so extreme soil thermal regimes negatively affect soil functioning and can cause thermal stress on root tissue, which compromises water and nutrient uptake, crop growth and yield (Gasparim et al., 2005).

Soil temperature is directly influenced by solar radiation incidents on the soil surface, as well as its thermal properties, exerting effects on plant growth and development, mainly on their metabolic functions, especially on water absorption (Carneiro et al., 2014). The way in which soil temperature responds to diurnal air temperature fluctuations is strongly affected by soil management and by the effective use of resources, especially when using intercropping systems (Barbieri et al., 2019).

Similar to soil temperature, soil moisture is of utmost importance, mainly for plant maintenance, and the presence of water affects the heat flow in the soil; that is, the presence of moisture in the soil modifies the thermal amplitude on the soil surface due to evaporation (Carneiro et al., 2014).

There is a high degree of variability in soil moisture in space and time, which is controlled by factors such as solar radiation, soil texture, type of vegetation or existing soil cover and topography of the land (Santos et al., 2011; Cortez et al., 2015). Soil management systems with the adoption of soil cover through the use of intercropping between agricultural crops maintain higher soil moisture compared to fewer conservationist practices or when they are compared to monocultures (Ghanbari et al., 2010).

Combined with the practice of intercropping, the use of irrigation increases the heat flux in the soil–atmosphere system, thus reducing soil heating, especially of the soil without cover with irrigation, which has a high calorific capacity of water in relation to the soil without cover and no irrigation (Ribas et al., 2015). The interaction between intercropping cultivation and irrigation generates water savings, with numerous advantages, such as higher crop yield, reduced soil water evaporation, increasing soil moisture, providing greater water availability for crops, and regulating the thermal amplitude of the soil (Blanco et al., 2011; Barbieri et al., 2019).

Green manures, such as crotalaria, when intercropped with maize, can be sown simultaneously with the maize crop or approximately 10 to 20 days after maize emergence (Souza et al., 2019). Thus, knowing the effect of different sowing times of crotalaria intercropped with maize on the dynamics of soil temperature and moisture, under irrigation and nonirrigation conditions, becomes an increasingly important factor in planning and in the management of irrigated agricultural crops, mainly for maize, due to the great impact this has on the country's economy, as it is one of the most exploited commodities in relation to Brazilian agriculture.

In view of the above, this study aims to evaluate the influence of different sowing times of crotalaria in an intercropping system with irrigated and non-irrigated off-season maize on the variability of soil temperature and moisture.

2. Material and Methods

2.1 General Description

The study was developed in the experimental field at the State University of Mato Grosso (UNEMAT), Campus Professor Eugênio Carlos Stieler, at the Centro Tecnológico de Geoprocessamento e Sensoriamento Remoto (CETEGEO-SR). According to the Köppen Climate Classification System, the climate in the municipality of Tangará da Serra, Mato Grosso, Brazil is megathermal or tropical with winter drought (Aw), comprising the dry season, between May and September, and a rainy season from October to April with average annual precipitation, average temperature, and relative humidity of 1,830 mm, 24.4 °C and 70-80%, respectively (Dallacort et al., 2011; Souza et al., 2013). The type of soil in the region is dystroferric Red Latosol with a very clayey texture (Santos et al., 2018a) or Oxisol (SOIL SURVEY STAFF, 2014).

Next to the experimental field is an automatic meteorological station with equipment from Campbell Scientific Inc., installed in the geographic coordinates 14°65’00” S, 57°43’15” W, with an elevation of 440 meters, from which the necessary meteorological data were obtained and used to estimate the reference evapotranspiration (ETo), calculated by the Penman–Monteith method - FAO 56 (Allen et al., 1998). ETo was used to determine when and how much to irrigate according to the Kc values of the maize crop for each stage of plant development (Andrea et al., 2019). The weather station has a Datalogger (CR1000, Campbell Scientific Inc., USA) programmed to collect data every 30 seconds and store the average in 15 minutes, sensor CS215 for air temperature (°C) and relative humidity (%); atmospheric pressure sensor (kPa) barometer CS106 that measures the range from 500 to 1100 mb; solar radiation sensor (MJ m^{-2} d^{-1}) - CMP3 pyranometer; speed sensor (m s^{-1}) and wind direction (degrees) - 03002-R. M anemometer, Young Wind and TB4 rain gauge.

2.2 Experimental Design

The experimental design adopted was a double factorial (System x Treatment) in a strip scheme consisting of two strips, one irrigated and the other without irrigation, so that the experiment consisted of twelve treatments and four replications (2 systems x 6 treatments). The treatments consisted of different sowing times of crotalaria intercropped with the maize crop, including single crop maize (MS); sowing of crotalaria simultaneous with maize (MCS); sowing of crotalaria with maize in the VE stage (MCVE); sowing of crotalaria with maize in the V2 stage (MCV2); sowing of crotalaria with maize in the V4 stage (MCV4); and sowing of crotalaria with maize in the V6 stage (MCV6), in irrigated and non-irrigated systems (Table 1). The stages of development of the maize crop were defined according to the scale proposed by Ritchie et al. (1993).

Table 1. Sowing and harvesting schedule of maize and crotalaria according to treatments

Treatments	Maize sowing date	Crotalaria sowing date	Crotalaria sowing time	Crotalaria emergency	Crotalaria DAS at harvest	Maize and crotalaria harvesting
MS	03/07/2020	--	Single maize	--	--	07/03/2020
MCS	03/07/2020	03/07/2020	Simultaneous with maize	03/12/2020	118	07/03/2020
MCVE	03/07/2020	03/14/2020	Maize in VE stadium	03/19/2020	111	07/03/2020
MCV2	03/07/2020	03/19/2020	Maize in V2 stadium	03/24/2020	106	07/03/2020
MCV4	03/07/2020	03/23/2020	Maize in V4 stadium	03/28/2020	102	07/03/2020
MCV6	03/07/2020	03/27/2020	Maize in V6 stadium	04/01/2020	98	07/03/2020

Note. DAS = days after sowing. VE: Maize emergence stage. V2, V4 and V6: Maize plants with two, four and six expanded leaves, respectively.

2.3 Installation, Conduction and Irrigation

A maize hybrid (*Zea mays* L.) of the early cycle (LG36790 PRO3) was used, with 5 plants per meter spaced by 0.90 m between rows, totaling 55,555 plants per hectare, where crotalaria (*Crotalaria spectabilis* Roth.) was sown between the rows of the maize crop, according to the treatments mentioned above, in the recommendation of 30 plants per its meter. The crop treatments were carried out in accordance with the recommendations for both crops (Cruz et al., 2008; Garcia and Staut, 2018).

Fertilization was carried out according to the soil analysis (Table 2). The base fertilization consisted of 500 kg ha^{-1} of NPK mineral fertilizer, formula 5-25-15, applied in the seeding line. Two applications of nitrogen (N) were carried out in coverage, totaling 200 kg ha^{-1} de N, in the urea form, the first when the maize was at stage V4 (10 days after emergence - DAE) and the second in stage V7 (17 DAE) of development. Crotalaria cropping was conducted without fertilization.

Table 2. Chemical and physical characteristics of the soil at a depth of 0-20 cm in the experimental field of the State University of Mato Grosso before carrying out the experiment

Chemical characteristics

Sample	pH	P	K	Ca	Mg	Al	H	SB	CEC	V	OM
	H_2O	mg dm^{-3}		------------------ cmol$_c$ dm^{-3} ------------------						%	g dm^{-3}
Irrigated area	6.1	2.7	68.4	2.0	1.0	0.0	3.1	3.1	6.3	50.2	21.2
Non-irrigated area	5.8	1.7	50.4	2.2	1.1	0.0	3.5	3.5	7.0	49.8	22.2

Physical characteristics

Sample	Sand	Silt	Clay
	g kg^{-1}		
Irrigated area	291.6	89.3	619.1
Non-irrigated area	307.0	89.0	604.0

Note. Plante Certo Laboratory - Analysis of: Soil, Limestone, Water, Nematode, Fertilizer, Animal Food, Salt and Leaf Tissue LTDA. Várzea Grande, Mato Grosso, Brazil. SB = sum of bases; CEC = cation exchange capacity; V = percentage base saturation; OM = organic matter.

The intercropping maize sowing systems were subjected to two irrigation systems, one under irrigation and the other without irrigation. In the irrigated system, the irrigation system used was a sprinkler consisting of twelve sprinklers (Eco 232 Frabrimar, Brazil) with 4.0 x 2.8 mm nozzles spaced 12 x 12 meters apart, with a Christiansen uniformity coefficient greater than 80%, under a pressure of 30 m.c.a., providing an applied water depth of 10.38 mm h^{-1}. The useful area of each treatment was 129.6 m^2 in each irrigation system, and with the border area, the total area of the experiment was 4,665.6 m^2 (Figure 1).

