

## EVAPOTRANSPIRATION, DUAL CROP COEFFICIENT AND OFF-SEASON MAIZE YIELD IN A SINGLE AND AN INTERCROPPING SYSTEM

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**ABSTRACT.** This work aims to evaluate the influence of different sowing times of crotalaria in an intercropping system with off-season maize on evapotranspiration, dual Kc values and the productive characteristics of maize and crotalaria. The experiment was carried out in the experimental field of the State University of Mato Grosso (UNEMAT) in Tangará da Serra, Mato Grosso, Brazil, with six treatments: 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); sowing of crotalaria with maize in the V6 stage (MCV6). The crop evapotranspiration (ETc) was determined through the mass variation of the weighing lysimeters and converted into mm d<sup>-1</sup>. The methodology used was the dual Kc of FAO bulletin 56, dividing the dual crop coefficient (dual Kc) into the soil water evaporation coefficient (Ke) and basal crop coefficient (Kcb). The phenological phases of the maize crop were determined as recommended by the FAO: initial (I), development (II), intermediate (III) and final (IV). At the end of the crop cycle, the productive characteristics of maize and crotalaria were evaluated. The soil water evaporation for single maize was 253.47 mm, 3.25% more than the average of the intercropping treatments. The ETc throughout the cycle was 497.42, 477.19, 481.95, 481.95, 480.76 and 486.71 mm and the average dual Kc obtained was 1.18, 1.11, 1.13, 1.11 and 1.14 for treatments MS, MCS, MCVE, MCV2, MCV4 and MCV6, respectively. The intercropped maize can be cultivated in any evaluated sowing time of crotalaria, but the sowing of crotalaria simultaneously with maize and with maize in stages VE, V2 and V4 are the most indicated.

**Keywords:** *lysimeters, evaporation coefficient, basal crop coefficient, Zea mays L., Crotalaria spectabilis Roth.*

### INTRODUCTION

Maize (*Zea mays* L.), a plant of the Poaceae family, has high productive potential, with Brazil being the third largest producer in the world of this important agricultural commodity [1], in a way that in the 2020/21 harvest, the average off-season maize productivity in Mato Grosso state was 6,392 kg ha<sup>-1</sup> cultivated in an area of approximately 5.41 million hectares, and the national productivity was 5,456 kg ha<sup>-1</sup> cultivated in an area of 13.8 million hectares [2]. Crotalaria (*Crotalaria spectabilis* Roth.) has been used as green fertilizer in the heartland of Brazil and has stood out due to tolerance to drought and adaptation to edaphoclimatic conditions in this region [3], and under Cerrado conditions, the dry matter production of this legume is approximately 5.45 t ha<sup>-1</sup> [4].

Crop intercropping, which consists of the cultivation of two or more crops in the same area, at least for part of the cycle, aims at better use of the resources available on the

property and minimizing the risk of loss of productivity [5]. The practice of intercropping between maize and crotalaria is of great importance, mainly because it is an alternative to increase the sustainability of agricultural systems [6]. It is noteworthy that the intercropping systems provide advantages such as the use of nitrogen fixed by legumes, greater soil coverage during the period of crop development, high efficiency in the use of water and soil nutrients, high efficiency of light use, increased organic matter content and increased grain yield [6, 7, 8]. However, these advantages are achieved as long as the intercropping crops are well managed, and the water supply of the crops is sufficient and at the right time and measure.

In the literature, information about the water demand of maize crops in an intercropping system is scarce, especially when the intention is to work in irrigated systems. Thus, with the use of weighing lysimeters, when well calibrated and operated, it is possible to reliably determine the crop evapotranspiration (ET<sub>c</sub>) and crop coefficients (K<sub>c</sub>) of agricultural crops [9]. The advantage of using lysimetry is that with weighing lysimeters, it is possible to determine the water demand of the plants in hourly periods, and thus the cultivation coefficients can be determined at all stages during the crop cycle [9]. Thus, there is a need for studies that generate knowledge about intercropped crops and especially that determine the water consumption of the crops involved, especially when they are not sown at the same time, that is, at different times of crotalaria sowing intercropped with maize.

The sowing time is a variable that can directly interfere with the development and yield of the main crop, and it is necessary that producers have knowledge of the best sowing time to avoid failure [10]. In the literature, authors reported that the presence of crotalaria in intercropping does not affect grain yield and maize productivity [11, 12]. Crotalaria growth is limited by shading, especially in conditions of low nutrient availability in the soil [13]. The different spatial arrangements and mainly the sowing time of crotalaria intercropped with the maize crop provide varied shading levels, which in turn interfere with the development of crotalaria, making it an alternative for intercropping management [11]. Many questions remain about the conditions that enhance the use of maize intercropping with *C. spectabilis* sowing times, whose delay in sowing will imply a greater risk for the success of this system. Santos et al. [14] and Souza et al. [15] mention that intercropping can be implemented simultaneously with the sowing of maize or approximately 10 to 20 days after its emergence, aiming to preserve the productivity of the cereal.

The sowing time of this legume between the maize rows can be considered a determining factor in the competition for water, nutrients and especially light [8]. This competition between cultivated species can result in a potential loss of productivity, requiring knowledge of water consumption and the best sowing times for *C. spectabilis* to minimize competition and to avoid losses in maize crop yield. Unfortunately, knowledge and management of irrigation water in intercropped crops on farms is still underdeveloped in the Brazilian Midwest, where most farmers act based on their own experience. Therefore, detailed information that can help farmers with reliable information can help with information on water consumption and crop coefficients, thus lowering farm costs and optimizing the management of irrigation systems. Given the above, this work aims to evaluate the influence of different sowing times of crotalaria in an intercropping system with off-season maize on evapotranspiration, dual K<sub>c</sub> values and the productive characteristics of maize and crotalaria.

## MATERIALS AND METHODS

### *Experimental Area and General Description*

The experiment was conducted in the experimental field of the State University of Mato Grosso – UNEMAT, Campus Professor Eugênio Carlos Stieler and in the Technological Center for Geoprocessing and Remote Sensing (CETEGEO-SR), located in the municipality of Tangará da Serra, Mato Grosso, Brazil. The location has the following geographic coordinates: Latitude: 14° 39' 00" S, Longitude: 57° 25' 54" W, 440.01 m above sea level.

The type of soil in the region is the dystroferric Red Latosol with a very clayey texture [16]. According to the Köppen Climate Classification System, the climate in the municipality of Tangará da Serra is megathermal or tropical with winter drought (Aw) [17], with an average annual precipitation of 1,830 mm and an average temperature of 24.4 °C [18].

The meteorological data used in the experiment were obtained from the automatic meteorological station located near the experimental area, which has the following equipment from Campbell Scientific Inc.: CS215 sensor of temperature (°C) and relative humidity (%); atmospheric pressure sensor (kPa) barometer CS106; solar radiation sensor ( $\text{MJ m}^{-2} \text{d}^{-1}$ ) - CMP3 pyranometer; speed sensor ( $\text{m s}^{-1}$ ) and wind direction (degrees) - anemometer 03002-R.M. Young Wind and pluviometer TB4 rain gauge, connected to a Datalogger (CR1000 model) programmed to store the average every 15 minutes.

### *Installation, Conduction and Experimental Design*

The experiment was carried out in a lysimetric set containing six weighing lysimeters. The external dimensions of the set of lysimeters are 7.2 m long and 5.3 m wide, where each lysimeter has an area of 2.25 m<sup>2</sup> and 1.20 m in depth, with the construction, calibration and validation methodology described by Fenner et al. [19]. The lysimeters have Alfa SV100 model load cells with a capacity of 100 kg +/- 50% with a response of 2 +/- 10% mV/V [20], connected to a Datalogger (CR1000, Campbell Scientific Inc., USA) programmed to log data every 30 seconds and store the average every 15 minutes.

The lysimeters were previously calibrated to establish the relationship between the signal emitted by the load cell (mV) and the mass oscillation of the set, by means of evapotranspiration, irrigation or precipitation and drainage [21]. The mass variation was obtained with the addition and removal of plastic bags with air-dried gravel, hermetically sealed, of different masses (2.250 kg and 15.750 kg) and weighed on an accuracy scale of 0.01 g. The mass addition and removal methodology, as well as the entire lysimeter calibration methodology, is described by Fenner et al. [19] and Campeche et al. [22].

