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TEMPERATURA E UMIDADE DO SOLO EM SISTEMAS DE MILHO CONSORCIADO E EM MONOCULTIVO COM E SEM IRRIGAÇÃO

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1 RESUMO

Cultivos consorciados visam à maximização sustentável do uso do solo e água, e têm-se tornado uma alternativa para regiões com períodos chuvosos relativamente curtos e temperaturas elevadas. O objetivo foi verificar a dinâmica e a manutenção da umidade do solo, em função das oscilações da temperatura do solo em sistemas de milho consorciado com e sem irrigação. O delineamento experimental foi composto por doze tratamentos, sendo: milho, braquiária e crotalária em monocultivo, consórcio entre milho e braquiária, consórcio entre milho e crotalária, e sem cobertura do solo, em dois sistemas (seis tratamentos irrigados e seis sem irrigação), com quatro repetições. Avaliou-se a temperatura do solo nas profundidades de 10, 20, 30 e 40 cm e umidade do solo na camada entre 0-30 cm. Foram avaliados os componentes de produção do milho ao final do ciclo. O cultivo do milho em consórcio com a crotalária ou braquiária, proporcionou redução da temperatura média do solo em 17,4 e 17,6%, respectivamente. O consórcio reduziu a amplitude térmica do solo quando comparado com o milho em monocultivo. A umidade do solo apresentou menores valores nas fases de desenvolvimento, intermediária e final para os cultivos de milho consorciado. O cultivo do milho em consórcio irrigado não apresentou diferença significativa na produtividade em relação ao monocultivo.

Palavras-chave: braquiária, consórcio, crotalária, reflectometria no domínio do tempo, *Zea mays* L.

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TEMPERATURE AND SOIL MOISTURE IN MAIZE CULTIVATE IN SINGLE AND INTERCROPPING SYSTEMS WITH AND WITHOUT IRRIGATION

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2 ABSTRACT

Intercropping aims at sustainable maximization of soil and water use, and has become an alternative for regions with relatively short rainy periods and high temperatures. The aim was to verify the dynamics and maintenance of soil moisture as a function of soil temperature oscillations in intercropped corn systems with and without irrigation. The experimental design was composed of twelve treatments: corn, brachiaria and crotalaria in monoculture, intercropping between corn and brachiaria, intercropping between corn and crotalaria, and uncovered soil, in two systems (six irrigated treatments and six without irrigation), with four replications. Soil temperature at depths of 10, 20, 30, and 40 cm and soil moisture in the 0–30 cm layer was evaluated. The production components of corn at the end of the cycle were evaluated. Corn intercropped with crotalaria or brachiaria provided a 17.4 and 17.6% reduction in average soil temperature, respectively. Intercropping reduced the temperature range of the soil compared to corn in monocrop. Soil moisture showed lower values at the development, intermediate, and final stages for the intercropped corn crops. Corn under irrigated intercropping showed no significant difference in yield compared with monocropping.

Keywords: brachiaria, intercrop, crotalaria, time domain reflectometry, *Zea mays* L.

3 INTRODUCTION

The advantages of intercropping systems over monocultures are increasingly evident. This system can be established with simultaneous sowing or with a difference of a few days between the sowing of the crops involved (CECCON, 2013; SOUZA et al., 2019). Several annual crops are used for this purpose, but the preference is for corn, with production allocated to grain or silage (JAKELAITIS et al., 2004).

The corn cultivation system in association with the crotalaria crop provides many advantages to the agricultural system, such as fixation of atmospheric nitrogen; a biomass rich in P, K and Ca; a branched and deep root system; facilitating nutrient cycling; and promoting soil decompaction, a crop that inhibits the proliferation of phytonematodes, among other advantages (TEODORO et al., 2011; GAZOLA et al., 2013).

The cultivation of corn intercropped with brachiaria also provides numerous advantages, such as improvements in soil physical properties, a reduction in weed infestation (PACHECO et al., 2009) and increases in the productivity of subsequent crops (BARDUCCI et al., 2009).

An important factor to be considered when cultivating intercropped crops is competition for resources, such as water, light and nutrients, which can vary according to the sowing season, types of crops involved, plant population, spacing used and cultivation location (CECCON, 2013).

Corn, a crop with carbon fixation metabolism (C4), is considered excellent for intercropping systems, as it has accelerated initial growth, is tall, has a high capacity to intercept photosynthetically active radiation, and adapts well to intercropping with other crops (OLIVEIRA et al., 2010). These characteristics are desirable in an intercrop, since the search is for systems in which forages or legumes are managed without harming the main crop.

Carneiro (2014), studying the temperature of the soil with vegetation cover, noted that soil moisture was of utmost importance, as it affected the heat flow in the soil, modifying the temperature amplitude in the soil profile as a function of the evaporation of water from the soil.

Soil moisture is influenced by factors such as vegetation, soil texture, topography and cultivation region and varies greatly over time and space (SANTOS; MONTENEGRO; SILVA, 2011). Thus, the use of intercropping or mulch systems on the soil affects soil dynamics, resulting in higher moisture values in relation to monoculture systems (GHANBARI et al., 2010).

Soil temperature and moisture are directly related so that soil warming reduces moisture, affecting the soil biota and plant root growth (BAO et al., 2016), and these two factors can be influenced by the presence or absence of biomass on the soil surface (CARNEIRO, 2014). Thus, soil cover, either by dry mass or by the leaf area of crops, results in a reduction in soil temperature and, consequently, a lower rate of soil water evaporation.

Soil water evaporation is the main component of the water balance for areas with irrigated or rainfed crops, especially in the early stages of crop development. In combination with intercropping, the use of irrigation increases heat flow in the soil–atmosphere system, reducing soil warming, especially in soils where no-till farming is used, as these soils have a higher water heat capacity than soils without mulch or without irrigation (RIBAS et al., 2015).

Therefore, understanding the effects of intercropping corn with different crops on soil temperature and moisture dynamics under irrigated and nonirrigated conditions is an increasingly important factor in the planning and management of intercropping, especially when corn is used as the main crop, owing to its enormous impact on the Brazilian economy and agriculture. Thus, the objective of this study was to investigate the influence of intercropping corn systems on soil moisture dynamics and maintenance as a function of soil temperature fluctuations in irrigated and nonirrigated environments.