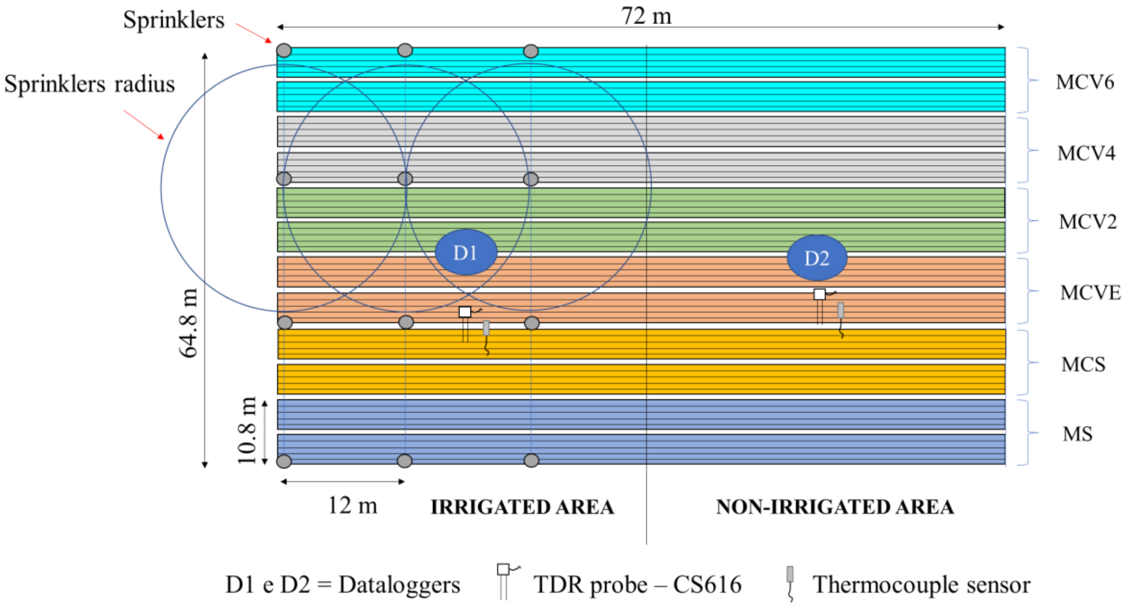


Figure 1. Sketch of the experiment, containing the two irrigation systems and the treatments

The irrigation blade was determined by calculating the reference evapotranspiration (ETo) (Allen et al., 1998) and divided by the efficiency of the irrigation system to determine the total availability of water in the soil (field capacity – 0.3490 m^3 m^{-3}; permanent wilting point – 0.2083 m^3 m^{-3}; $Z_{rad.}$ - 50 cm; e $Factor_{av.}$ - 50), obtaining the net irrigation blade and the gross irrigation blade according to Equations 1 to 5. The values of field capacity (FC) and permanent wilting point (PWP) were obtained through samples sent to the Instituto Agronômico de Campinas (IAC), according to the methodology of Camargo et al. (2009).

$$ETc = ETo * Kc \tag{1}$$

$$SWA = (FC - PWP) * Bd / 10 \tag{2}$$

$$ASW = SWA * Factor_{av.} \tag{3}$$

$$NIB = ASW * Z_{rad.} \tag{4}$$

$$GIB = NIB / Se \tag{5}$$

where ETc is the crop evapotranspiration (mm), ETo is the reference evapotranspiration (mm), Kc is the crop coefficient, SWA is total soil water availability (mm cm^{-1}), FC is field capacity (%), PWP is permanent wilting point (%), Bd is soil bulk density (g cm^{-3}), ASW is available soil water (mm), and $Factor_{av.}$ is a factor in the availability of water in the soil, NIB is the net irrigation blade, and $Z_{rad.}$ is the effective depth of the root system in phase (cm), GIB is the gross irrigation blade, and Se is the system efficiency (decimal).

2.4 Soil Temperature and Moisture Sensors

From the elevation of soil moisture to field capacity after sowing, soil temperature was monitored with sensors installed vertically in the soil in the central area of each treatment at depths of 10, 20, 30 and 40 cm. To measure the soil temperature, K-type thermocouple sensors were used, made of copper and aluminum, joined at one end, wrapped in an aluminum capsule, and sealed with resin and self-fusion tape to protect them against oxidation. Soil temperature values were expressed in °C.

To monitor soil moisture, time-domain reflectometry probes (TDR), CS-616 type (Campbell Scientific Inc., USA) were used, installed in the soil profile at a depth of 20 cm, in the center of each treatment, horizontally, obtaining an average of the soil moisture at this depth, with an accuracy of ±0.01 m^3 m^{-3} (CAMPBELL SCIENTIFIC, 2015). The probes were previously calibrated and measured in the laboratory, and the soil moisture values obtained by the TDR probes were adjusted by the equation proposed by Vasconcelos et al. (2018), where the quadratic equation best fits the data relating soil temperature with soil moisture. Soil moisture data were expressed in volumetric moisture (m^3 m^{-3}).

The sensors used to measure the soil temperature and moisture were connected to a multiplexer board connected to a Datalogger (CR1000, Campbell Scientific Inc., USA), programmed to take a reading every 5 seconds and store the collected data at 15-minute intervals, storing the average hourly values. These data were obtained between March 14 and July 3, 2020 (1 to 112 days after plant emergence – DAE), were separated in Microsoft Excel® software spreadsheets and analyzed the daily and hourly values of the temperature and average soil moisture, evaluating its behavior for each treatment and for the irrigated and non-irrigated systems.

For a better understanding of the variations in soil temperature and moisture during the experimental period, the crop cycle was divided into 4 phases: initial (I): from sowing to 10% soil cover (sowing to V3 – 1 to 15 days after sowing - DAS); development (II): end of the initial phase until the beginning of tasseling (V4 to V14 – 16 to 42 DAS); intermediate (III): the beginning of tasseling until the beginning of grain maturation (VT to R5 – 43 to 95 DAS); and final (IV): from the beginning of maturation to harvest (R6 until harvest – 110 to 118 DAS), according to the methodology described by Ritchie et al. (1993) and Allen et al. (2006).

2.5 Harvest and Statistical Analysis

Maize harvest was carried out on July 03, 2020, completing the cycle 118 days after sowing (DAS) and 112 days after emergence (DAE). The yield (kg ha^{-1}) of the maize crop was evaluated. On the same day as maize harvest, green mass production and dry mass production (kg ha^{-1}) were evaluated in the crotalaria crop, according to the treatments and irrigated and non-irrigated systems.

The soil temperature values in the 10 cm layer and the soil moisture values in the 20 cm layer among the systems and treatments were subjected to analysis of variance (ANOVA) using the F test, with the means compared using the Tukey test at 5% probability. For data analysis, the computer programs Sisvar version 5.8 (Ferreira, 2011) and SigmaPlot version 12.0 were used (SYSTAT SOFTWARE, 2021).

3. Results and Discussion

3.1 Meteorological Elements

The cultivation period was 118 days after sowing (DAS) between March 07, 2020 and July 03, 2020. The average temperature and relative humidity of the air during this period were 24.13 °C and 78.07%, respectively. During the period of the experiment, the precipitation and irrigation values were 336.05 and 533.89 mm, respectively, totaling a volume of 869.94 mm, and the average incidence of solar radiation was 17.37 MJ m^{-2} d^{-1} (Figure 2). The irrigation shown in Figure 2 was carried out only in the treatments in the irrigated system.

Considering the ecophysiology of maize and crotalaria and the meteorological conditions existing in the experimental period, it can be said that there were no periods of thermal or water stress, causing good development and production of the crop even in the system that did not have water supplementation with the practice of irrigation. During the entire cycle, the maize crop needs between 350 and 800 mm of water for its development to occur at its maximum productive potential and for there to be no loss of productivity and the need for complementary irrigation, with the ideal precipitation being approximately 500 and 800 mm (Francisco et al., 2017). These values can vary according to the place of cultivation and sowing time, and studies show that the water requirement of maize varies between 200 and 400 mm for the complete cycle (Bergamaschi et al., 2006).

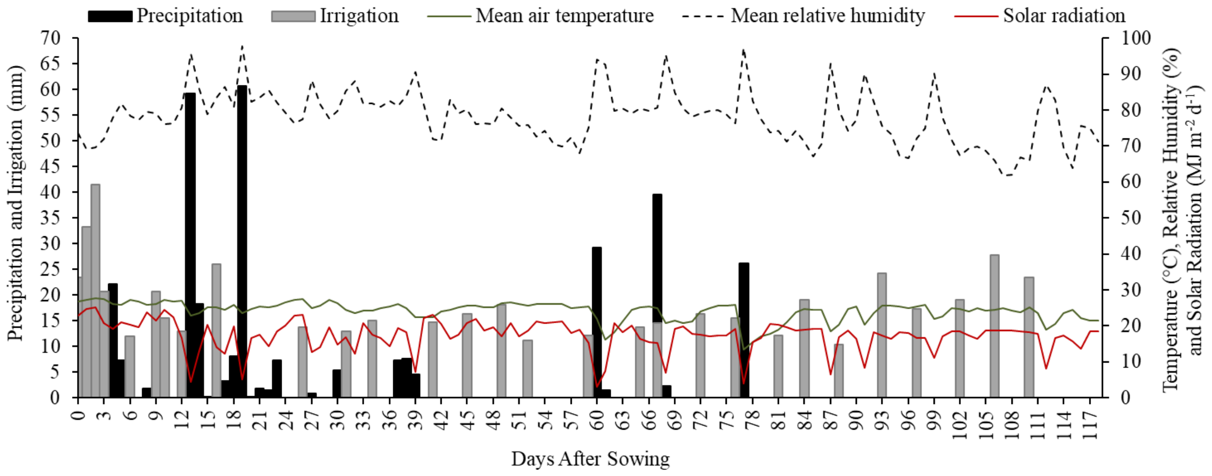


Figure 2. Daily values of precipitation, irrigation, air temperature, relative humidity and solar radiation during the experimental period (March 07, 2020 to July 03, 2020) in Tangará da Serra, Mato Grosso, Brazil

Barbieri et al. (2020), studying maize crops in the same region and time of year, mention that maize in a single cropping system has a water demand of 335.94 mm throughout the cycle, with a daily average of 3.40 mm d^{-1}. In an intercropping system, studies show that maize has an average evapotranspiration demand between 315.00 and 420.00 mm during an average cycle of 110 to 115 days, with greater water demand compared to single maize (Araújo et al., 2017). The ideal temperature range for the development of the maize crop is 19 to 34 °C, with limits between 10 and 34 °C, so temperatures below 10 °C and above 34 °C damage the development capacity of the maize crop (Cruz et al., 2008; Francisco et al., 2017). For the experimental conditions and the maize cultivar used, the crop cycle in single and intercropped cultivation was 118 DAS. Most maize hybrids have an average cycle between 110 and 140 days, but this cycle depends on the hybrid chosen and the climatic and soil conditions in each region.