In the lysimeters, sowing was carried out manually, and around the lysimeters, sowing was carried out by means of a mechanized seeder through no-tillage, totaling 1,200 m<sup>2</sup> of the experimental area. The early cycle maize hybrid (*Zea mays* L.) (LG36790 PRO3) was used, with 5 plants per linear meter spaced by 0.90 m between rows, totaling 55,555 plants per hectare, where crotalaria (*Crotalaria spectabilis* Roth.) was planted between the lines of the maize crop, with the recommendation of 30 plants per meter. The cultural treatments were carried out in accordance with the recommendations for both cultures [23, 24, 25].

The experiment consisted of 6 treatments, with each lysimeter receiving one treatment. The treatments consisted of different sowing times of the crotalaria intercropped with the maize crop: single crop maize (MS); sowing of crotalaria simultaneous with maize

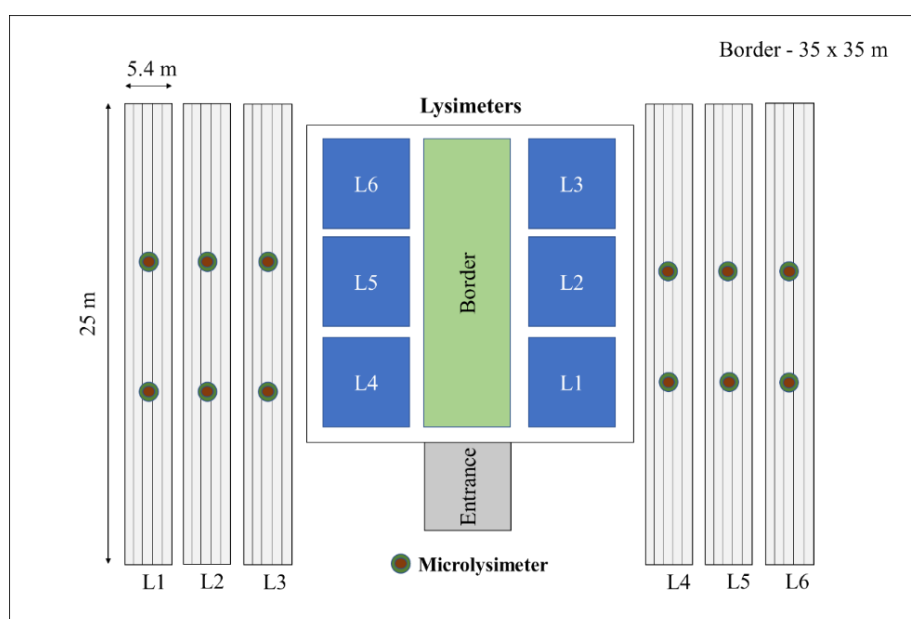
(MCS); sowing of crotalaria with maize in the VE stage (MCVE); sowing of crotalaria with maize in the V2 stage (MCV2); sowing of crotalaria with maize in the V4 stage (MCV4); sowing of crotalaria with maize in the V6 stage (MCV6). Crotalaria was sown manually between the maize rows, according to the treatments. The maize crop development stages were defined according to the scale proposed by Ritchie et al. [26]. Sowing followed the schedule shown in Table 1.

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

Treatments	Maize sowing	Crotalaria sowing	Crotalaria emergency	Crotalaria DAS at harvest	Maize and crotalaria harvesting
MS	03/07/2020	--	--	--	07/03/2020
MCS	03/07/2020	03/07/2020	03/12/2020	118	07/03/2020
MCVE	03/07/2020	03/14/2020	03/19/2020	111	07/03/2020
MCV2	03/07/2020	03/19/2020	03/24/2020	106	07/03/2020
MCV4	03/07/2020	03/23/2020	03/28/2020	102	07/03/2020
MCV6	03/07/2020	03/27/2020	04/01/2020	98	07/03/2020

DAS = days after sowing.

The same treatments were also carried out around the lysimeters in strips measuring 5.4 x 25 m, with the objective of placing microlysimeters to determine the soil water evaporation (Fig. 1).



**Fig. 1.** Sketch of the experimental area showing the arrangement of treatments inside the lysimeters and in the surrounding plots. Treatments: L1 = MS; L2 = MCS; L3 = MCVE; L4 = MCV2; L5 = MCV4; and L6 = MCV6

Fertilization was carried out according to the soil analysis (Table 2). The base fertilization consisted of 500 kg ha<sup>-1</sup> of NPK mineral fertilizer, formula 5-25-15, applied in the sowing line. Two applications of nitrogen (N) in topdressing were carried out, totaling 200 kg ha<sup>-1</sup> of N, in the form of urea, in the maize development stages V4 (10 days after emergence - DAE) and V7 (17 DAE). Crotalaria was cultured without fertilization.

**Table 2.** Chemical and physical characteristics of the soil at a depth of 0-20 cm in the experimental area before carrying out the experiment

Sample	pH	P	K	Ca	Mg	Al	H	SB	CEC	V	O.M.
	H <sub>2</sub> O	mg dm <sup>-3</sup>			cmol <sub>c</sub> dm <sup>-3</sup>					%	g dm <sup>-3</sup>
Lysimeters	6.10	2.66	68.40	1.98	1.00	0.00	3.12	3.15	6.27	50.24	21.17
Lysimeters border	5.80	1.72	50.40	2.20	1.14	0.00	3.50	3.47	6.97	49.78	22.25

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; O.M = Organic Matter.

The irrigation system used was a sprinkler composed of 9 sprinklers (Eco232 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 mca, providing an applied water depth of 10.38 mm h<sup>-1</sup>. The irrigation depth used was determined through the evapotranspiration recorded in the lysimeters. Irrigation was always carried out after 6 p.m.

### Data Analysis and Statistics

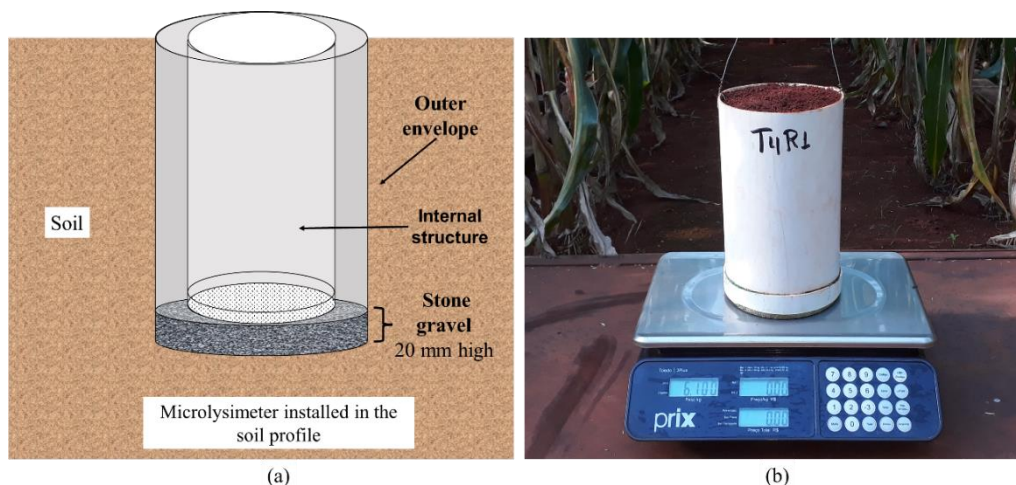
The reference evapotranspiration (ET<sub>o</sub>) was calculated using the Penman-Monteith methodology - FAO bulletin 56 [27], observed in 'Eqn. 1':

$$ET_o = \frac{0,408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0,34U_2)}$$

#### Eqn. 1

where, ET<sub>o</sub> = reference evapotranspiration (mm d<sup>-1</sup>); R<sub>n</sub> = net solar radiation on the crop (MJ m<sup>-2</sup> d<sup>-1</sup>); G = soil heat flux density (MJ m<sup>-2</sup> d<sup>-1</sup>); T = air temperature at two meters above the ground (°C); U<sub>2</sub> = wind speed at two meters above the ground (m s<sup>-1</sup>); e<sub>s</sub> = vapor saturation pressure (kPa), which is estimated by the average of e<sub>s</sub> (T.max) and e<sub>s</sub> (T.min); e<sub>a</sub> = current vapor pressure (kPa), e<sub>s</sub> - e<sub>a</sub> = pressure deficit and vapor saturation (kPa °C<sup>-1</sup>); Δ = vapor pressure curve (kPa °C<sup>-1</sup>); and γ = psychrometric constant (kPa °C<sup>-1</sup>).