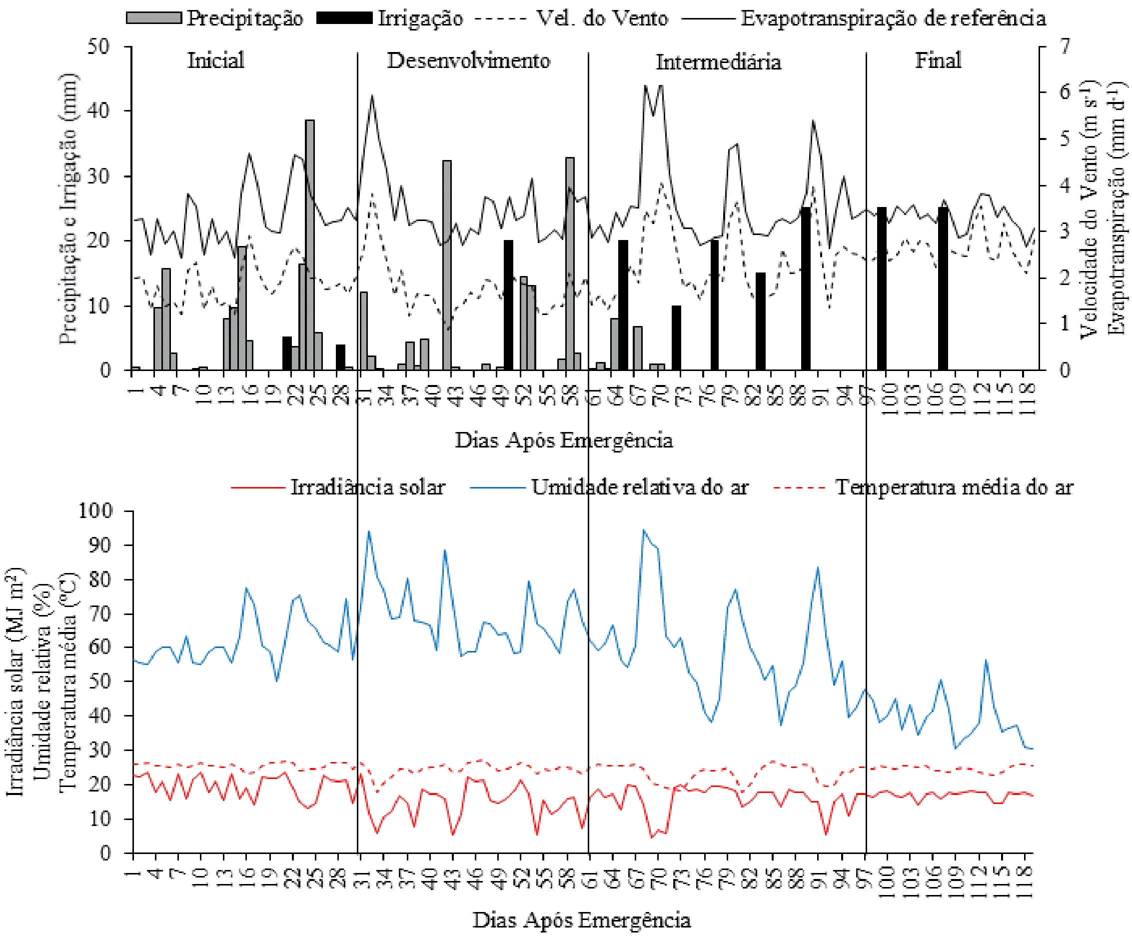
4 MATERIAL AND METHODS

The experiment was implemented in the experimental field of the Technological Center for Geoprocessing and Remote Sensing (CETEGEO-SR) at the State University of Mato Grosso - UNEMAT, in the municipality of Tangará da Serra - MT. Near the experimental area, an automatic meteorological station with equipment from Campbell Scientific Inc., installed at the geographic coordinates latitude 14° 65' 00” S, longitude 57° 43' 15” W and altitude of 440 m, from which the meteorological data used to estimate the reference evapotranspiration - ETo, calculated via the Penman–Monteith method - FAO 56 (ALLEN et al., 1998; ALLEN et al., 2006), were obtained. ETo was used to determine when and how much to irrigate according to the Kc values of the crop for each growth stage (ALLEN et al., 1998).

According to Köppen, the region's climate is classified as megathermal humid tropical (Aw), with high temperatures, a dry season from May to September and a rainy season from October to April, with an average annual rainfall of 1,830 mm and an average air temperature of 24.7°C (DALLACORT et al., 2011; DANIEL et al., 2021). The soil is classified as a dystroferric Red Latosol with a clayey texture (SANTOS et al., 2018).

The daily data on precipitation, irrigation, average temperature, solar irradiance, and relative humidity from sowing to harvest are presented in Figure 1. The amount of precipitation and irrigation applied corresponded to 286 and 170 mm, respectively, totaling 356 mm of water during the growing season. There is an inverse relationship between humidity and radiation, with increased solar irradiance tending to decrease humidity, whereas the air temperature decreases on days with low solar irradiance. Plant emergence occurred on March 6, 2019. During this period, constant rainfall continued, meeting the crop's water needs during the initial and developmental phases. At 70 DAE, the dry season began.

Figure 1. Data on precipitation, irrigation, average air temperature, solar irradiance, relative humidity, wind speed and reference evapotranspiration during the experiment were obtained .



Source: The authors (2022).

Corn (*Zea mays* L.) was sown after the soybean harvest to represent the second crop in the state of Mato Grosso on February 28, 2019, via the direct seeding method with a Baldan PP-SOLO-4500 seeder. The corn hybrid Agrisure Viptera3 Syngenta SX7341, with an average cycle of 105 days, was used, with 3 plants per meter, spaced 0.50 m between rows, totaling 60,000 plants per hectare. The intercropping crops used were sunn hemp (*Crotalaria spectabilis* Roth.) and Brachiaria dictyoneura (*Brachiaria humidicola* cv. Llanero), sown simultaneously with corn sowing, with a regulation of 30 seeds per meter. The spacing used for the intercropping system was 0.50 m; however, the rows of corn and secondary crops (sunn hemp or brachiaria) were interspersed.

Fertilization was performed according to soil analysis (Table 1), as recommended by Sousa and Lobato (2004). For soybean cultivated in the total area prior to this experiment (first harvest in Mato Grosso), soil correction was performed with 1.49 t ha $^{-1}$ dolomitic limestone. The base fertilization for soybean consisted of 400 kg ha $^{-1}$ NPK mineral fertilizer (formulas 5--25-

-15) applied at the seeding line. For the sowing in this experiment (second corn harvest), liming was not performed; however, 250 kg ha $^{-1}$ NPK mineral fertilizer, formula 5-25-15, was applied in the seeding line, both in the irrigated and nonirrigated areas. The crotalaria and brachiaria crops were grown without fertilization. Cultural treatments were carried out in accordance with the recommendations for crops (FANCELLI; DOURADO NETO, 2004; CARVALHO; AMABILE, 2006; OLIVEIRA et al., 2010).

Table 1 Chemical and physical analysis of the soil in the 0–20 cm layer of the experimental area of UNEMAT in Tangará da Serra-MT **.**

Chemical characteristics											
Sample	pH	P	K	Here	Mg	Al	H	SB	CTC	V	MO
	H_2O	-- mg dm $^{-3}$ --		------------ cmol $_c$ dm $^{-3}$ ----------- -						%	g dm $^{-3}$
Irrigated area	6.4	2.8	27.2	3.3	1.7	0.0	2.9	5.1	8.0	63.7	28.1
Nonirrigated area	5.5	1.8	37.4	1.5	1.0	0.1	5.2	2.6	7.8	33.1	28.7