In Figure 3, the hourly average values of air temperature, relative humidity, solar radiation, and wind speed for the period of the experiment are shown. It can be seen that relative humidity is inversely proportional to air temperature and global solar radiation during the day. It is notorious that the variability of the hourly average values for the period from March 07, 2020 to July 03, 2020 is that at sunrise, where the incidence of global solar radiation starts at 7:00 a.m. The humidity starts to reduce its potential between the hours of 10:00 a.m. to 3 p.m., the maximum point of solar radiation occurs (2.57 MJ m^{-2} at 12 a.m.), maximum point of air temperature (29.05 °C at 3 p.m.) and the minimum humidity point (64.90% at 3:00 p.m.).

Solar radiation is the main phenomenon that triggers the process of influencing other climatic variables, as the radiant energy that reaches the Earth's surface, in addition to promoting soil water evaporation, is also used in the convection process, related to air heating, and in the heat conduction, used in soil heating, significantly influencing the soil temperature, which is responsible for the temperature variations in these media (Pereira et al., 2002).

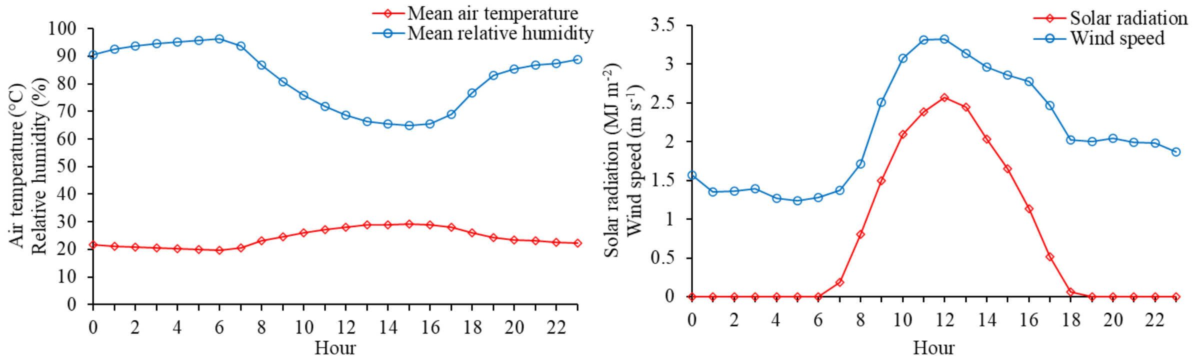


Figure 3. Hourly average values of air temperature, air relative humidity, solar radiation and wind speed for the experimental period (March 07, 2020 to July 03, 2020) in Tangará da Serra, Mato Grosso, Brazil

3.2 Soil Temperature

The hourly variation in soil temperature can be observed at depths of 10, 20, 30 and 40 cm throughout the crop cycle for treatments used in irrigated and non-irrigated systems (Figures 4 and 5). It is observed that the variation in soil temperature is greater at a depth of 10 cm, so that at greater depths (20, 30 and 40 cm), the variation in the values found is smaller.

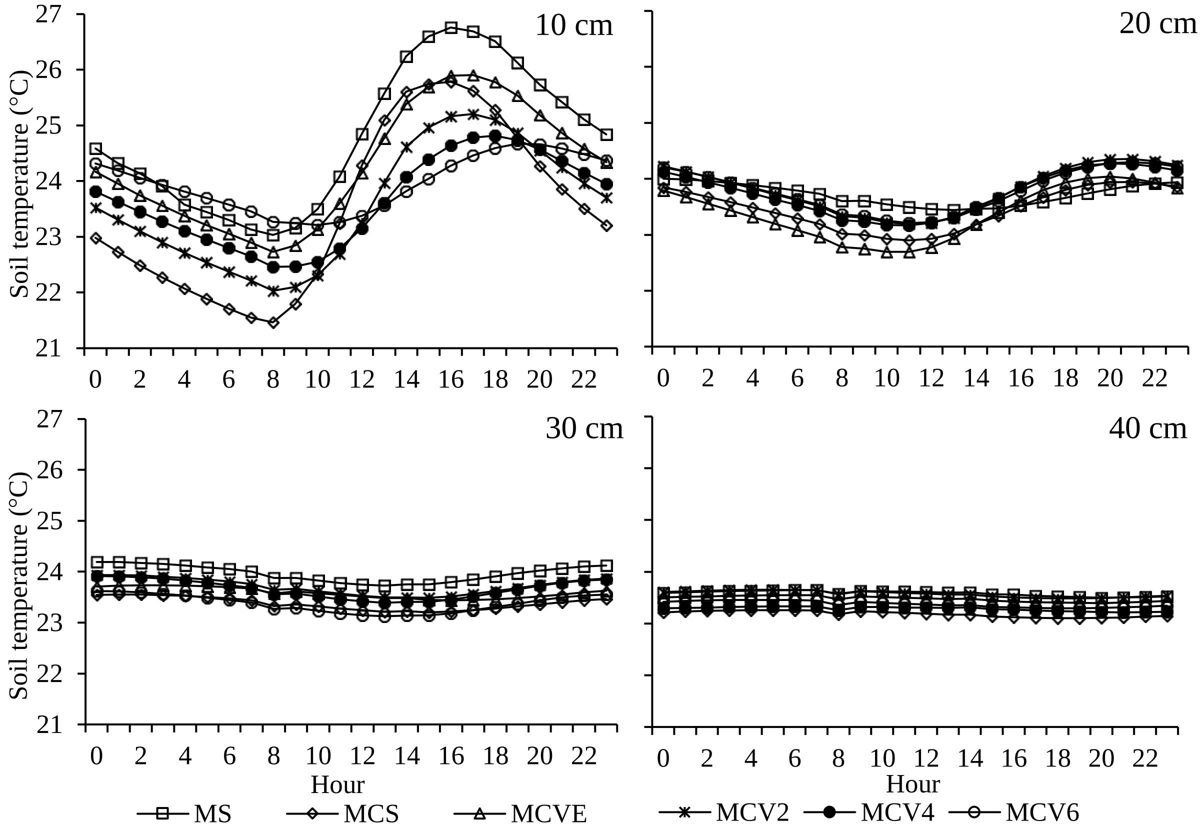


Figure 4. Hourly variation in mean soil temperature at different depths (10, 20, 30 and 40 cm) for each treatment in an irrigated system

At a depth of 10 cm, the greatest variations in soil temperature during the day were observed. The minimum and maximum temperature peaks occur between 07:00 and 09:00 a.m. and between 2:00 and 7:00 p.m. of the day, respectively, for both irrigated and non-irrigated systems (Figures 4 and 5). This same behavior of soil temperature at these times of day was observed in other studies with intercropped maize (Yin et al., 2016; Yin et al., 2020). Regarding the intercropping of maize with *C. spectabilis*, the behavior of soil temperature was similar to that of the intercropping of maize with other crops, with lower soil temperature values at the beginning of the day (8:00 a.m.) and higher values from approximately 5:00 p.m., mainly in more superficial layers, where there is greater variability (Barbieri et al., 2019; Trevisan, 2019).