The soil water evaporation was accounted for using 12 microlysimeters (E<sub>ML</sub>) installed in the soil profile within the treatments, which were 150 mm in diameter and 200 mm in height and arranged within a 200 mm diameter and 220 mm high sheath (Fig. 2a). Flumignan et al. [28] describe the methodology for building and using microlysimeters. For microlysimeters, two repetitions were performed for each treatment. Considering that the 150 mm diameter microlysimeter corresponds to an area of 0.01766 m<sup>2</sup>, each variation of 17.66 g corresponds to an E<sub>ML</sub> of 1 mm of the water layer.



**Fig. 2.** Microlysimeter. a) Illustrative image of a microlysimeter installed in the soil profile. b) Microlysimeter weighing process to obtain the mass variation of evaporated water

Data collection from the microlysimeters was performed daily at the same time (6 a.m. and 6 p.m.), through manual weighing on a high-precision scale, and organized in a spreadsheet to calculate the mass variation from one day to another (Fig. 2b). Soil water evaporation was determined in millimeters ( $E_{ML}$ ) according to 'Eqn. 2' [28]:

$$E_{ML} = \frac{\Delta M_{ML}}{A_{ML}} + P$$

**Eqn. 2**

where,  $E_{ML}$  = microlysimeter evaporation (mm);  $\Delta M_{ML}$  = microlysimeter mass variation (kg);  $A_{ML}$  = microlysimeter area ( $m^2$ ); and  $P$  = precipitation (mm).

To calculate the soil water evaporation coefficient ( $K_e$ ), the relationship between soil water evaporation ( $E_{ML}$  in millimeters) and reference evapotranspiration ( $E_{To}$ ) was obtained daily according to 'Eqn. 3':

$$K_e = \frac{E_{ML}}{E_{To}}$$

**Eqn. 3**

where,  $K_e$  = soil water evaporation coefficient;  $E_{ML}$  = microlysimeters evaporation (mm);  $E_{To}$  = reference evapotranspiration by Penman-Montheith FAO-56 method (mm).

The data collection of the experiment was from sowing to harvest, totalling 119 days of record during the crop cycle. The values of crop evapotranspiration ( $ET_c$ ) were obtained daily through the mass variation of the lysimeters converted into  $mm\ d^{-1}$  [19, 21]. The  $ET_c$  of single maize and maize intercropped with crotalaria according to the treatments was determined according to 'Eqn. 4':

$$ET_c = \frac{I_m - F_m}{A}$$

**Eqn. 4**

where,  $ET_c$  = crop evapotranspiration ( $mm\ d^{-1}$ );  $I_m$  = lysimeter initial mass;  $F_m$  = lysimeter final mass; and  $A$  = lysimeter area ( $m^2$ ).

To determine the basal crop coefficient ( $K_{cb}$ ) values that are linked to plant transpiration, 'Eqn. 5' was used:

$$K_{cb} = \left( \frac{ET_c}{ET_o} \right) - K_e$$

**Eqn. 5**

where,  $K_{cb}$  = basal crop coefficient;  $ET_c$  = crop evapotranspiration;  $K_e$  = soil water evaporation coefficient; and  $ET_o$  = reference evapotranspiration by the Penman-Montheith FAO-56 method (mm).

The determination of dual  $K_c$ , which is divided into two coefficients, one for crop transpiration ( $K_{cb}$ ) and another for the soil water evaporation coefficient ( $K_e$ ), was determined according to the methodology proposed by FAO Bulletin 56 [27]. Therefore,  $K_c \text{ dual} = K_{cb} + K_e$ .

For a better understanding of crop evapotranspiration values, crop basal coefficients and soil water evaporation coefficients during the experimental period, the crop cycle was divided into 4 phases: initial (I): from sowing to 10% ground cover (sowing up to V3); development (II): end of the initial phase to the beginning of bracing (V4 to V14); intermediate (III): beginning of bracing to the beginning of grain maturation (VT to R5); and final (IV): from the beginning of maturation to harvest (R6 to harvest) [26, 27].

The leaf area index (LAI) was estimated, where 5 plants were collected in each treatment in stages V3, V6, V9, V12, VT, R1, R3 and R6 of maize crop development [26], so that each plant was a repetition. The leaf area was determined using the destructive method [29, 30]. The LAI was estimated using 'Eqn. 6':

$$LAI = \frac{(0,75 * W * L)}{A}$$

**Eqn. 6**

where, LAI = leaf area index ( $\text{m}^2 \text{m}^{-2}$ );  $W$  = leaf width;  $L$  = leaf length; 0,75 = correction factor; and  $A$  = area of land occupied by a plant ( $\text{m}^2$ ).

The following characteristics were evaluated in the maize crop at the end of the cycle at harvest in accordance with the treatments: plant height (PH, cm); cob insertion height (CIH, cm); stem diameter (SD, mm); cob diameter (CD, mm); cob length (CL, cm); cob mass (CM, g); number of rows per cob (NRC); number of grains per row (NGR); number of grains per cob (NGC); grain mass per plant (GMP, g); plant dry mass (PDM, g); dry root mass (DRM, g); root length (RL, cm); harvest index (HI); 1,000 grain mass (1000GM, g); and maize yield ( $Y$ ,  $\text{kg ha}^{-1}$ ).

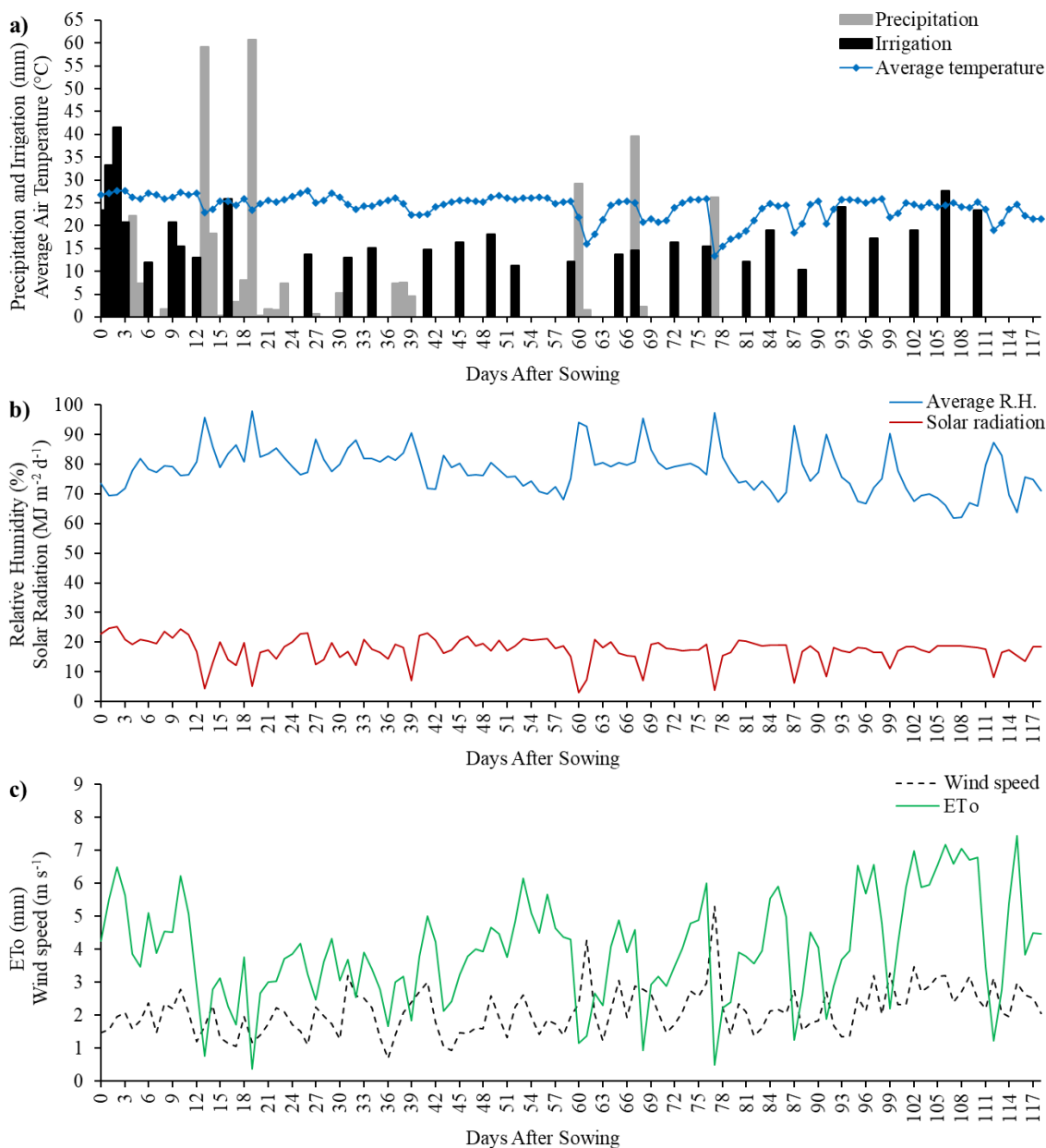
On the same day as the maize harvest, the following variables were evaluated in the crotalaria crop: plant height (PH, cm); stem diameter (SD, mm); root length (RL, cm); green plant mass (GPM,  $\text{g planta}^{-1}$ ); plant dry mass (PDM,  $\text{g planta}^{-1}$ ); root dry mass (RDM,  $\text{g planta}^{-1}$ ); green mass production (GMP,  $\text{kg ha}^{-1}$ ); and dry mass production (DMP,  $\text{kg ha}^{-1}$ ), according to the treatments.