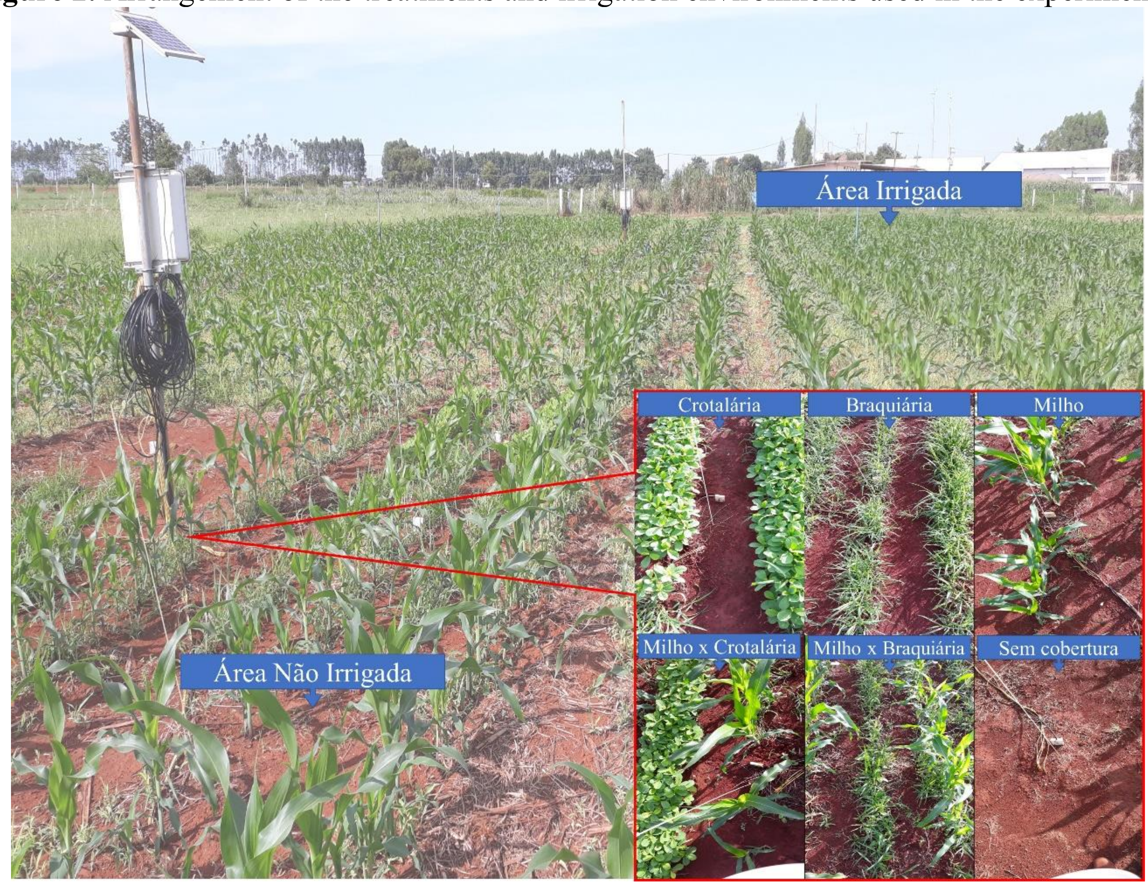
Sample	**Physical** Sand	Silt	Clay	**Micronutrients** Zn	Ass	Faith	Mn	B
	---------- g kg $^{-1}$ ----------			--------------- mg dm $^{-3}$ ---------------				
Irrigated area	337.8	88.4	573.8	1.4	1.9	71.4	64.1	0.5
Nonirrigated area	384.0	72.4	543.6	1.1	2.0	70.7	64.1	0.3

SB: (sum of bases) = Ca + Mg + K; CEC = total cation exchange capacity; V: base saturation; MO: organic matter.
Source: The authors (2022).

The experimental design adopted was a double factorial design (environment × treatments) in a strip scheme composed of two strips, one irrigated and one without irrigation, with twelve treatments: corn in monoculture; Brachiaria in monoculture; crotalaria in monoculture; intercropping between corn and Brachiaria (corn × Brachiaria); intercropping between corn and Crotalaria (corn × Crotalaria); and without soil cover (no crop), in two irrigation systems (six irrigated treatments and six without irrigation), with four replicates per treatment (Figures 2 and 3). Each experimental plot had an area of 20 m² (4 × 5 meters) and was composed of 10 rows of 4 meters in length, of which the six central rows were used as the useful area for each replicate (Figure 3).

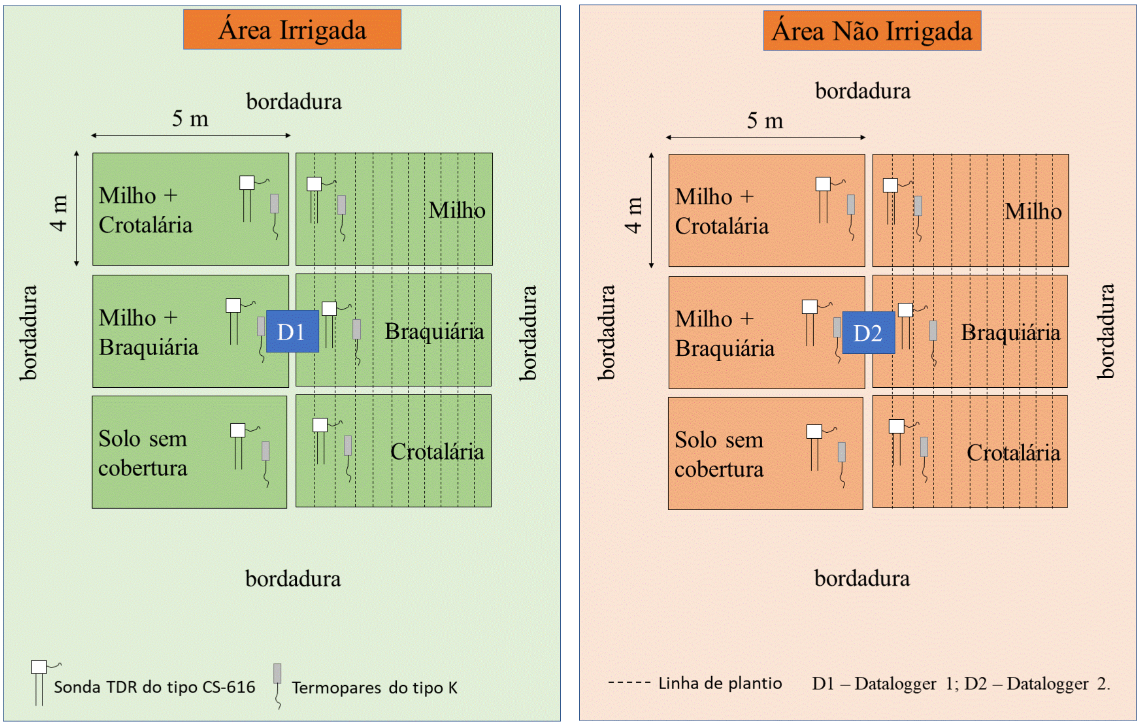
With respect to the monitoring and comparison of soil temperature and moisture values, the experimental design adopted was a triple factorial design (environments × treatments × phases). The environments and treatments were the same as those mentioned above, and the corn development phases were determined to better understand the variations in soil temperature and moisture during the experiment, dividing the crop cycle into four phases: initial (I): from planting to 10% soil cover (sowing to V3); development (II): from the end of the initial phase until the beginning of tasseling (V4--V14); intermediate (III): from the beginning of tasseling until the beginning of grain maturation (VT--R5); and final (IV): from the beginning of maturation until harvest (R6--Harvest), according to the methodology described by Ritchie, Hanway and Benson (1993) and Allen et al. (2006).