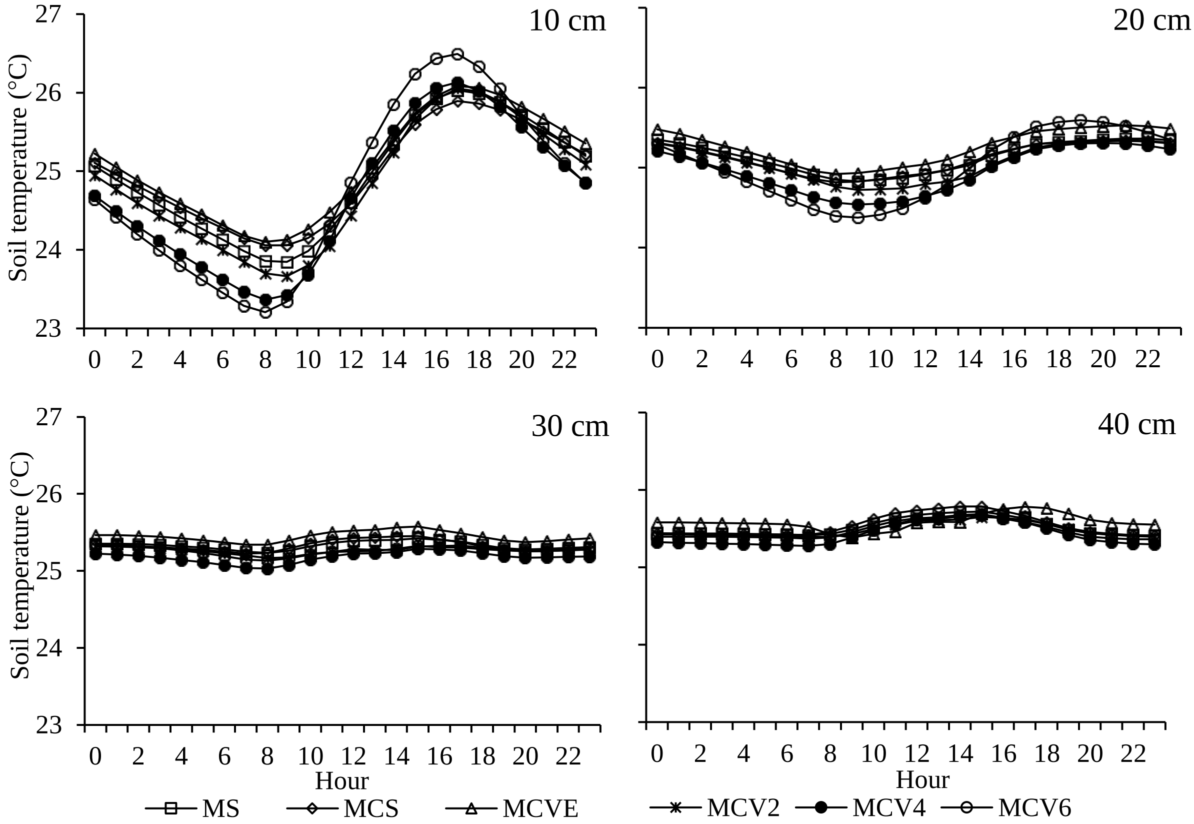


Figure 5. Hourly variation in mean soil temperature at different depths (10, 20, 30 and 40 cm) for each treatment in a non-irrigated system

The highest soil temperature was observed in the treatment of single maize (MS) at a depth of 10 cm, with an average of 26.76 °C at 04:00 p.m. in an irrigated system (Figure 4). For the non-irrigated system, the treatment of maize intercropped with crotalaria (MCV6) had the highest temperature of 26.49 °C at 5:00 p.m. at a depth of 10 cm (Figure 5). The minimum soil temperature during the 24 hours of the day was recorded in the treatment of sowing of crotalaria simultaneous with maize (MCS), with 21.46 °C at 8:00 a.m. in an irrigated system. In the non-irrigated system, the MCV6 treatment presented a lower soil temperature at 8:00 a.m. at 23.21 °C.

For the treatment with the sowing of crotalaria with maize at the emergency stage (MCVE), the maximum soil temperature was 25.90 °C at 5:00 p.m. and a minimum 22.73 °C at 8:00 a.m.. Treatments with the sowing of crotalaria with maize in stages V2, V4 and V6 showed maximum soil temperatures of 25.20, 24.81 and 24.67 °C at 5:00, 6:00 and 7:00 p.m., respectively, and minimal temperatures at 8:00, 9:00 and 10:00 a.m. at 22.03, 22.46 and 23.21 °C, respectively. However, it should be noted that the coverage generated by intercropping crops, in addition to reducing the maximum soil temperature, presents a lower minimum soil temperature at all depths.

The greatest variations and the greatest soil temperature values, as was to be expected, occurred in single maize (MS), as there is only one crop, decreasing the leaf area index (LAI) of that cultivation area and consequently the shading on the soil, with a higher incidence of solar rays and thus providing heat to the soil, increasing its temperature. The efficiency of radiation use is directly influenced by the LAI (Ferreira Junior et al., 2014). Oliveira et al. (2005) mention that the nature of the soil cover and the level of shading caused by the amount of foliar cover existing on the soil directly influence its temperature fluctuations. The shading caused by the aerial part of intercropped crops reduces the incidence of radiation, increasing the interception of incident solar radiation and reducing the amount of energy that reaches it, directly influencing the absorption of energy used for soil water evaporation and delaying soil heating.

At 20, 30 and 40 cm in depth, there was a smoothing of the temperature variation in all evaluated treatments; however, the highest averages were observed in single maize (Figure 4), and in the non-irrigated system, this smoothing was even greater, not differentiating the temperatures between treatments (Figure 5). Soil temperature variations tend to decrease with increasing sampling depth (Oliveira et al., 2005). At greater depths in the soil profile, phenomena such as conduction and convection are able to transfer and retain heat, but this heat transfer is a slow phenomenon, which causes a delay in soil heating at greater depths, hence the lower variability of temperature in larger layers (Kojima et al., 2018; Trevisan, 2019). In this experiment, we can observe the delay in soil heating at depths greater than 20 cm, in agreement with the results obtained by the authors.

The maximum temperature observed at a depth of 20 cm reached 24.28 °C at 08:00 p.m., that is, the maximum temperature of the soil occurred in a delayed manner to the soil profile in an intercropped maize system when irrigation was used in the cultivation. For depths of 20, 30 and 40 cm, the thermal amplitude of the soil is reduced as expected, a behavior observed in other studies, proving these dynamics of the soil temperature at greater depths (Awe et al., 2015; Oliveira et al., 2019).

When maize was cultivated in an irrigated intercropping system, the soil temperature for single maize was reduced by 1.3, 0.26, 0.59 and 0.4 °C at depths of 10, 20, 30 and 40 cm, respectively, compared with that cultivated in a non-irrigated system. The average hourly soil temperatures for the irrigated system were lower than for the non-irrigated system because the irrigations were carried out at times always after 6 p.m., a time when soil temperatures are at high values. In this study, there was a reduction of 1.22 °C in the irrigated system when compared to the system without irrigation for single maize and of 1.86 °C for maize cultivated intercropped with crotalaria. This greater reduction in soil temperature in the intercropped maize is because in the intercropped system, the soil moisture is higher. The higher the soil moisture value is, the greater the contact between the particles and the mass flow, increasing the thermal conductivity (Kojima et al., 2018).

The thermal amplitude of the soil temperature can be verified at the depths evaluated as a function of the treatments and irrigation systems (irrigated and non-irrigated) evaluated (Figure 6).

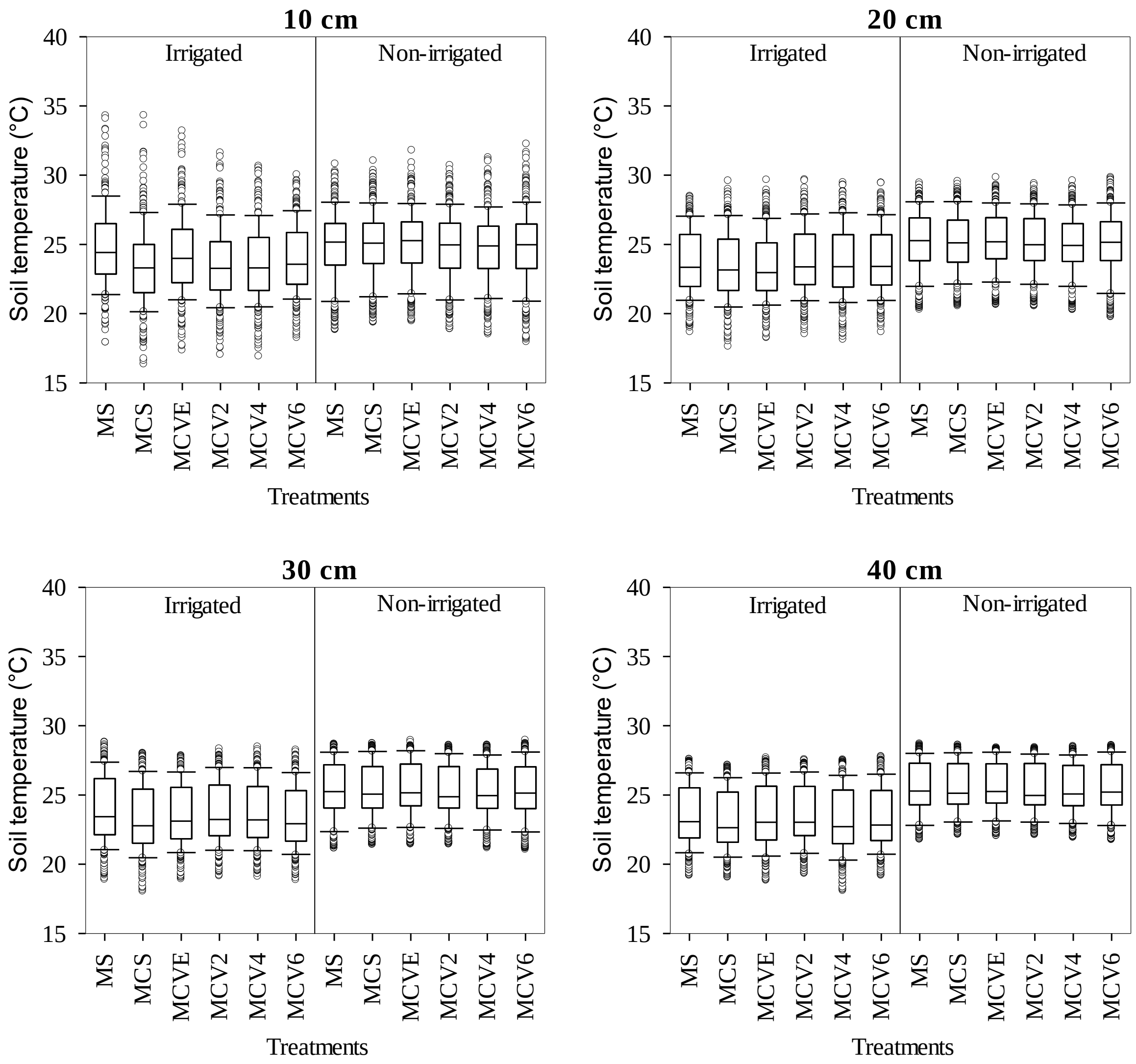


Figure 6. Hourly variation in soil temperature values at different depths (10, 20, 30 and 40 cm) for treatments used in irrigated and non-irrigated systems

The treatment of single maize presented a greater range of soil temperature, as it does not provide plant coverage and protection against solar radiation, when compared to treatments with the use of intercropping with crotalaria, as in this case, the presence of two crops causes a range of lower soil temperature due to greater soil coverage, a consequence of greater shading made by the aerial part of the plants of the two species together.