The mean values of soil water evaporation, plant transpiration, crop evapotranspiration and the productive characteristics of maize and crotalaria crops were submitted to analysis of variance (ANOVA) by the F test, and the means were compared by the Scott-Knott and Tukey tests at 5% probability. For data analysis, the computer program SISVAR version 5.8 was used [31].

## RESULTS AND DISCUSSION

### *Meteorological Data*

The conditions of the meteorological variables and the reference evapotranspiration from sowing to harvest lasting 119 days and the days with irrigation during the experiment are shown in Fig. 3.



**Fig. 3.** a) Daily values of precipitation, irrigation and average air temperature. b) Daily values of relative humidity (RH) and solar radiation (SR). c) Daily values of wind speed and reference evapotranspiration (ETo) during the period of the experiment

The experiment started with soil in field capacity for all treatments. The air temperature ranged between 19.2 and 30.5 °C, with an average of 24.1 °C, and the relative humidity varied between 58 and 98%, with an average of 78%, during the experimental period. These variables are important in determining the reference evapotranspiration (ET<sub>o</sub>). For growth and development, the culture requires the optimum temperature range between 19 and 34 °C [32, 33], with the maximum growth occurring between 26 and 34 °C [34], so the experimental site met the thermal requirements of maize.

The precipitation and irrigation values were 336.05 and 533.89 mm, respectively, totaling a volume of 869.94 mm. The maize crop requires a minimum consumption of 350 to 800 mm to ensure satisfactory production, whose average water consumption during the cycle is 600 mm [35]. Fietz et al. [36] mention that the maize crop in an intercropping system demands approximately 400 mm of water throughout the cycle.

The reference evapotranspiration values (ET<sub>o</sub>) showed variations of 0.38 to 7.45 mm d<sup>-1</sup> between the minimum and the maximum, respectively, with a daily average of 3.98 mm d<sup>-1</sup>, totaling 473.13 mm for the period in which the data were recorded. The accumulated values of ET<sub>o</sub> by maize development stage were 65.02, 95.34, 190.58 and 122.19 mm for the initial, intermediate, development and final stages, respectively (Fig. 3c).

### *Soil Water Evaporation, Plant Transpiration and Crop Evapotranspiration*

The soil water evaporation, plant transpiration and crop evapotranspiration are presented in Table 3, referring to the cultivation of single maize and at different sowing times of crotalaria in intercropping, divided into established stages of the crop.

**Table 3.** Mean values of soil water evaporation, plant transpiration and crop evapotranspiration of single maize and maize intercropped with crotalaria

Soil Water Evaporation (mm d <sup>-1</sup> )									
Phases	Days	MS	MCS	MCVE	MCV2	MCV4	MCV6	Average	SD
Initial	15	3.36 Aa	2.47 Aa	2.80 Aa	3.11 Aa	2.89 Aa	3.28 Aa	2.98	0.32
Development	31	2.22 Ab	2.11 Aa	2.05 Ab	2.08 Ab	2.04 Ab	2.29 Ab	2.13	0.17
Intermediate	50	1.05 Ac	0.96 Ab	0.83 Ad	0.85 Ac	0.93 Ac	1.08 Ac	0.95	0.14
Final	23	1.87 Ab	1.75 Aa	1.66 Ac	1.78 Ab	1.68 Ab	2.02 Ab	1.79	0.19
Average	--	2.13	1.82	1.84	1.95	1.88	2.17	1.96	0.17
SD	--	0.96	0.65	0.82	0.97	0.81	0.90	0.86	--
Total (mm)	119	253.47	216.58	218.96	232.05	223.72	258.23	236.81	16.39
Plant Transpiration (mm d <sup>-1</sup> )									
Phases	Days	MS	MCS	MCVE	MCV2	MCV4	MCV6	Average	SD
Initial	15	1.18 Ab	1.13 Ab	1.02 Ab	1.07 Ab	1.42 Ab	0.79 Ab	1.10	0.36
Development	31	3.10 Aa	3.01 Aa	3.27 Aa	3.24 Aa	2.91 Aa	2.95 Aa	3.08	0.20
Intermediate	50	2.96 Ba	3.23 Aa	3.29 Aa	2.87 Ba	2.87 Ba	2.86 Ba	3.01	0.15
Final	23	0.95 Ab	1.38 Ab	1.26 Ab	1.23 Ab	1.43 Ab	1.06 Ab	1.22	0.21
Average	--	2.05	2.19	2.21	2.10	2.16	1.92	2.10	0.12
SD	--	1.14	1.09	1.24	1.12	0.85	1.15	1.09	--
Total (mm)	119	243.95	260.61	262.99	249.90	257.04	228.48	249.90	11.76
Crop Evapotranspiration (mm d <sup>-1</sup> )									
Phases	Days	MS	MCS	MCVE	MCV2	MCV4	MCV6	Average	SD
Initial	15	4.75 Aa	3.60 Ac	3.83 Ab	4.28 Ab	4.31 Aa	4.07 Ab	4.14	0.42
Development	31	5.34 Aa	5.12 Aa	5.32 Aa	5.32 Aa	4.94 Aa	5.24 Aa	5.21	0.23
Intermediate	50	4.00 Ab	4.19 Ab	4.12 Ab	3.72 Ac	3.80 Ab	3.95 Ab	3.96	0.18
Final	23	2.82 Ac	3.13 Ac	2.92 Ac	3.01 Ac	3.11 Ab	3.08 Ac	3.01	0.25
Average	--	4.18	4.01	4.05	4.05	4.04	4.09	4.06	0.08
SD	--	1.08	0.86	0.99	0.98	0.78	0.89	0.90	--
Total (mm)	119	497.42	477.19	481.95	481.95	480.76	486.71	483.14	6.54

Means followed by the same lowercase letter in the columns and uppercase in the lines do not differ statistically by the Scott-Knott test. SD: Standard Deviation.

Evaporation values were statistically higher in the initial phase of the cultures in relation to the other phases and lower in the treatment of crotalaria grown simultaneously with maize. In the initial phase of the cultures, there is greater evaporation of water from the soil when cultivated individually; when cultivated in intercropping, the evaporation is reduced due to the shading that the two cultures provide to the soil.