Figure 2. Arrangement of the treatments and irrigation environments used in the experiment.



Source: The authors (2022).

Figure 3. Sketch of the experiment, arrangement of treatments and sensors used.



Source: The authors (2022).

For the irrigated environment, ETo data obtained from the meteorological station were used to calculate the crop evapotranspiration (ETc), which was determined by multiplying the ETo by the crop coefficient (Kc) and dividing by the efficiency of the irrigation system to determine the total availability of water in the soil, net irrigation depth and gross irrigation depth. The following values were used: field capacity = 0.361 $m^3 m^{-3}$ and permanent wilting point = 0.232 $m^3 m^{-3}$ (DANIEL, 2011). To calculate the irrigated quantity, Equations 1, 2, 3, 4 and 5 were used.

$$ETc = ETo * Kc \quad (1)$$

$$DTA = \frac{CC - PMP * Ds}{10} \quad (2)$$

$$DRA = DTA * Fator_{disp.} \quad (3)$$

$$LLI = DRA * Z_{rad.} \quad (4)$$

$$LBI = LLI * Ef \quad (5)$$

where ETc is crop evapotranspiration (mm); ETo is reference evapotranspiration (mm); Kc is the crop coefficient; DTA is total soil water availability (mm cm^{-1}); CC is field capacity (%); PMP is permanent wilting point (%); Ds is soil bulk density (g cm^{-3}); DRA is real soil water availability (mm); $_{Disp.}$ factor is the soil water availability factor (50); $Z_{rad.}$ where LLI is the net irrigation depth, LBI is the gross irrigation depth, and Ef is the system efficiency (decimal).

Irrigation was performed by a sprinkler system composed of 6 sprinklers (Eco232 Frabrimar, Brazil) with 4.0 × 2.8 mm nozzles spaced 12 × 12 m apart, with a distribution uniformity coefficient of 83% and system efficiency of 80% under a pressure of 30 mca, providing an applied water depth of 9.80 mm h^{-1}.

The sensors used to measure the soil temperature were K-type thermocouples, which consisted of a thermocouple junction composed of chromium and aluminum alloys (Chromel $^+$ and Alumel $^-$) at the tips. These were protected by aluminum capsules and properly sealed with resin and self-fusing tape (3 M™ Scotch™ Self-Fusing Tape 23, Brazil) to prevent corrosion of the thermocouple tips (WERNECK, 1996; THOMAZINI; ALBUQUERQUE, 2005). In the central area of each treatment, four sensors were installed horizontally at depths of 10, 20, 30, and 40 cm. The soil temperature values were expressed in °C.

To monitor soil moisture, CS-616 time-domain reflectometry (TDR) probes (CAMPBELL SCIENTIFIC, 2004) were installed at a depth of 20 cm, also horizontally in the center of each treatment. The TDR probes were previously calibrated and measured in the laboratory, and the soil moisture values obtained were adjusted via the equation proposed by Vasconcelos et al. (2018). The soil moisture data were expressed in volumetric moisture ($m^3 m^{-3}$). Both the temperature and moisture sensors were connected to a multiplexer board connected to two *dataloggers* (CR1000, Campbell Scientific Inc., USA), one in each system (irrigated and nonirrigated), programmed to store the collected data at 30-s intervals.

The leaf area index (LAI) for corn was calculated according to the procedure described by Mckee (1964), in which four plants from each treatment were collected in each irrigation environment at stages V6, V9, V12, VT, R1, and R5. The leaf area was estimated by the sum of the lengths of all the leaves multiplied by the maximum width and multiplied by the conversion factor (0.75). To obtain the LAI, the leaf area ($^{m2)}$ is added and divided by the soil surface available for each plant (^{m2}).

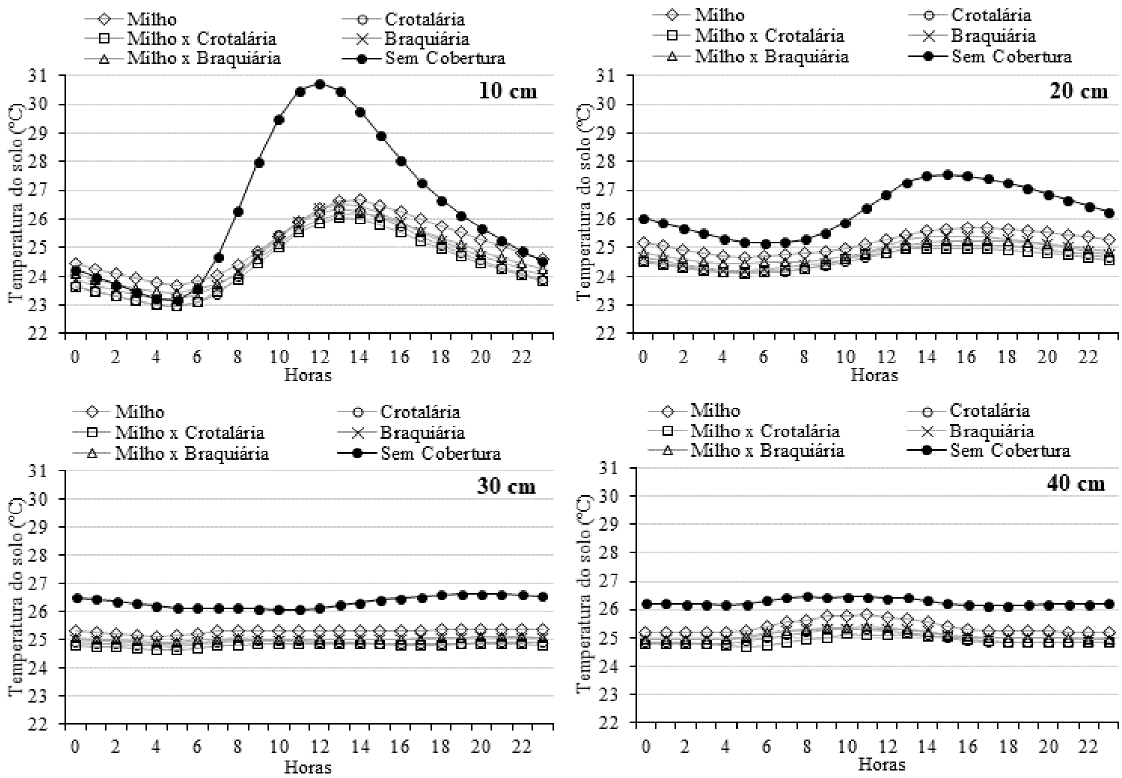
The corn harvest was carried out on July 1, 2019, completing the cycle 124 days after sowing (DAS) and 120 days after emergence (DAE). The following parameters were evaluated in the corn crop: plant height, stalk diameter, plant dry matter accumulation, ear insertion height, ear diameter and length, number of rows and grains per row, 1000-grain weight, grain mass, and yield.

Data on corn production components, as well as soil temperature and moisture values, were subjected to analysis of variance (ANOVA) via the F test, and when significance was reached at 5% probability, the means were compared via the Tukey test. The SISVAR statistical program, version 5.8 (FERREIRA, 2011), was used for data analysis.