The amplitude of soil temperature was smaller in a non-irrigated system at all evaluated depths. With the increase in depth, there was a considerable decrease in the thermal amplitude in all treatments, especially at 30 and 40 cm, so that the treatments in the non-irrigated system had lower thermal amplitudes at these depths (Figure 6).

It is important to note and understand that the intercropping system does not reduce its temperature but rather reduces the thermal amplitude; that is, the coverage made by the greater amount of aerial part of the two crops promotes lower temperatures on hot days and higher temperatures on cold days compared with soil without this greater coverage made by the larger amounts of aerial part of the crops involved in the intercropping.

In an irrigated system, temperatures were lower than those in a system without irrigation. This reduction in soil temperature was caused by the fact that irrigations are carried out in the late afternoon, where the soil temperature presents high values, and when irrigating in this period, there is a reduction in the thermal amplitude when compared to the non-irrigated system.

The average soil temperature suitable for sowing maize should be above 15 °C, ideally above 18 °C for a rapid emergence of plants, with a uniformly high temperature (Fancelli, 2015). These soil temperature conditions, combined with moisture close to field capacity, enable the normal triggering of germination and emergence processes (Fancelli, 2015).

Soil temperature is related to the processes that involve the interaction that takes place between soil and plants (Gasparim et al., 2005). Very high soil temperatures, above 42 °C, negatively affect seedlings and roots, promoting changes in the metabolism of soil biota (Zhou et al., 2013; Heinze et al., 2017) and significantly affecting soil water evaporation (Chen et al., 2007). Irrigation can cause an average reduction of up to 6 °C in the maximum soil temperature, reducing the thermal amplitude of this soil and changing the soil thermal regime, especially in more superficial soil layers, when compared to soils without irrigation (Ribas et al., 2015).

Soil temperature showed significance between the system and treatment only for a depth of 10 cm. For the other depths (20, 30 and 40 cm), there was only significance in isolation for the sources of variation. Statistically analyzing the irrigated and non-irrigated systems as a function of crop stages, it is noted that temperatures are higher in the initial phase, mainly due to the low leaf area index (LAI) of the crop in this phase (Table 3).

Regarding the irrigated system, temperatures were lower in the development, intermediate and final phases, and there was no significant difference in the initial phase between the systems. This is because in the initial phase there is a low LAI and because the irrigations were carried out at times after 6 p.m., providing a reduction in soil temperature (Table 3).

In the initial, development and final phases, the soil temperature between treatments did not show significant differences; only in the intermediate phase was there a difference in soil temperature between the treatments, and the single maize treatment did not differ from the MCS treatment and did not show higher values compared to other treatments.

Table 3. Average soil temperature for the irrigated and non-irrigated systems at each stage of the single maize crop and intercropped with crotalaria according to the treatments used (sowing times of crotalaria intercropped with maize) at 10 cm depth

Factors	Soil temperature - 10 cm (°C)				Mean square
Systems (S)	Initial	Development	Intermediate	Final	
Irrigated	27.25aA	26.40bB	22.68cB	22.25cB	278.31**
Non-irrigated	27.93aA	27.08bA	23.55cA	24.78dA	203.82**
Mean square	11.03^{ns}	43.07**	37.75**	146.16**	--
Treatments (T)	Initial	Development	Intermediate	Final	Mean square
MS	26.77aA	27.19aA	23.77bA	23.95bA	183.38**
MCS	27.65aA	26.48bA	22.91cB	23.34cA	237.29**
MCVE	28.01aA	27.11aA	23.32bAB	23.67bA	257.88**
MCV2	27.54aA	26.49aA	22.87bB	23.33bA	237.60**
MCV4	27.74aA	26.46aA	22.83bB	23.26bA	249.36**
MCV6	27.83aA	26.69bA	23.01cB	23.54cA	246.86**
Mean square	2.97^{ns}	6.69^{ns}	13.21**	3.20^{ns}	--
T x S	Irrigated		Non-irrigated		Mean square
MS	24.78aA		25.15aA		7.97^{ns}
MCS	23.49bC		25.16aA		157.32**
MCVE	24.27bAB		25.28aA		57.33**
MCV2	23.56bC		25.04aA		121.66**
MCV4	23.63bBC		24.92aA		92.62**
MCV6	23.96bBC		25.00aA		61.35**
Mean square	28.05**		1.89^{ns}		--

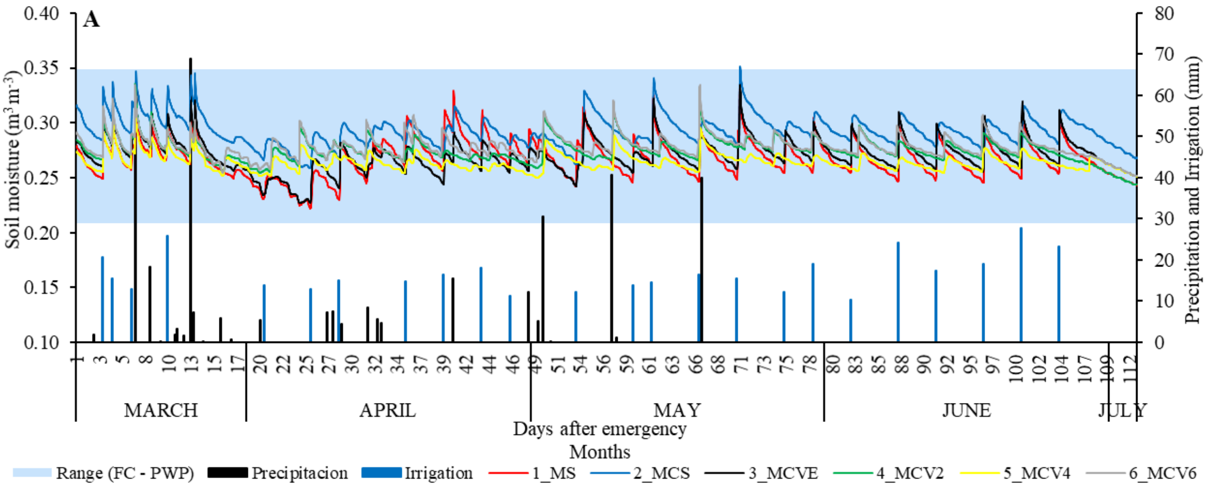
Note. Means followed by the same lowercase letter in the lines and uppercase in the columns do not differ statistically by the Tukey test at the 5% probability of error. ^{ns} = not significant; * = significant at 5% probability by F test; ** = significant at 1% probability by F test. Phases: Initial (I): from sowing to 10% soil cover (sowing to V3 – 1 to 15 days after sowing - DAS); Development (II): end of the initial phase until the beginning of tasseling (V4 to V14 – 16 to 42 DAS); Intermediate (III): the beginning of tasseling until the beginning of grain maturation (VT to R5 – 43 to 95 DAS); Final (IV): from the beginning of maturation to harvest (R6 until harvest – 110 to 118 DAS).

The treatments of single maize and crotalaria sown in intercropping at the VE, V2 and V4 maize stages showed significantly higher soil temperatures in the initial and development phases compared to the intermediate and final phases. For the treatments in which crotalaria was sown in intercropping on the same day as maize (MCS) and at maize stage V6 (MCV6), the soil temperature was higher only in the initial phase.

In the comparison between the system and treatment, analyzing irrigation as a source of variation, it is noted that for the non-irrigated system, the soil temperature did not differ between treatments. In the irrigated system, there was a difference between treatments, as single maize presented higher values, with no significant differences between the MCVE treatment and the latter not differing from the MCV4 and MCV6 treatments.

3.3 Soil Moisture

The values of irrigation, precipitation and volumetric soil water content ($m^3\ m^{-3}$) throughout the cycle in the treatments used in irrigated and non-irrigated systems are shown in Figure 7. The soil in the study region presents moisture in the field capacity and permanent wilting point in the values of 0.3490 and 0.2083 $m^3\ m^{-3}$, respectively.