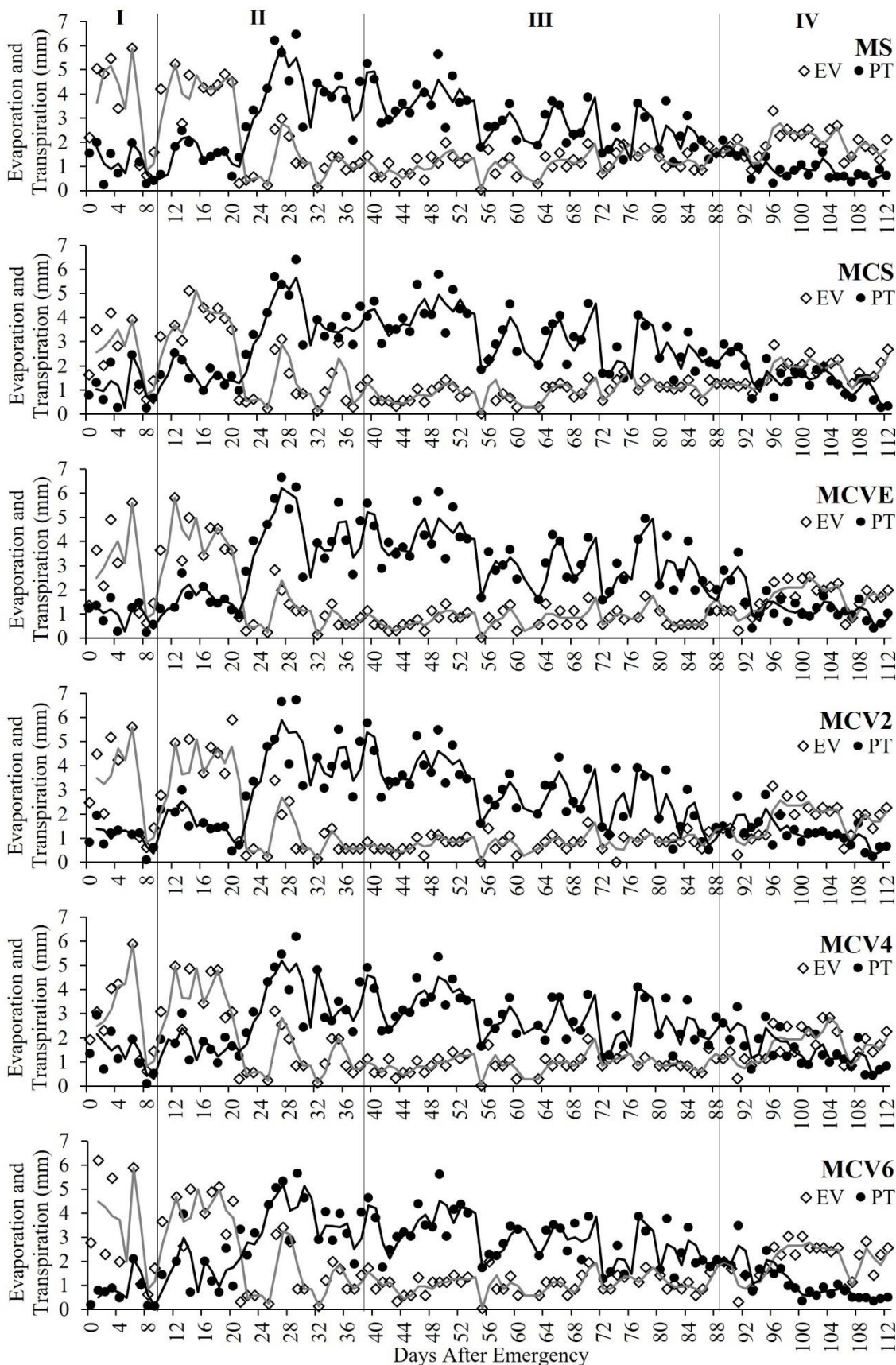
In relation to transpiration, there were significant differences between treatments only in the intermediate phase, with 3.23 and 3.29 mm d<sup>-1</sup> for treatments with crotalaria sowing simultaneously with maize and crotalaria sowing with maize in the VE stage, respectively. Crop evapotranspiration did not show significant differences in the values obtained between treatments in any of the development stages, showing some differences between stages within the same treatment. The total value represented in the table refers to the sum of the averages for each stadium, multiplied by the duration of days in each stadium. To obtain crop evapotranspiration (ET<sub>c</sub>), evaporation plus transpiration is added. The ET<sub>c</sub> values of single maize and maize intercropped with crotalaria showed the same behavior trend, increasing according to the stage of the crop and decreasing values in the final stage.

The ET<sub>c</sub> values in a single maize crop were higher than those found in treatments with different sowing times in the intercropping of crotalaria with maize. This difference occurs because in the intercropping system, there are two cultures involved, as opposed to the single cultivation system. Studies mention that the demand for water in an intercropping system tends to be higher compared to single cultivation [37, 38]; however, this depends on the cultivar used, location and time of year of cultivation, among other factors intrinsic to the intercropping system [39].

The results obtained corroborate those found by Souza et al. [40], who found ET<sub>c</sub> values for maize in single cultivation and in intercropping systems, of 387.1 to 439.4 mm, respectively, where it reports that the consumption of water by the culture in single cultivation was 12% lower compared to cultivation in intercropping systems. For the cultivation of maize intercropped with brachiaria (*Urochloa ruziziensis*), Fietz et al. [36] observed a water demand of 401 mm, with an average of 3.1 mm d<sup>-1</sup>. However, there is little information on water consumption in the intercropping between maize and crotalaria, and only recently have some studies been carried out on the water demand of intercropped maize in Brazil. However, authors emphasize that the ET<sub>c</sub> of a single or intercropped crop varies according to climate elements and may vary from region to region [41, 42].

Fig. 4 shows the average daily values of soil water evaporation and plant transpiration for the treatments evaluated during the experimental period. Evaporation was responsible for a considerable proportion of ET<sub>c</sub> in the first two phases and decreased with time and with the increase in the leaf area index (LAI) [43]. Both the single crop maize and the intercropping system with crotalaria showed higher values in relation to soil water loss by evaporation in the initial phase of the crops, reducing evaporation in the development and intermediate phases and with a slight increase in the final stage.

Soil water evaporation presents higher values in the initial period of the cultures because in this period the LAI of the culture is smaller in relation to the other phases, so the soil received more solar energy and this resulted in greater loss of water for the atmosphere [43]. The small increase in soil water evaporation observed in the final phase is because maize is in the senescence period, with lower LAI values, which is also due to the greater passage of sunlight, which results in greater heat flux in the soil [44].



**Fig. 4.** Daily values of soil water evaporation (EV) and plant transpiration (PT). Phases: I = Initial; II = Development; III = Intermediate; and IV = Final

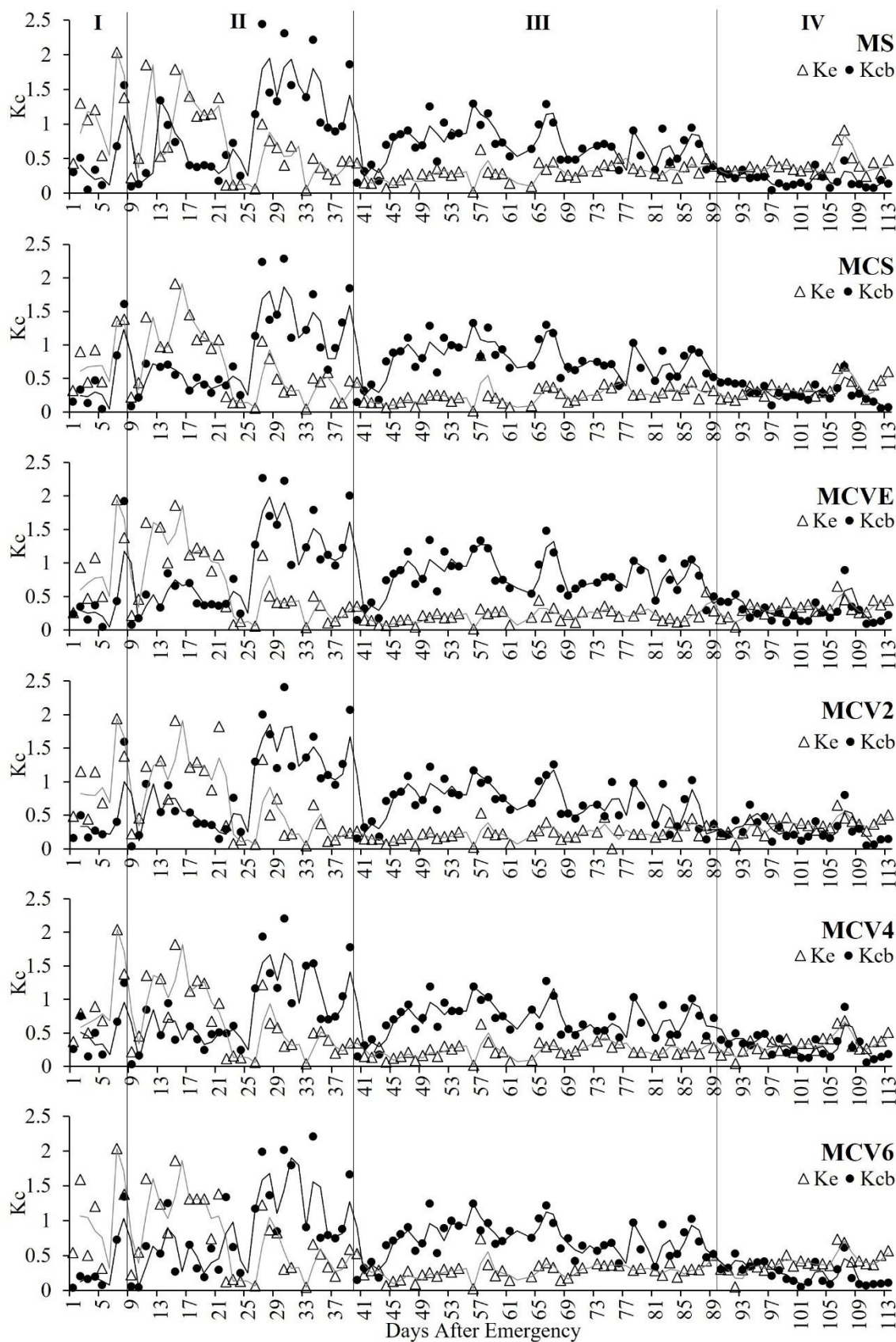
For plant transpiration, the behavior was the inverse of soil water evaporation in all treatments. In the development and intermediate phases, the plants presented an advanced leaf area development, where the shading of the soil between the rows of the crop was greater than in the initial phase, so that plant transpiration assumes greater importance in the crop's water consumption, reducing soil water evaporation. In the final stage of the crops, the plants start to senesce, the leaf area starts to decrease, and thus, the plants decrease their transpiration, and the evaporation values return and increase. Transpiration was less than evaporation at the early stage of crop growth in all treatments, where the total contribution to  $ET_c$  at this stage was almost entirely by soil water evaporation due to more water loss through evaporation from the soil surface and with low development of the aerial part of the plants and consequently low LAI [27, 45].