5 RESULTS AND DISCUSSION

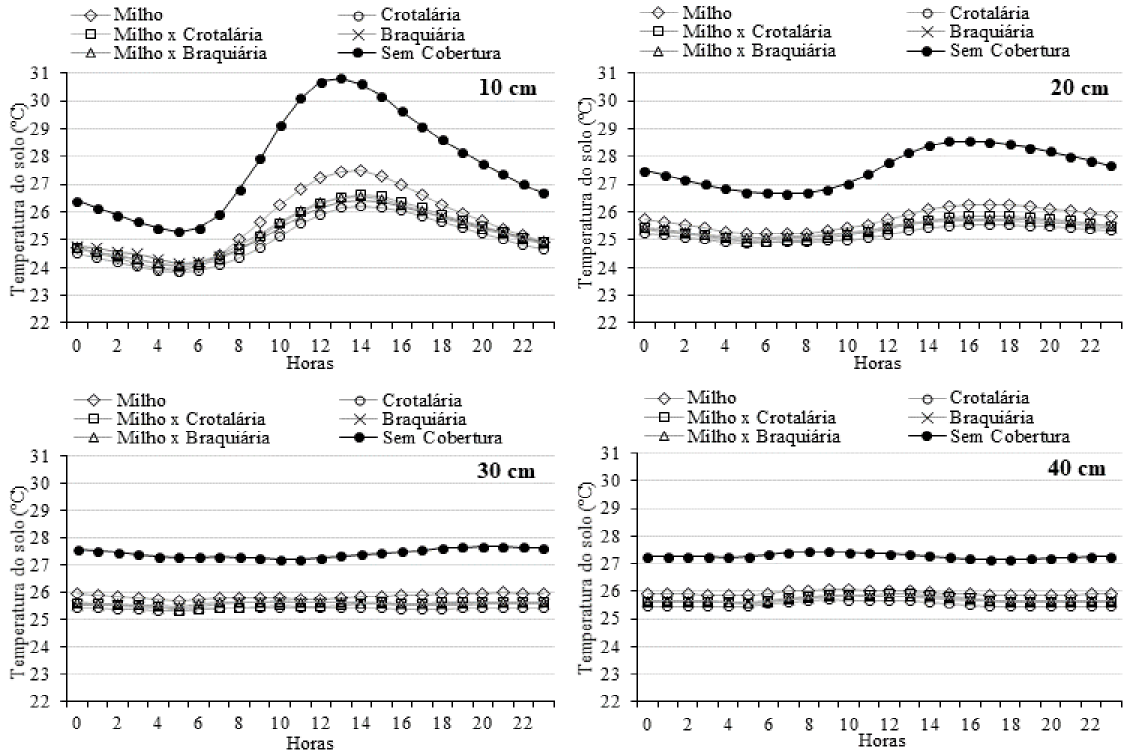
The highest average soil temperature was observed at 12:00 hours for the treatment without soil cover, i.e., "exposed soil and no crop", with averages of 30.8 and 30.7°C for the nonirrigated and irrigated environments, respectively (Figures 4 and 5).

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



Source: The authors (2022).

Figure 5. Hourly variation in average soil temperature at different depths (10, 20, 30 and 40 cm) for each treatment in a nonirrigated environment.



Source: The authors (2022).

For both the monoculture and intercropping treatments, the highest temperatures occurred between 1:00 PM and 3:00 PM at a depth of 10 cm, both for the irrigated and nonirrigated environments. These are also the times that presented the highest soil temperatures in experiments conducted by Trevisan (2019), who worked with intercropped crops in the state of São Paulo, for corn in monoculture and in intercropping with *Crotalaria spectabilis*.

The treatment without soil cover presented a greater soil temperature range because of the lack of vegetation cover and protection from solar radiation. For the intercropping treatments, the range was smaller because of greater soil cover by plants. Gasparim et al. (2005), in experiments in the state of Paraná, used the same types of sensors and reported that dry matter cover reduces the temperature range in the soil profile compared with bare soil, and the greater the density of the cover on the soil is, the lower the temperature in the soil profile.

At a depth of 20 cm, we observed that the highest temperatures occurred between 2:00 PM and 4:00 PM and presented a reduced soil thermal amplitude, as expected, which was also observed by Gasparim et al. (2005), who used the same types of sensors but in treatments with straw as the soil cover. Kojima et al. (2018) reported that soil thermal conductivity increases as soil moisture increases, as does the increased contact between soil particles and mass flow. These phenomena occur slowly, gradually transferring heat and resulting in delayed soil heating in deeper layers. In this experiment, we observed delayed soil heating at depths greater than 20 cm, corroborating the results obtained by the authors.

The average hourly soil temperatures for the irrigated environment were lower than those for the nonirrigated environment because irrigation occurred between 5:00 PM and 6:00 PM, when the soil temperatures were the highest. Despite the limited irrigation, there was a 0.73°C reduction compared with the nonirrigated environment. In terms of soil quality, a study by Crusciol et al. (2010) revealed that intercropping Brachiaria with corn resulted in greater soil aeration, lower soil mechanical resistance to penetration, lower soil surface temperatures, and greater water availability for plants. All of these changes are favorable for plant growth.

The soil temperature significantly differed between the environment and treatment only at a depth of 10 cm (Table 2). For the other depths and for soil moisture, there was only isolated significance for the sources of variation.

Table 2 Average soil temperature at 10 cm depth in irrigated and nonirrigated systems according to treatments for each stage of the corn crop **.**

Factors	**Soil temperature - 10 cm (°C)**				
	Phases				
Environment (AM)	**I**	**II**	**III**	**IV**	**QM**
Irrigated	27.98bA	26.31 bB	23.98bC	23.33bD	110.42 **
Nonirrigated	28,29aA	26.71aB	25.06 BC	25.21 BC	54.97 **
QM	1.17 *	1.95 **	14.09 **	42.35 **	--
Treatment (TR)	**Phases**				
	I	**II**	**III**	**IV**	**QM**
Corn	28.19aA	26.29 bB	23.96bC	24.15cC	31.87 **
Crotalaria	27.87aA	25.56cB	23.75 bC	22.86dD	39.02 **
Brachiaria	28.11aA	27.42aB	26.08 BC	25.25bD	13.24 **
Corn x Crotalaria	28.13aA	25.91cB	23.55 bC	23.29 AD	41.24 **
Corn x Brachiaria	28.07aA	26.22 bB	23.72 bC	23.22 AD	40.91 **
No Coverage	28.48aA	27.67aB	26.06aD	26.85 BC	8.72 **
QM	0.32 ^{ns}	5.73 **	11.68 **	18.69 **	--
AM x TR	**Irrigated**		**Nonirrigated**		**QM**
Corn	25.52bA		25.78bA		0.55 ^{ns}
Crotalaria	24.92cA		25.10cA		0.25 ^{ns}
Brachiaria	25.17bcB		28.26aA		76.49 **
Corn x Crotalaria	24.97cB		25.47bcA		1.99 **
Corn x Brachiaria	25.18bcA		25.44bcA		0.53 ^{ns}
No Coverage	26.65aB		27.88aA		12.01 **
QM	6.73 **		30.38 **		--

Means followed by the same lowercase letter in the same column and uppercase letter in the same row do not differ statistically according to Tukey's test at the 5% probability of error. ^{ns} = not significant; * = significant at 5% probability; ** = significant at 1% probability according to the F test. QM = Root mean square. Phases: Initial (I): from planting to 10% soil cover (sowing to V3); Development (II): end of the initial phase until the beginning of tasseling (V4 to V14); Intermediate (III): beginning of tasseling until the beginning of grain maturation (VT to R5); Final (IV): from the beginning of maturation until harvest (R6 to harvest). **Source:** The authors (2022).