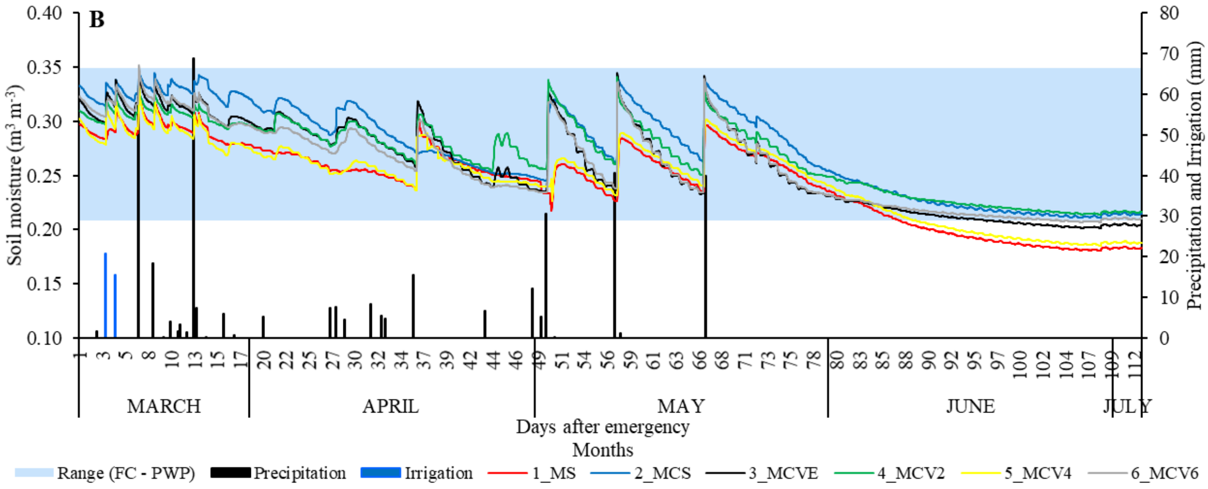


Figure 7. Irrigation, precipitation and average soil moisture during the experiment (March 14, 2020 and July 03, 2020 - 1 to 112 days after emergence - DAE) for the treatments evaluated in the irrigated system (A) and non-irrigated system (B). FC = field capacity; PWP = permanent wilting point

For the variation in soil moisture, it was verified that the treatment with the sowing of crotalaria simultaneous with maize (MCS) presented the highest values in relation to the other treatments (Figure 7). The soil moisture values for each treatment in irrigated and non-irrigated systems show that there is a difference between the treatments within the systems, where in the treatment with single crop maize (MS), the soil moisture presented a lower value.

It is noted that at the average depth of 20 cm, the variation in soil moisture between the systems remains close to 0.275 m^3 m^{-3} in all treatments in the irrigated system (Figure 7A) and close to 0.265 m^3 m^{-3} in the system without supplementary irrigation (Figure 7B). During the crop cycle, that is, when analyzing all treatments within the irrigated and non-irrigated systems, it is noted that in the irrigated system, the soil moisture was higher by 0.010 m^3 $m\text{-}^3$ in relation to the system without irrigation. In the system with complementary irrigation, soil moisture did not reach field capacity in any treatment or at any time of the experiment (Figure 7A). In the non-irrigated system, the MS and MCV4 treatments reached field capacity from 85 DAS, and the MCVE treatment reached field capacity from 95 DAS (Figure 7B).

The treatment with the sowing of crotalaria simultaneous with maize (MCS) did not reach field capacity, even in the system without complementary irrigation. Thus, it can be observed that with the use of crotalaria intercropping systems such as maize crops, even if there is a lack of rain from halfway to the end of the cycle, the soil moisture will not reach field capacity, with water available for plants. This is because there is a higher leaf area index (LAI) provided by the two intercropped crops, with less soil water evaporation.

With the suspension of irrigation in the irrigated system on the final days of the experiment, where the maize crop is in the senescence phase, the soil water content for the MCS treatment remains superior to the other systems, which is explained by the fact that the crop of crotalaria is in the full reproductive stage, that is, with greater LAI, so for these systems, the soil moisture is greater (Figure 7A). In the system without irrigation, this behavior is observed when the rains stop in the region (Figure 7B).

Soil moisture was lower for single maize (MS) in the two evaluated systems (with and without irrigation), as it had only one planted crop, and greater evaporation of soil water may have occurred (Figure 8).

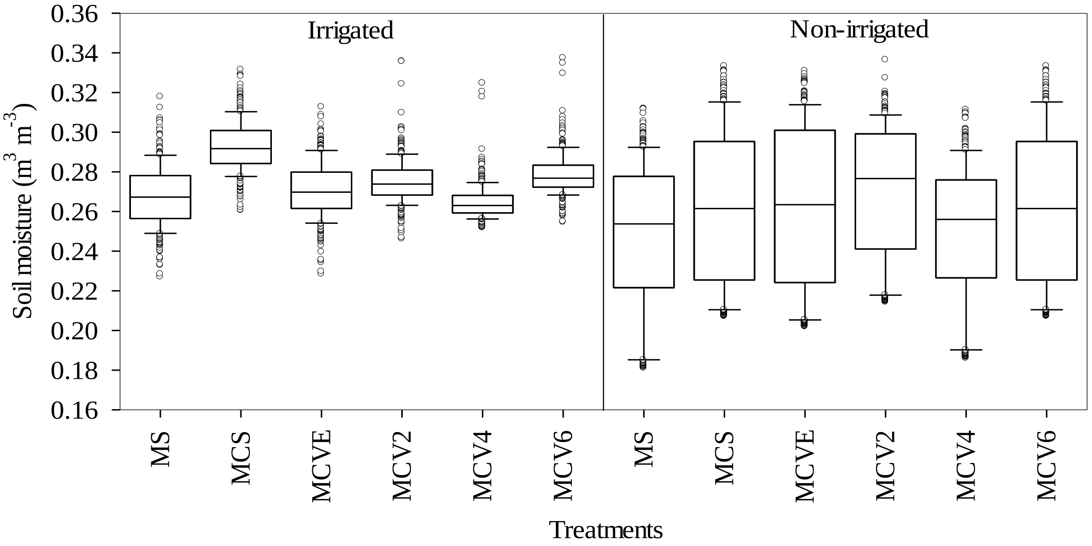


Figure 8. Variation in mean soil moisture values for treatments evaluated in irrigated and non-irrigated systems

In the system without irrigation, the variability in soil moisture was greater than that in the irrigated system during the experiment. This happened due to the great variability that occurred during the cycle, where in the system without irrigation, at the beginning of the crop cycle, the humidity values were higher in relation to the end of the cycle, where the rains in the region were interrupted.

Analyzing the soil moisture between the systems with and without irrigation, there was a significant difference between the crop stages (Table 4). For both systems, the initial phase had the highest soil moisture values. This is because in the development and intermediate phases, the evapotranspiration rate of crops is higher, and thus, the consumption of water by plants is also higher than in the initial phase.

Table 4. Average soil moisture for the irrigated and non-irrigated systems at each stage of the single maize crop and intercropped with crotalaria according to the treatments used (sowing times of crotalaria intercropped with maize) at 20 cm depth

Factors	Soil moisture - 20 cm (m^3 m^{-3})				Mean square
Systems (S)	Initial	Development	Intermediate	Final	
Irrigated	0.282aB	0.271cB	0.277bA	0.272cA	0.003**
Non-irrigated	0.309aA	0.288bA	0.260cB	0.205 dB	0.224**
Mean square	0.017**	0.026**	0.043**	0.304**	--
Treatments (T)	Initial	Development	Intermediate	Final	Mean square
MS	0.283aC	0.266bC	0.260bDE	0.226cC	0.021**
MCS	0.316aA	0.298bA	0.285cA	0.253dA	0.024**
MCVE	0.298aB	0.279bB	0.264cCD	0.239 dB	0.020**
MCV2	0.296aBC	0.283bB	0.274cB	0.244 dB	0.018**
MCV4	0.283aC	0.267bC	0.258cE	0.227dC	0.019**
MCV6	0.301aB	0.283bB	0.268cC	0.243 dB	0.021**
Mean square	0.002**	0.008**	0.018**	0.005**	--
T x S	Irrigated		Non-irrigated		Mean square
MS	0.268aDE		0.246bD		0.027**
MCS	0.292aA		0.276bA		0.016**
MCVE	0.270aCD		0.261bC		0.005**
MCV2	0.275aBC		0.269bB		0.001**
MCV4	0.264aE		0.248bD		0.015**
MCV6	0.278aB		0.260bC		0.018**
Mean square	0.011**		0.015**		--

Note. Means followed by the same lowercase letter in the lines and uppercase in the columns do not differ statistically by the Tukey test at the 5% probability of error. ns = not significant; * = significant at 5% probability by F test; ** = significant at 1% probability by F test. Phases: Initial (I): from sowing to 10% soil cover (sowing to V3); Development (II): end of the initial phase until the beginning of tasseling (V4 to V14); Intermediate (III): the beginning of tasseling until the beginning of grain maturation (VT to R5); Final (IV): from the beginning of maturation to harvest (R6 until harvest).

Regarding the treatments, it is noted that in all stages, the treatment with the sowing of crotalaria simultaneous with maize (MCS) showed higher soil moisture values compared to the others, where in the initial stage all treatments showed significant differences from the other stages due to the pluviometric regime observed at the beginning of the cycle in the system without complementary irrigation and due to the irrigations carried out in the irrigated system.