The soil water evaporation corresponds to 50.96%, and the transpiration of plants is 49.04% of the evapotranspiration process of the maize crop in single cultivation. For the cultivation of the consortium of maize and crotalaria planted simultaneously, soil water evaporation corresponds to 45.39%, and plant transpiration is 54.61%. For the partition of crop evapotranspiration from other sowing times of crotalaria intercropped with maize, soil water evaporation varied between 45.43 and 53.06%, and plant transpiration varied between 46.94 and 54.61%.

### ***Soil Water Evaporation Coefficient and Basal Crop Coefficient***

The real curves of daily soil water evaporation coefficient ( $K_e$ ) and basal crop coefficient ( $K_{cb}$ ) values show the same behavior between treatments, with higher  $K_e$  values at the beginning and higher  $K_{cb}$  values in the development and intermediate stages of the cultures (Fig. 5). The cultivation of maize intercropped with crotalaria provided a reduction in soil water evaporation, reducing  $K_e$  values, especially in the initial phase of the crops, provided by the shading of both crops. The mean values of  $K_e$  measured during the experiment were 0.60, 0.41, 0.51, 0.54, 0.52 and 0.59 for the MS, MCS, MCVE, MCV2, MCV4 and MCV6 treatments, respectively. Andrea et al. [46], working with lysimeters and microlysimeters for the maize crop, also reported similar behavior of  $K_e$  values, that is, initially high values, decreasing with the development of the crop and increasing again with its senescence. These same authors found  $K_e$  values of 0.71, 0.66, 0.26 and 0.55 and  $K_{cb}$  values of 0.39, 0.74, 0.94 and 0.54 for the initial, development, intermediate and final phases, respectively.

With respect to  $K_{cb}$ , the trend of initially low values is observed, with a slight increase, remaining with high values throughout the period of greater water demand for the crop. As the plants aged and entered senescence, the values of the basal culture coefficient also decreased. The peaks of  $K_{cb}$  values were observed in the developmental and intermediate stages, when the LAI had the maximum values. The  $K_{cb}$  increased for the intercropping treatments, but in the final phase, it decreased compared to the single maize treatment. The measured mean values of  $K_{cb}$  for these same treatments were 0.58, 0.61, 0.62, 0.59, 0.59 and 0.55, respectively. Zhang et al. [47] evaluated the  $K_{cb}$  values for summer off-season maize for three years, where they obtained values of 0.15, 1.15 and 0.45 for the initial, development and final phases. These values were similar to those estimated in the initial and intermediate phases and lower for the final phase compared to the present study for the region of Tangará da Serra, Mato Grosso, Brazil, where  $K_{cb}$  was 0.15 for the initial phase, 1.14 for the intermediate phase and 0.96 for the final phase, which demonstrates the variability of values for different regions with different temperatures.



**Fig. 5.** Daily values of soil water evaporation coefficient ( $K_e$ ) and basal crop coefficient ( $K_{cb}$ ). Phases: I = Initial; II = Development; III = Intermediate; and IV = Final

### Leaf Area Index (LAI)

In response to crop development, Ke was higher than Kcb in the early stage, and with an increase in LAI and plant shading, the resulting decreases in water evaporation from the soil surface and increases in plant transpiration can be explained by variations in Kcb and Ke as LAI results (Table 4).

**Table 4.** Leaf area index (LAI) of single maize and maize intercropped with crotalaria according to development stages and treatments (sowing times of crotalaria intercropped with maize)

Date	DAS	DAE	Maize stages	LAI for treatments (m <sup>2</sup> m <sup>-2</sup> )					
				MS	MCS	MCVE	MCV2	MCV4	MCV6
03/21/2020	14	8	V3	0.122	0.111	0.118	0.132	0.128	0.151
03/27/2020	20	14	V6	0.725	0.690	0.706	0.775	0.797	0.746
04/08/2020	32	26	V9	2.424	2.372	2.400	2.441	2.428	2.444
04/15/2020	39	33	V12	3.722	3.710	3.761	3.750	3.726	3.767
04/22/2020	46	40	VT	3.940	3.921	3.959	3.932	3.989	3.921
04/29/2020	53	47	R1	4.227	4.111	4.153	4.088	4.241	4.214
05/19/2020	73	67	R3	4.142	4.140	4.110	4.107	4.164	4.152
06/25/2020	110	104	R6	3.688	3.599	3.579	3.584	3.643	3.581

DAS = Days after sowing. DAE = Days after emergence. The maize crop development stages were defined according to the scale proposed by Ritchie et al. [26].

### Dual Crop Coefficient

The dual crop coefficient (dual Kc) values for the four phenological phases of the single maize crop and for the intercropping treatments are shown in Table 5. It is observed that the dual Kc showed little variation from the average, being reduced in the intercropped systems compared to the single maize, where the initial and developmental stages are characterized by greater water demand from crops. The dual Kc presented the highest values of standard deviation in the phases of greater water demand of the cultures.

**Table 5.** Dual crop coefficient (dual Kc) of single maize and maize intercropped with crotalaria according to the treatments used (sowing times of crotalaria intercropped with maize), measured in weighing lysimeters

Phases	Duration (days)	Dual Crop Coefficient (dual Kc)						SD	Average
		MS	MCS	MCVE	MCV2	MCV4	MCV6		
Initial	15	1.48	1.21	1.30	1.35	1.34	1.33	0.09	1.34
Development	31	1.66	1.57	1.61	1.61	1.50	1.62	0.05	1.60
Intermediate	50	1.00	1.04	1.01	0.92	0.95	0.99	0.04	0.99
Final	23	0.59	0.64	0.60	0.63	0.64	0.64	0.02	0.62
Total/Average	119	1.18	1.11	1.13	1.13	1.11	1.14	0.05	1.13

SD = Standard Deviation.

In the average of the entire cycle, the maize in single cultivation showed a higher value of dual Kc in relation to the intercropping treatments due to a greater participation of soil water evaporation in the process. A point to be considered is that at the end of the maize crop cycle at 119 DAE, crotalaria still had a high evapotranspiration power, with a high leaf area index.

Dehghanisani et al. [43] observed dual Kc values of single maize, in the initial phase from 0.38 to 0.44, in the development and intermediate phases from 1.22 to 1.90 and in the final phase from 0.63 to 0.65, close to those found in this work. Maize growth and senescence rates vary with maize cultivar, climate, soil nutrition level and field management practice, directly influencing phenology, which are the most vital aspects of developing appropriate dual crop coefficient values and with differences between different growing places [48].