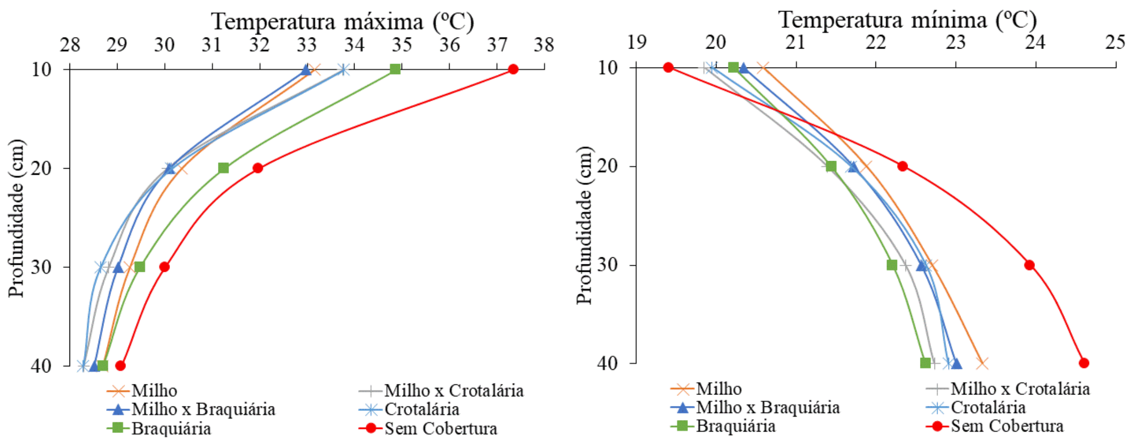
A statistical analysis of the environments according to crop stage revealed that the temperatures were relatively high during the initial and developmental phases of the crop, likely due to the low leaf area index and low evapotranspiration, which promoted water circulation between the soil and atmosphere, creating a microclimate with relatively low temperatures during the hottest hours of the day. With respect to the irrigated environment, temperatures were lower at all crop stages because irrigation was carried out between 5:00 PM and 6:00 PM, reducing soil temperatures.

In the initial phase, the temperature did not significantly differ among the treatments, with the highest values observed for all the treatments. The highest soil temperature values were obtained for the no-crop treatment at all stages. Among the treatments with plant cover, the Brachiaria treatment presented the highest temperature values, and in the development and intermediate stages, the values were similar to those of the no-crop treatment. In the comparison between the environment and treatment, we observed that the brachiaria treatment for the nonirrigated environment did not differ statistically from the no-crop treatment, with values of 28.3 and 27.9°C, respectively, for the brachiaria and no-crop treatments.

Soil temperature influences nutrient uptake. Corn crops utilize nitrogen (N) in its nitric and ammoniacal forms. When corn is exposed to extreme soil temperatures, N uptake can be impaired, especially during the phases with the greatest demand for this nutrient (vegetative phases V4 and V8), resulting in crop productivity losses. N uptake occurs because genes present in corn roots and leaves are activated during these stages. They are responsible for stomatal regulation, stimulating water movement in the roots, forming carbon chains for N assimilation, and phosphorus absorption and transport (SAKAKIBARA; TAKEI; HIROSE, 2006). Thus, intercropping can maintain and regulate soil temperature, avoiding extreme temperatures that could impair nutrient uptake.

Despite the similar trend between the systems (Figure 6), a greater temperature range was observed in the uncropped system, which presented the highest average maximum temperature values compared to those of the other systems, whether intercropped or monocultured. For the minimum soil temperature in an uncropped environment (without cropping) at a depth of 10 cm, the air temperature variation is transmitted to the soil, causing decreases in the soil temperature, as observed in the other treatments.

Figure 6. Average values of maximum and minimum soil temperatures at different depths for the evaluated treatments .

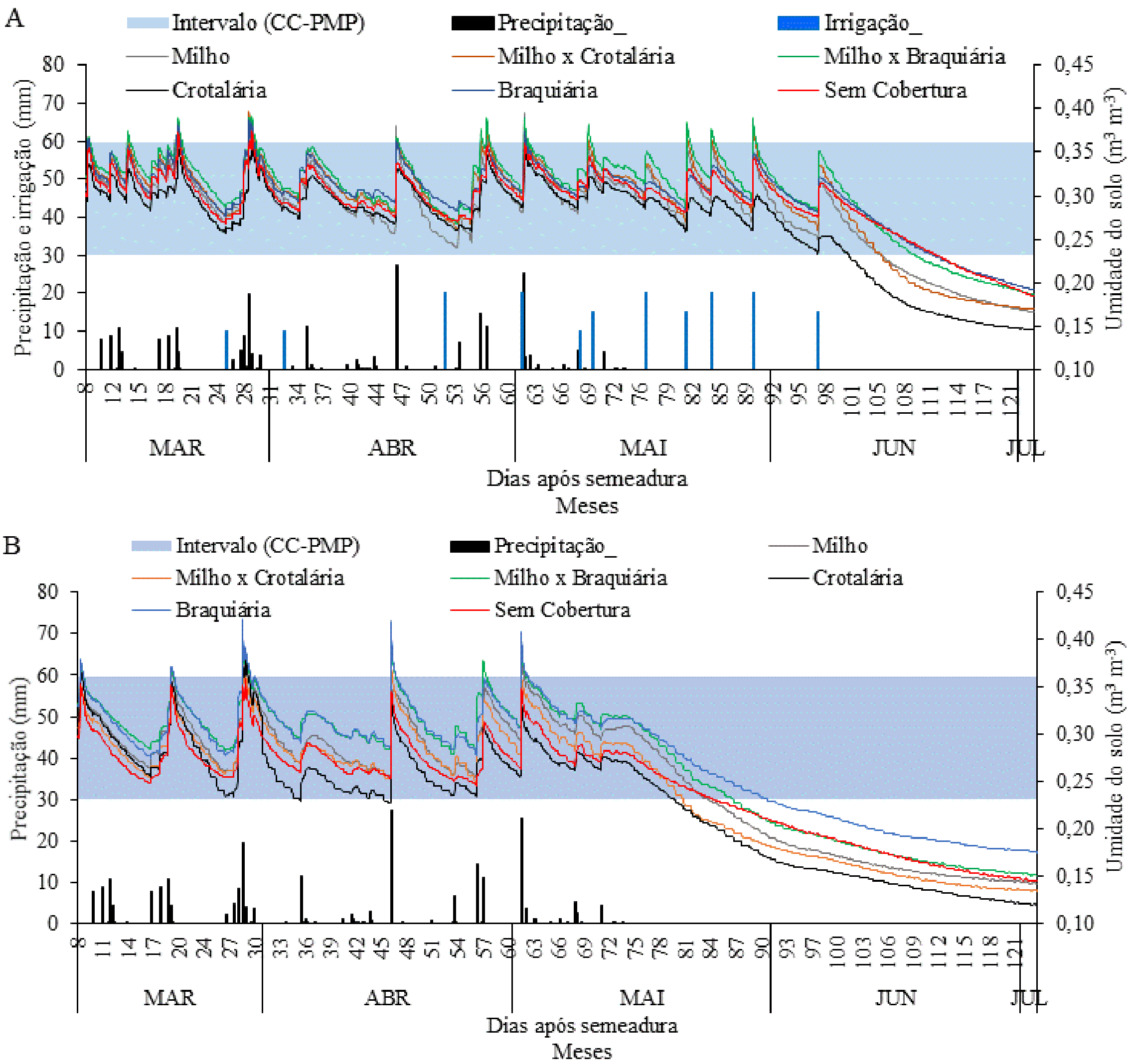


Source: The authors (2022).