Analyzing the influence of the systems in the treatments, we noticed that for the two systems (irrigated and non-irrigated), the highest values of soil moisture at 20 cm depth were in the treatment with the sowing of crotalaria simultaneously with maize. The irrigated system presented higher soil moisture values in all treatments than the system without irrigation (Table 4).

For the irrigated and non-irrigated system, the lowest soil moisture was observed for the treatments of maize in a single crop and for the treatments with the last sowing times of crotalaria intercropped with maize, caused by the higher rate of water evaporation from the soil, because at a certain point in the maize crop cycle, it was cultivated in a single system, with greater soil water evaporation.

Studies show that temperature and soil moisture are inversely related, as the heat flux in the soil is affected by the presence of water in it; thus, the soil temperature values due to the presence of moisture in the soil are due to evaporation (Carneiro et al., 2014; Cortez et al., 2015). It is extremely important to know the soil temperature and moisture values at different stages of the crop cycle, and these physical and water attributes of the soil stand out, directly influencing the growth and development of plants (Oliveira et al., 2005; Stefanoski et al., 2013).

Regarding the yield of the maize crop, the irrigated system showed higher productivity values in all treatments compared to the non-irrigated system, highlighting the importance of irrigation in the final productivity of the maize crop, both in single cultivation and in intercropping with the crotalaria. The productivity of the maize for the irrigated system was 11,534.9, 11,790.4, 12,292.7, 12,501.7, 11,623.3 and 11,962.0 kg ha^{-1} for the MS, MCS, MCVE, MCV2, MCV4 and MCV6 treatments, respectively. In the non-irrigated system, the maize yield was 7,561.3, 7,691.1, 9,310.1, 8,989.3, 9,189.0 and 9,701.9 kg ha^{-1} for the MS, MCS, MCVE, MCV2, MCV4 and MCV6 treatments, respectively.

The sowing times of crotalaria intercropped with maize considerably affect the crotalaria crop. When crotalaria is sown simultaneously with the maize crop, it presents higher values of characteristics compared to when intercropping sowing is delayed, affecting the green mass and dry mass final production. The final green mass production (GMP) of crotalaria in an irrigated system was 11,666.2, 7,206.6, 7,193.3, 6,769.8 and 5,719.9 kg ha^{-1} for the MCS, MCVE, MCV2, MCV4 and MCV6 treatments, respectively. In the non-irrigated system, the GMP of crotalaria was 8,694.0, 5,222.8, 5,476.8, 5,245.6 and 5,087.2 kg ha^{-1} for the MCS, MCVE, MCV2, MCV4 and MCV6 treatments, respectively. The dry mass production (DMP) of crotalaria in an irrigated system was 3,932.2, 3,110.8, 3,121.1, 3,020.6 and 2,822.4 kg ha$^{-1,}$ and in the non-irrigated system, it was 3,082.1, 2,220.2, 2,272.2, 2,200.9 and 2,237.0 kg ha^{-1} for the MCS, MCVE, MCV2, MCV4 and MCV6 treatments, respectively.

4. Conclusions

The soil temperature was reduced in the treatments with intercropping, mainly in the intermediate phase of the crops in the treatment with maize and crotalaria cultivated simultaneously. The intercropping of maize with crotalaria provides the soil with a smaller range of soil temperature, with higher values in a system without irrigation compared to an irrigated system. The treatment of single maize presented a greater range of soil temperature when compared to treatments with the use of intercropping with crotalaria.

The variation in soil moisture between the systems remained close to 0.275 m^3 m^{-3} in all treatments in the irrigated system and close to 0.265 m^3 m^{-3} in the system without irrigation, whereas in the irrigated system, the soil moisture was higher by 0.010 m^3 m^{-3} in relation to the system without irrigation. Soil moisture at a depth of 20 cm was lower in the single maize treatment, as it increased soil water evaporation compared to the intercropping treatments.

The irrigated system obtained better results than the non-irrigated system for the maize crop yield and final production of green mass and dry mass of crotalaria. You can opt to carry out the sowing of crotalaria intercropped with maize at any time of sowing analyzed in an irrigated system.

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References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements*. FAO Irrigation and drainage paper 56. Rome, IT: Food and Agriculture Organization of the United Nations.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (2006). *Evapotranspiración del cultivo: Guías para la determinación de los requerimientos de agua de los cultivos*. Estudio FAO Riego y Drenaje, 56. Rome, IT: Food and Agriculture Organization of the United Nations.

Andrea, M. D. S., Vieira, F. F., Dallacort, R., Barbieri, J. D., de Freitas, P. S. L., Tieppo, R. C., ... & Daniel, D. F. (2019). Effect of soil coverage on dual crop coefficient of maize in a region of Mato Grosso, Brazil. *Journal of Agricultural Science*, *11*(13), 143-155. https://doi.org/10.5539/jas.v11n13p143

Araújo, M. S. P. de, Sousa, E. F. de, Pereira, V. R., Ferreira, F. H. A., & Carvalho, D. F. (2017). Evapotranspiration and crop coefficients of corn in monoculture and intercropped with jack bean. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *21*(1), 27-31. https://doi.org/10.1590/1807-1929/agriambi.v21n1p27-31

Arf, O., Meirelles, F. C., Portugal, J. R., Buzetti, S., Sá, M. E. de, & Rodrigues, R. A. F. (2018). Benefits of intercropping corn with grassy and legumes and their effects on yield in no tillage system. *Revista Brasileira de Milho e Sorgo*, *17*(3), 431-444. https://doi.org/10.18512/1980-6477/rbms.v17n3p431-444

Awe, G. O., Reichert, J. M., & Wendroth, O. O. (2015). Temporal variability and covariance structures of soil temperature in a sugarcane field under different management practices in southern Brazil. *Soil and Tillage Research*, *150*(1), 93-106. https://doi.org/10.1016/j.still.2015.01.013

Barbieri, J. D., Dallacort, R., Daniel, D. F., Dalchiavon, F. C., & Freitas, P. S. L. (2020). Soil coverage, evapotranspiration and productivity of off-season corn. *Cultura Agronômica: Revista de Ciências Agronômicas*, *29*(1), 76-91. http://dx.doi.org/10.32929/2446-8355.2020v29n1p76-91

Barbieri, J. D., Freitas, P. S. L. de, Dallacort, R., Zolin, C. A., Daniel, D. F., Fenner, W., & Souza, A. C. S. (2019). Thermal and soil moisture amplitude of intercropped crops. *Journal of Experimental Agriculture International*, *41*(6), 1-13. http://dx.doi.org/10.9734/jeai/2019/v41i630445

Bergamaschi, H., Dalmago, G. A., Comiran, F., Bergonci, J. I., Müller, A. G., França, S., Santos, A. O., Radin, B., Bianchi, C. A. M., & Pereira, P. G. (2006). Water deficit and yield in maize crop. *Pesquisa Agropecuária Brasileira*, *41*(1), 243-249. https://doi.org/10.1590/S0100-204X2006000200008

Blanco, F. F., Cardoso, M. J., Freire Filho, F. R., Veloso, M. E. da C., Nogueira, C. C. P., & Dias, N. da S. (2011). Green maize intercropped with cowpea under different irrigation depths and phosphorus doses. *Pesquisa Agropecuária Brasileira*, *46*(5), 523-529. https://doi.org/10.1590/S0100-204X2011000500010

Camargo, O. A., Moniz, A. C., Jorge, J. A., & Valadares, J. M. A. S. (2009). *Métodos de análise química e física de solos do Instituto Agronômico de Campinas*. Campinas, SP: Instituto Agronômico de Campinas. Embrapa Soja. Documentos, 106. [Online] Available at: http://www.iac.sp.gov.br/produtoseservicos/analisedosolo/docs/Boletim_Tecnico_106_rev_atual_2009.pdf (January 26, 2020).

CAMPBELL SCIENTIFIC. (2015). *Instruction manual: CS616 and CS625 water content reflectometers*. Logan, UT: Campbell Scientific Inc. [Online] Available at: https://s.campbellsci.com/documents/ca/manuals/cs616_625_man.pdf (September 30, 2020).

Carneiro, R. G., Moura, M. A. L., Silva, V. de P. R. da, Silva Junior, R. S., Andrade, A. M. de, & Santos, A. B. dos (2014). Variability of soil temperature as function of litter in fragment of Atlantic Forest remanant. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *18*(1), 99-108. https://doi.org/10.1590/S1415-43662014000100013

Chen, S. Y., Zhang, X. Y., Pei, D., Sun, H. Y., & Chen, S. L. (2007). Effects of straw mulching on soil temperature, evaporation and yield of winter wheat: field experiments on the North China Plain. *Annals of Applied Biology*, *150*(3), 261-268. https://doi.org/10.1111/j.1744-7348.2007.00144.x

Chieza, E. D., Guerra, J. G. M., Araújo, E. da S., Espíndola, J. A., & Fernandes, R. C. (2017). Yield and economic aspects of corn and sunn hemp intercropped in different seeding intervals under organic management. *Revista Ceres*, *64*(2), 189-196.

https://doi.org/10.1590/0034-737X201764020012

Cortez, J. W., Nagahama, H. de J., Olszevski, N., Patrocinio Filho, A. P., & Souza, E. B. de (2015). Soil moisture content and surface temperature in tillage systems and stages of development of maize crop. *Engenharia Agrícola*, *35*(4), 699-710. https://doi.org/10.1590/1809-4430-Eng.Agric.v35n4p699-710/2015

Coser, T. R., Ramos, M. L. G., Figueiredo, C. C. de, Carvalho, A. M. de, Cavalcante, E., Moreira, M. K. dos R., & Oliveira, S. A. de (2016). Soil microbiological properties and available nitrogen for corn in monoculture and intercropped with forage. *Pesquisa Agropecuária Brasileira*, *51*(9), 1660-1667. https://doi.org/10.1590/S0100-204X2016000900066

Cruz, J. C., Karam, D., Monteiro, M. A. R., & Magalhães, P. C. (Eds.). (2008). *A cultura do milho*. Sete Lagoas, MG: Embrapa Milho e Sorgo. (In Brazilian Portuguese).