### Maize productive characteristics

Based on the analysis of variance, for the analyzed variables of the maize crop, significant effects were verified for plant height, cob insertion height, stem diameter, cob diameter, cob mass, grain mass per plant, plant dry mass, root dry mass, root length, 1,000 grain mass and maize yield, with all other variables showing no significant effect by the F test between treatments (Table 6).

Among the intercropping systems when compared to single cultivation, we highlight that the height of the maize plant showed a reduction, as did the height of ear insertion and stem diameter. Maize yield in single cultivation did not show significant differences compared to the treatment with simultaneous sowing of crotalaria in intercropping. When the sowing of crotalaria was delayed in the MCV4 treatment, it decreased the yield compared to single maize. In a simultaneous maize and crotalaria sowing system (MCS), single maize yield does not show a significant difference in relation to intercropping. A correct choice of the species to be used, the proper sowing time and the proper management of intercropped crops are important factors and can significantly influence the maize yield [12].

**Table 6.** Variables analyzed for single and intercropped maize (*Zea mays L.*) according to the treatments used (sowing times of crotalaria intercropped with maize)

Variables	Treatments						MSD	CV (%)
	MS	MCS	MCVE	MCV2	MCV4	MCV6		
PH (cm)	245.6ab	253.6a	253.7a	246.0ab	240.6b	243.9b	9.2**	1.6
CIH (cm)	106.9ab	112.8a	111.3ab	107.9ab	100.2b	104.5ab	11.7*	4.8
SD (mm)	22.0a	21.7ab	21.2ab	21.0ab	20.4ab	20.0b	1.7*	3.6
CL (cm)	20.1a	19.6a	19.5a	19.8a	19.0a	19.2a	1.5 <sup>ns</sup>	3.4
CD (mm)	52.1ab	52.2ab	52.5a	51.9ab	49.4b	49.7b	2.7**	2.3
CM (g)	332.0a	326.9ab	319.1abc	316.1abc	280.6bc	279.6c	46.4**	6.5
NRC	15.9a	15.6a	16.0a	15.9a	15.1a	15.0a	1.2 <sup>ns</sup>	3.4
NGR	33.6a	34.2a	34.5a	34.3a	33.3a	35.0a	3.9 <sup>ns</sup>	5.0
NGC	529.1a	533.1a	550.9a	542.8a	501.6a	523.9a	69.9 <sup>ns</sup>	5.7
GMP (g)	210.7a	208.6ab	203.9ab	201.2ab	184.4b	186.9ab	26.3*	5.7
PDM (g)	157.3a	156.4a	154.7a	145.3a	145.9a	148.9a	22.6 <sup>ns</sup>	6.5
DRM (g)	96.4a	91.5b	83.0c	86.1c	89.8b	92.2b	3.7**	1.8
RL (cm)	51.3ab	49.7b	50.8ab	51.4ab	52.1ab	53.1a	3.0*	2.6
HI	1.35a	1.34a	1.33a	1.39a	1.28a	1.26a	0.2 <sup>ns</sup>	5.1
1000GM (g)	404.4a	393.4ab	372.5ab	372.7ab	369.1ab	358.0b	40.5*	4.7
Y (kg ha <sup>-1</sup> )	11705.0a	11587.1ab	11327.1ab	11179.2ab	10244.8b	10384.0ab	1458.4*	5.7

Means followed by the same letter in the line do not differ statistically from each other by the Tukey test. <sup>ns</sup> = not significant; \* = significant at 5% probability; \*\* = significant at 1% probability by F test. MSD = Minimum Significant Difference; CV = Coefficient of variation; PH = Plant height; CIH = Cob insertion height; SD = Stem diameter; CL = Cob length; CD = Cob diameter; CM = Cob mass; NRC = Number of rows per cob; NGR = Number of grains per row; NGC = Number of grains per cob; GMP = Grain mass per plant; PDM = Plant dry mass; DRM = Dry root mass; RL = Root length; HI = Harvest index; 1000GM = 1,000 grain mass; and Y = Maize yield.

### *Crotalaria Productive Characteristics*

For the studied variables of the crotalaria crop, it can be observed in the summary of the variance analysis that there was a significant difference between the treatments for all the studied variables (Table 7). As seen in this study, the sowing time of crotalaria intercropped with maize influenced all its characteristics. When the maize crop is sown simultaneously, it presents higher values of characteristics compared to when the intercropping sowing is delayed, affecting the final green and dry mass.

**Table 7.** Mean values of the analyzed variables of crotalaria (*Crotalaria spectabilis* Roth.) intercropped with maize, according to the treatments used (sowing times of crotalaria intercropped with maize)

Variables	Treatments					Fc	MSD	CV (%)
	MCS	MCVE	MCV2	MCV4	MCV6			
PH (cm)	102.8a	63.5b	55.7c	55.1c	46.1d	147.9**	7.2	15.5
SD (mm)	7.3a	5.5b	5.2c	4.9c	4.5d	125.4**	0.4	9.6
RL (cm)	33.7a	24.5b	24.1b	21.7b	21.4b	29.6**	3.6	20.2
GPM (g plant <sup>-1</sup> )	32.3a	18.8bc	19.2bc	19.9b	18.0c	162.5**	1.9	11.9
DMP (g plant <sup>-1</sup> )	11.1a	5.7c	6.1bc	6.1b	6.0bc	540.2**	0.4	7.8
RDM (g plant <sup>-1</sup> )	3.5a	3.1b	3.1b	3.1b	3.1b	148.9**	0.1	2.3
GMP (kg ha <sup>-1</sup> )	10769.7a	6272.1bc	6405.7bc	6644.5b	5981.7c	162.6**	615.4	11.9
DMP (kg ha <sup>-1</sup> )	3687.9a	1897.0c	2016.4bc	2032.5b	1988.3bc	540.2**	128.9	7.8

Means followed by the same letter in the line do not differ statistically from each other by the Tukey test. <sup>ns</sup> = not significant; \* = significant at 5% probability; \*\* = significant at 1% probability by F test. MSD = Minimum Significant Difference; CV = Coefficient of variation; PH = Plant height; SD = Stem diameter; RL = Root length; GPM = Green plant mass; DPM = Dry plant mass; RDM = Root dry mass; GMP = Green mass production; DMP = Dry mass production.

The cultivation of maize intercropped with crotalaria becomes viable for installation, mainly because it can be carried out in a mechanized manner, and it can be sown simultaneously with maize or even with maize at stage V6. At the time of harvest, crotalaria between rows can harm the harvest, so delaying sowing can help, because as seen in this study, the longer it took to sow crotalaria between the rows of maize (maize in stages V2, V4 and V6), lower plant height and dry mass it presented.

Mechanized maize harvesting with the use of intercropping is made possible by the maize having greater crop spacing, 0.75 to 1.00 m between rows when grown in intercropping, and having ear insertion height above 1.0 m, harvesting only the maize seed, which allows harvesting without further damage to intercropping and provides straw for soil protection [8, 49].

The use of intercropped crops usually presents significant results after a few years of cultivation due to the greater accumulation of nutrients and organic matter in the soil, an effect that only occurs over time [50]; therefore, it is believed that the greatest benefits of vegetable coverings in intercropping with maize, especially crotalaria, are used by crops in succession to intercropping [51].

## CONCLUSIONS

The cultivation of maize intercropped with crotalaria showed lower soil water evaporation and greater plant transpiration compared to single maize for all times of crotalaria sowing, except for the last one (MCV6 treatment). The water demand was similar among all the treatments evaluated, with an average of 483.14 mm during the

cycle. There was no competition for water in the cultivation of maize intercropped with crotalaria, as the transpiration of plants observed in the cultivation of single and intercropped maize proves this. The use of intercropping between maize and crotalaria at any time of sowing of crotalaria between maize rows reduces  $K_e$  values and increases  $K_{cb}$  values; that is, it reduces soil water evaporation and increases plant transpiration. The intercropping of maize with crotalaria provided a reduction in the average dual  $K_c$  throughout the cycle due to the reduction in soil water evaporation, resulting in a reduction in the volume of water to be applied via irrigation when necessary. Intercropping significantly influenced most of the maize yield variables at different times of crotalaria sowing between maize rows. Maize productivity showed significant differences only for the MCV4 treatment between the sowing times of crotalaria intercropped with single maize cultivation. It is possible to cultivate maize in an intercropping system in any evaluated sowing time of crotalaria, but sowing of crotalaria simultaneously with maize and with maize in the VE, V2 and V4 stages is the most indicated.