dynamics are influenced by several factors, one of which is soil depth (OLIVEIRA et al., 2005). The main source of energy for the soil is solar radiation, which heats the soil via heat conduction from the surface to the interior of the soil profile, where there is a delay in the diffusion of thermal energy at greater soil depths (GASPARIM et al., 2005; OLIVEIRA et al., 2005). This behavior can be demonstrated by the soil reaching its maximum daily temperature only after the air reaches its maximum temperature. At greater depths in the soil profile, the range of soil temperature variation is greater, and the oscillations are smaller.

Figure 7 shows the soil moisture values for each treatment in the irrigated (7A) and nonirrigated (7B) environments. Notably, for the nonirrigated environment with the sunn hemp monoculture treatment, the soil moisture reached values corresponding to moisture at the permanent wilting point at 27, 35, 43, and 45 DAS. From 80 DAS onward, all the treatments presented soil moisture close to the permanent wilting point, a period in which the corn crop was at the end of the intermediate phase. For the irrigated environment, there were no days in which the soil moisture reached the permanent wilting point. From 100 DAS onward (the final phase of the corn crop), all the treatments reached the permanent wilting point, including the irrigated environment, since irrigation was interrupted when the corn reached physiological maturity.

Figure 7. Soil moisture (m3 m $^{-3}$) in the evaluated environments (A – irrigated environment; B – nonirrigated environment), according to treatments during the corn cycle.



Source: The authors (2022).

The soil moisture content varied with respect to the intercropped crops, since at the end of the corn cycle at 120 DAS, the crotalaria and brachiaria crops were still in full development owing to their longer cycle than corn, which presented leaves, flowers and fruits. In other words, these crops had high evapotranspiration rates, as observed by Souza, Lima and Carvalho (2012). These same authors reported that the intercropped crop presented higher evapotranspiration values because of the simultaneous development of velvet bean and corn, with a consequent increase in the total leaf area responsible for the transpiration of both.

In the analysis of soil moisture between environments, significant differences were observed at all crop stages. Notably, at all crop stages, the treatment with Brachiaria in monoculture presented higher moisture values than the other treatments did; however, the crop stages presented significant differences due to the rainfall regime that occurred up to 63 DAS (Table 3).

Table 3 Soil moisture at an average depth of 0--30 cm for irrigated and nonirrigated systems according to the treatments evaluated for each stage of the corn crop **.**

Factors	**Soil moisture (Depth 0-30 cm) (m ^{3} m $^{-3}$)**				
	Phases				
Environment (AM)	**I**	**II**	**III**	**IV**	**QM**
Irrigated	0.319aA	0.303 BC	0.309aB	0.210aD	0.061 **
Nonirrigated	0.297bA	0.288bB	0.251bC	0.158bD	0.098 **
QM	0.006 **	0.003 **	0.040 **	0.033 **	--
Treatment (TR)	**Phases**				
	I	**II**	**III**	**IV**	**QM**
Corn	0.312bA	0.291bB	0.278bC	0.177cD	0.027 **
Crotalaria	0.280 dA	0.274cA	0.255cB	0.153 dC	0.028 **
Brachiaria	0.321abA	0.312aA	0.296aB	0.210 BC	0.020 **
Corn x Crotalaria	0.310bcA	0.297 bB	0.277bC	0.172cD	0.031 **
Corn x Brachiaria	0.327aA	0.314aB	0.297 BC	0.195bD	0.029 **
No Coverage	0.300 AC	0.286 bB	0.278 bB	0.197bC	0.017 **
QM	0.002 **	0.002 **	0.002 **	0.003 **	--
AM x TR	**Irrigated**		**Nonirrigated**		**QM**
Corn	0.279 dA		0.250cB		0.004 **
Crotalaria	0.263eA		0.218eB		0.016 **
Brachiaria	0.295abA		0.274aB		0.004 **
Corn x Crotalaria	0.287cA		0.241 dB		0.017 **
Corn x Brachiaria	0.300aA		0.266 bB		0.009 **
No Coverage	0.289bcA		0.242 dB		0.017 **
QM	0.003 **		0.006 **		--

Means followed by the same lowercase letter in the same column and uppercase letter in the same row do not differ statistically according to Tukey's test at the 5% probability of error. ^{ns} = not significant; * = significant at 5% probability; ** = significant at 1% probability according to the F test. QM = Root mean square. Phases: Initial (I): from planting to 10% soil cover (sowing to V3); Development (II): end of the initial phase until the beginning of tasseling (V4 to V14); Intermediate (III): beginning of tasseling until the beginning of grain maturation (VT to R5); Final (IV): from the beginning of maturation until harvest (R6 to harvest). **Source:** The authors (2022).

An analysis of the influence of the environment on the treatments revealed that, for the irrigated environment, the highest moisture values were found in the corn x Brachiaria and Brachiaria treatments, whereas for the nonirrigated environment, the highest value was found only in the Brachiaria treatment. Sunn hemp grows rapidly, similar to corn. Therefore, for both the irrigated and nonirrigated environments, the lowest moisture values were observed for the corn × sunn hemp and sunn hemp monoculture treatments, with high evapotranspiration rates being a major contributing factor.

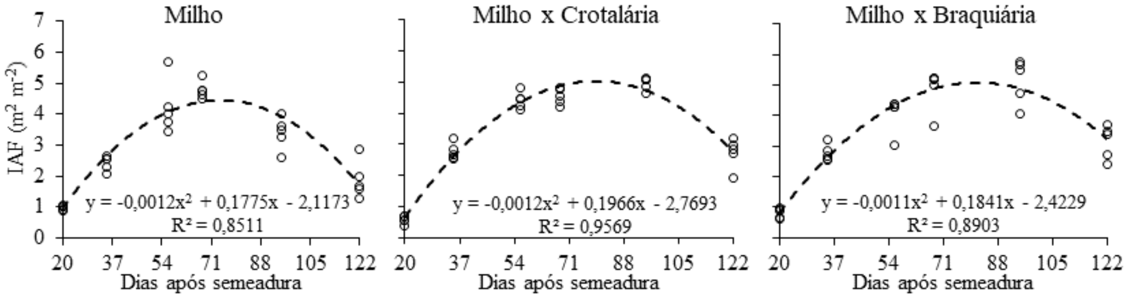
The increase in LAI in corn crops indirectly affects soil water evaporation by increasing the interception of incident solar radiation, increasing soil shading and reducing the energy reaching the soil. Soil water evaporation is greater at the beginning of the corn crop cycle because of the lower percentage of leaf area. As the canopy closes the crop interrows, evaporation becomes less important and decreases considerably (BERGAMASCHI et al., 2004; DALMAGO et al., 2010). This presence of water at the beginning of the cycle affects the soil heat flux, modifying the soil temperature amplitude values as a function of evaporation (CARNEIRO et al., 2014; CORTEZ et al., 2015). Similarly, the absence of water also affects the flow of heat in the soil, making it difficult to conduct heat from the surface layers to deeper layers (FUNARI; PEREIRA FILHO, 2017; OLIVEIRA et al., 2019).