Dallacort, R., Martins, J. A., Inoue, M. H., Freitas, P. S. L. de, & Coletti, A. J. (2011). Rain distribution in Tangará da Serra, mid-northern Mato Grosso state, Brazil. *Acta Scientiarum. Agronomy*, *33*(2), 193-200. https://doi.org/10.4025/actasciagron.v33i2.5838

Fancelli, A. L. (2015). Cultivo racional e sustentável requer maior conhecimento sobre planta do milho. *Visão Agrícola*, *13*(9), 20-23. (In Brazilian Portuguese).

Ferreira Junior, R. A., Souza, J. L. de, Teodoro, I., Lyra, G. B., Souza, R. C. de, & Araújo Neto, R. A. de (2014). Radiation use efficiency in corn crop in Alagoas. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *18*(3), 322-328. https://doi.org/10.1590/S1415-43662014000300012

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e agrotecnologia*, *35*(6), 1039-1042. https://doi.org/10.1590/S1413-70542011000600001

Francisco, P. R. M., Santos, D., Guimarães, C. L., Araujo, S. R. D., & Oliveira, F. P. de. (2017). Climatic aptitude for corn (*Zea mays* L.) for the Paraíba state. *Revista de Geografia*, *34*(1), 290-305. https://doi.org/10.51359/2238-6211.2017.229254

Garcia, R. A., & Staut, L. A. (2018). *Como inserir crotalária em sistemas de produção de grãos*. Dourados, MS: Embrapa Agropecuária Oeste. Circular Técnica, 44. Available at: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/191614/1/CT-44.pdf (January 01, 2020).

Gasparim, E., Ricieri, R. P., Silva, S. de L., Dallacort, R., & Gnoatto, E. (2005). Temperature in soil profile using two densities of mulching and nude soil. *Acta Scientiarum. Biological Sciences*, *27*(1), 107-115. https://doi.org/10.4025/actasciagron.v27i1.2127

Gerlach, G. A. X., Silva, J. C. da, & Arf, O. (2019). Response of corn in a consortium with green manure in the no-till system. *Acta Iguazu*, *8*(2), 134-146. https://doi.org/10.48075/actaiguaz.v8i2.16938

Ghanbari, A., Dahmardeh, M., Siahsar, B. A., & Ramroudi, M. (2010). Effect of maize (*Zea* *mays* L.) - cowpea (*Vigna unguiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment. *Journal of Food, Agriculture & Environment*, *8*(1), 102-108.

Heinze, J., Gensch, S., Weber, E., & Joshi, J. (2017). Soil temperature modifies effects of soil biota on plant growth. *Journal of Plant Ecology*, *10*(5), 808-821. https://doi.org/10.1093/jpe/rtw097

Kojima, Y., Heitman, J. L., Sakai, M., Kato, C., & Horton, R. (2018). Bulk density effects on soil hydrologic and thermal characteristics: A numerical investigation. *Hydrological Processes*, *32*(14), 2203-2216. https://doi.org/10.1002/hyp.13152

Oliveira, K. A. S. de, Daniel, D. F., Dallacort, R., Barbieri, J. D., Tieppo, R. C., & Araújo, D. V. de (2019). Influence of brachiaria coverage in growing soil temperature with green corn. *Acta Iguazu*, *8*(3), 105-125. https://doi.org/10.48075/actaiguaz.v8i3.20652

Oliveira, M. L. de, Ruiz, H. A., Costa, L. M. da, & Schaefer, C. E. G. R. (2005). Soil temperature and moisture fluctuations in response to vegetation cover. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *9*(4), 535-539. https://doi.org/10.1590/S1415-43662005000400015

Patel, S., & Dhillon, N. K. (2017). Evaluation of sunnhemp (*Crotalaria juncea*) as green manure/amendment and its biomass content on root knot nematode (*Meloidogyne incognita*) in successive crop brinjal. J*ournal of Entomology and Zoology Studies*, *5*(6), 716-720.

Pereira, A. R., Angelocci, L. R., & Sentelhas, P. C. (2002). *Agrometeorologia: fundamentos e aplicações*. Guaíba, RS: Agropecuária. (In Brazilian Portuguese).

Ribas, G. G., Streck, N. A., Silva, S. D. da, Rocha, T. S. M. da, & Langner, J. A. (2015). Effect of irrigation and mulching on soil temperature. *Engenharia Agrícola*, *35*(5), 817-828. https://doi.org/10.1590/1809-4430-Eng.Agric.v35n5p817-828/2015

Ritchie, S. W., Hanway, J. J., & Benson, G. O. (1993). *How a corn plant develops*. Ames: IA: Iowa State University. (Special Report, 48).

Santos, H. G. dos, Jacomine, P. K. T., Anjos, L. H. C. dos, Oliveira, V. A. de, Lumbreras, J. F., Coelho, M. R., Almeida, J. A. de, Araújo Filho, J. C. de, Oliveira, J. B. de, & Cunha, T. J. F. (2018a). (5th ed.). *Brazilian Soil Classification System*. Brasília, DF: Embrapa Solos.

Santos, P. R. A. dos, Chioderoli, C. A., Silva, A. O. da, Nicolau, F. E. de A., Lopes, J. E. L., Amorim, M. Q., & Mendonça, C. de A. (2018b). Physical attributes of the soil and maize productivity under an intercrop system. *Journal of Agricultural Science*, *10*(12), 358-365. https://doi.org/10.5539/jas.v10n12p358

Santos, T. E. M. dos, Montenegro, A. A. A., & Silva, D. D. (2011). Soil moisture in Pernambuco semiarid using time domain reflectometry (TDR). *Revista Brasileira de Engenharia Agrícola e Ambiental*, *15*(7), 670-679. https://doi.org/10.1590/S1415-43662011000700004

SOIL SURVEY STAFF. (2014). *Keys To Soil Taxonomy*. 12th edn. Washington DC, USA: Natural Resources Conservation Service, United States Department of Agriculture.

Souza, A. P., Mota, L. L., Zamadei, T., Martin, C. C., Almeida, F. T., & Paulino, J. (2013). Climate classification and climatic water balance in Mato Grosso state, Brazil. *Revista Nativa*, *1*(1), 34-43. https://doi.org/10.31413/nativa.v1i1.1334

Souza, R. T. de, Valadão, F. C. de A., Valadão Júnior, D. D., Guimarães, P. R., & Paula, V. R. R. de. (2019). Maize-crotalaria intercropping systems. *Semina: Ciências Agrárias*, *40*(4), 1455-1468. http://dx.doi.org/10.5433/1679-0359.2019v40n4p1455

Stefanoski, D. C., Santos, G. G., Marchão, R. L., Petter, F. A., & Pacheco, L. P. (2013). Soil use and management and its impact on physical quality. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *17*(12), 1301-1309. https://doi.org/10.1590/S1415-43662013001200008

SYSTAT SOFTWARE. (2021). *Sigmaplot for Windows - version 12*. https://systatsoftware.com/sigmaplot/download-sigmaplot-software/ (August 29, 2021).

Trevisan, M. (2019). *Atributos físico-hídricos do solo em sistemas consorciados de milho com adubos verdes sob manejo orgânico*. (Masters dissertation). Federal University of São Carlos, Araras, Brazil. (In Brazilian Portuguese).

Vasconcelos, A. T., Tieppo, R. C., Dallacort, R., Santi, A., & Andrea, M. C. da. S. (2018). Laboratory temperature-compensating calibration procedure for soil water content determination by reflectometry. *Científica*, *46*(3), 221-225. http://dx.doi.org/10.15361/1984-5529.2018v46n3p221-225

Yin, W., Chai, Q., Guo, Y., Fan, Z., Hu, F., Fan, H., Yu, A., & Coulter, J. A. (2020). Straw and plastic management regulate air–soil temperature amplitude and wetting-drying alternation in soil to promote intercrop productivity in arid regions. *Field Crops Research*, *249*(1), 107758. https://doi.org/10.1016/j.fcr.2020.107758

Yin, W., Feng, F., Zhao, C., Yu, A., Hu, F., Chai, Q., Gan, Y., & Guo, Y. (2016). Integrated double mulching practices optimizes soil temperature and improves soil water utilization in arid environments. *International Journal of Biometeorology*, *60*(9), 1423-1437. https://doi.org/10.1007/s00484-016-1134-y

Zhou, Z., Jiang, L., Du, E., Hu, H., Li, Y., Chen, D., & Fang, J. (2013). Temperature and substrate availability regulate soil respiration in the tropical mountain rainforests, Hainan Island, China. *Journal of Plant Ecology*, *6*(5), 325-334. https://doi.org/10.1093/jpe/rtt034

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