Conventional agricultural production systems can cause changes that harm soil physical and water attributes, such as porosity, density, water retention, temperature, and soil moisture, which are used as indicators of soil quality (ROSSETTI; CENTURION, 2013). Thus, these soil quality indicators provide parameters and signs of soil degradation for alternative management and systems that improve soil structure (SANTI et al., 2012; STEFANOSKI et al., 2013).

Among the physical–hydric attributes of soil, temperature and humidity stand out, as they directly impact the development of agricultural crops (HEINRICHS et al., 2005; OLIVEIRA et al., 2005). According to Gasparim et al. (2005), soil temperature is directly related to soil–plant–atmosphere interaction processes. Soil temperatures above 42°C promote changes in the soil biota, negatively affecting the roots and seedlings of agricultural crops (ZHOU et al., 2013; HEINZE et al., 2017), the mineralization of organic matter (CONANT et al., 2011), and the evaporation of soil water. Therefore, more conservationist systems that maintain soil moisture at more appropriate values can benefit agricultural crops.

The average leaf area index (LAI) of the corn crop did not differ between the treatments and environments because of adequate plant spacing and density. The crotalaria and brachiaria crops are smaller than the corn crop is, which does not affect the LAI (Figure 8). Corn growth and development can be affected by, or even directly affect, the intercropping systems in which it is grown. Thus, factors such as soil water evaporation and the LAI determine a crop's water demand. Considering that plants extract their water from the soil, the LAI indirectly influences water withdrawal, determining the speed of the process depending on their stage of development (DALMAGO, 2010). Andrade (2008), studying corn crops in two cultivation systems (direct planting and conventional planting), also reported no differences in IAF, with values close to 0.40 $m^2 m^{-2}$ (20 DAS) and a maximum of 5.30 $m^2 m^{-2}$ (62 DAS).

Figure 8. Leaf area index (LAI) of corn crops in monocultures and intercropping systems .



Source: The authors (2022).

The analyzed variables of the corn crop revealed that the height of the plants was lower in the corn monoculture treatment in the nonirrigated environment; however, in the irrigated environment, there was no significant difference between the treatments (Table 4).

Table 4. Average values of the variables analyzed in corn cultivation with the interaction between environments (with or without irrigation) and treatments (cultivation systems).

Treatments x Environment	Plant height (cm)		Spike insertion height (cm)		Culm diameter (cm)	
	Irrigated	Nonirrigated	Irrigated	Nonirrigated	Irrigated	Nonirrigated
Corn monoculture	197.1aA	187.2 bB	103.6aA	99.8aA	2.1A	2.1A
Corn x Crotalaria	192.5aB	203.9aA	101.1aA	99.9aA	1.7B	2.1A
Corn x Brachiaria	202.2aA	201.7aA	107.6aA	100.1aB	2.1A	2.2A
DMS column:	8.40		8.36		1.47	
DMS line:	9.28		6.86		1.21	

Treatments x Environment	Ear diameter (cm)		Number of rows		Dry mass of plant (g)	
	Irrigated	Nonirrigated	Irrigated	Nonirrigated	Irrigated	Nonirrigated
Corn monoculture	4.8abA	4.9aA	15.5aA	15.2aA	129.3aA	124.6aA
Corn x Crotalaria	4.8bA	4.8aA	14.2 bB	15.6aA	105.3 bB	131.6aA
Corn x Brachiaria	5.0aA	4.9aA	15.5aA	15.5aA	138.2aA	142.4aA
DMS column:	1.7		1.1		22.5	
DMS line:	1.4		0.9		18.4	

Treatments x Environment	Productivity (kg ha $^{-1}$)	
	Irrigated	Nonirrigated
Corn monoculture	9765.3aA	8403.7aB
Corn x Crotalaria	9391.3aA	8793.8aA
Corn x Brachiaria	10298.7aA	9882.9aA
DMS column:	1222.0	
DMS line:	1002.2	

Means followed by the same lowercase letter in the same column and uppercase letter in the same row do not differ statistically from each other according to the Tukey test at the 5% probability level. LSD = least significant difference. **Source:** The authors (2022).

Productivity differed only in the nonirrigated environment, with the lowest productivity being obtained in the corn monoculture. This is related to soil moisture, which, for corn monocultures, had a lower moisture content between treatments, causing a water deficit. In intercropping, soil coverage by leaf area occurs more quickly, reducing the rate of soil water evaporation. Chieza et al. (2017) mentioned that correct management of intercropped crops, as well as choosing the correct sowing time, has a significant effect on corn production and may have influenced the productivity reported in this experiment.

Another factor that can affect the yield of corn intercropped with Brachiaria, for example, the presence of weeds from the Poaceae family, which can coexist with crops and can affect Brachiaria and corn due to their difficult control. The main weeds found in this experiment were *Digitaria sanguinalis*, *Cenchus echinatus*, *Dactyloctenium aegyptium*, and *Cynodon dactylon*. Jakelaitis et al. (2004) reported that subdoses of herbicides, such as foransulfuron+iodosulfuron-methyl or nicosulfuron, are necessary when managing areas of corn intercropped with Brachiaria, with the aim of controlling weeds and reducing the Brachiaria growth rate.

Although corn crop productivity is not greater in intercropping treatments, the use of green manures and cover crops can benefit agroecosystems, improve the N supply through the biological fixation of legumes, accumulate organic matter on the soil surface, improve the physical-chemical and biological attributes of the soil, control the dynamics of soil temperature and moisture and reduce soil losses due to erosion (OLIVEIRA et al., 2010; CECCON, 2013; WUTKE et al., 2014).

6 CONCLUSIONS

Compared with the corn monoculture, the cultivation of corn in association with Crotalaria or Brachiaria resulted in a reduction in the average soil temperature of 17.4 and 17.6%, respectively, compared with the corn monoculture, which reduced the thermal amplitude.

The average daily temperature of the uncovered soil was 4°C higher than that of the environments cultivated in the consortium.

For the intercropping treatments, soil moisture presented the lowest values in the development, intermediate and final phases, confirming that water consumption by intercropping crops is relatively high because of the number of plants per ^{m2}.

Compared with monocultures, corn intercropped crops presented no significant difference in productivity. Productivity for intercropped crops did not differ between irrigated and nonirrigated environments, but monoculture corn experienced reduced productivity when nonirrigated.

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