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## REFERENCES

- [1] USDA. United States Department of Agriculture (2022): Production, Supply and Distribution (PSD) online. <http://apps.fas.usda.gov/psdonline/app/index.html#/app/home> (Date of access: 12.11.2022).
- [2] CONAB (2021): Acompanhamento da safra brasileira: grãos. Safra 2020/21. 1st ed. Brasília, Brazil: Companhia Nacional de Abastecimento. <https://www.conab.gov.br/info-agro/safra/safra-graos/boletim-da-safra-de-graos> (Date of access: 08.12.2022). (In Brazilian Portuguese)
- [3] Teodoro, P. E., Silva Junior, C. A. da, Ribeiro, L. P., Silva, F. A. da, Corraa, C. C. G., Zanuncio, A. D. S., Torres, F. E. (2015): Sample dimension for estimation of biomass and yield of sunn (*Crotalaria juncea* L.) and showy rattlebox (*C. spectabilis* Roth.). *Journal of Agronomy* 14(2): 98-101. <https://dx.doi.org/10.3923/ja.2015.98.101>
- [4] Teodoro, R. B., Oliveira, F. L. de, Silva, D. M. N. da, Fávero, C., Quaresma, M. A. L. (2011): Agronomic aspects of leguminous to green fertilization in the Cerrado of the High Jequitinhonha Valley. *Revista Brasileira de Ciência do Solo* 35(2): 635-643. <http://dx.doi.org/10.1590/S0100-06832011000200032>
- [5] Bedoussac, L., Journet, E. P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E. S., Prieur, L., Justes, E. (2015): Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. *Agronomy for Sustainable Development* 35(3): 911-935. <http://dx.doi.org/10.1007/s13593-014-0277-7>
- [6] Paz, L. B. da, Gallo, A. de S., Souza, R. de L., Oliveira, L. V. N. de, Cunha, C. da, Silva, R. T. da. (2017): Performance and productivity of winter maize intercropped with legumes in an organic system. *SCAP - Revista de Ciências Agrárias* 40(4): 788-794. <https://doi.org/10.19084/RCA16240>
- [7] 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. *Brazilian Journal of Maize and Sorghum* 17(3): 431-444. <http://dx.doi.org/10.18512/1980-6477/rbms.v17n3p431-444>
- [8] 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>
- [9] Silva, G. S. da, Pereira, F. A. de C., Santana, R. A., Meneses, T. N., Sobrinho, O. P. L., Rosario, A. S. do. (2020). Calibration of a weighing lysimeter for measuring cocoa evapotranspiration. *Revista Caatinga* 33(3): 803-814. <https://doi.org/10.1590/1983-21252020v33n324rc>
- [10] Alcântara Neto, F. de, Petter, F. A., Pavan, B. E., Schmitt, C. R., Almeida, F. A. de, Pacheco, L. P., Piauilino, A. C. (2012): Agronomic performance of soybean cultivars under two sowing times in the savanna of Piauí State, Brazil. *Comunicata Scientiae* 3(3): 215-219. <https://doi.org/10.14295/cs.v3i3.107>
- [11] Gitti, D. de C., Arf, O., Vilela, R. G., Portugal, J. R., Kaneko, F. H., Rodrigues, R. A. F. (2012): Sowing dates of sunn hemp intercropped with corn. *Brazilian Journal of Maize and Sorghum* 11(2): 156-168. <http://dx.doi.org/10.18512/1980-6477/rbms.v11n2p156-168>
- [12] Chieza, E. D., Guerra, J. G. M., Araújo, E. da S., Espíndola, J. Á., 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. <http://dx.doi.org/10.1590/0034-737X201764020012>
- [13] Tiecher, T. (2016): Manejo e conservação do solo e da água em pequenas propriedades rurais no sul do Brasil: práticas alternativas de manejo visando a conservação do solo e da água. Ph.D Diss., Federal University of Rio Grande do Sul, Porto Alegre, Brazil. (In Brazilian Portuguese)
- [14] 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. D. A. (2018): 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>
- [15] Souza, R. T. de, Valadão, F. C. de A., Júnior, D. D. V., 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>
- [16] Santos, H. G. dos, Jacomine, P. K. T., Anjos, L. H. C. dos, Oliveira, V. A. de, Lumberras, J. F. (2018): Brazilian Soil Classification System. 5th ed. Brasília, Brazil: Brazilian Agricultural Research Corporation. (In Brazilian Portuguese)
- [17] Souza, A. P. de, Mota, L. L. da, Zamadei, T., Martin, C. C., Almeida, F. T. de, Paulino, J. (2013): Climate classification and climatic water balance in Mato Grosso state, Brazil. *Nativa* 1(1): 34-43. <https://doi.org/10.31413/nativa.v1i1.1334>
- [18] 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>
- [19] Fenner, W., Dallacort, R., Faria Junior, C. A., Freitas, P. S. L. de, Queiroz, T. M. de, Santi, A. (2019): Development, calibration and validation of weighing lysimeters for measurement of evapotranspiration of crops. *Revista Brasileira de Engenharia Agrícola e Ambiental* 23(4): 297-302. <https://doi.org/10.1590/1807-1929/agriambi.v23n4p297-302>
- [20] ALFA INSTRUMENTOS (2020): Célula de Carga – SV. <https://www.alfainstrumentos.com.br/produto/sv/>. (Date of access: 11.10.2019). (In Brazilian Portuguese)
- [21] Faria, R. T. de, Campeche, L. F. de S. M., Chibana, E. Y. (2006): Construction and calibration of high precision lysimeters. *Revista Brasileira de Engenharia Agrícola e Ambiental* 10(1): 237-242. <https://doi.org/10.1590/S1415-43662006000100035>
- [22] Campeche, L. F. de S. M., Netto, A. O. A., Sousa I. F., Faccioli G. G., Silva V. de P. R. da, Azevedo, P. V. D. (2011): A large-scale weighting lysimeter. part I: development and

- calibration. *Revista Brasileira de Engenharia Agrícola e Ambiental* 15(5): 519-525. <http://dx.doi.org/10.1590/S1415-43662011000500013>
- [23] Fancelli, A. L., Dourado Neto, D. (2004): *Produção de milho*. 2nd ed. Guaíba, Brazil: Agropecuária. (In Brazilian Portuguese)
- [24] Oliveira, P. de, Kluthcouski, J., Favarin, J. L., Santos, D. de C. (2010): *Sistema Santa Brígida – Tecnologia Embrapa: consorciação de milho com leguminosas*. Brazilian Agricultural Research Corporation - Embrapa Arroz e Feijão. Santo Antônio de Goiás, Brazil. (In Brazilian Portuguese)
- [25] Garcia, R. A., Staut, L. A. (2018): Como inserir crotalária em sistemas de produção de grãos. Brazilian Agricultural Research Corporation - Embrapa Agropecuária Oeste. Dourados, Brazil, pp. 1-12. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/191614/1/CT-44.pdf>. (Date of access: 11.08.2020). (In Brazilian Portuguese)
- [26] Ritchie, S. W., Hanway, J., Benson, J. B. (1993): *How a corn plant develops*. Iowa State University of Science and Technology. Ames, United States of America.
- [27] Allen, R. G., Pereria, L. S., Raes, D., Smith, M. (1998): *Crop evapotranspiration. Guildelines for Computing Crop Water Requirements*. Fao Irrigation and Drainage Paper No.56, Rome, Italy.
- [28] Flumignan, D. L., Faria, R. T. de, Lena, B. P. (2012): Test of a microlysimeter for measurement of soil evaporation. *Engenharia Agrícola* 32(1): 80-90. <https://doi.org/10.1590/S0100-69162012000100009>
- [29] Wolschick, D., Carlesso, R., Petry, M. T., Jadoski, S. O. (2003): Nitrogen application on maize cultivated under no-tillage system in a year with normal precipitation and with "El-Niño". *Revista Brasileira de Ciência do Solo* 27(3): 461-468. <http://dx.doi.org/10.1590/S0100-06832003000300008>
- [30] Sangoi, L., Schmitt, A., Zanin, C. G. (2007): Leaf area and grain yield of maize hybrids at different plant populations. *Brazilian Journal of Maize and Sorghum* 6(3): 263-271.
- [31] Ferreira, D. F. (2011): Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia* 35(6): 1039-1042. <https://doi.org/10.1590/S1413-70542011000600001>
- [32] Cruz, J. C., Karam, D., Monteiro, M. A. R., Magalhães, P. C. (2008): *A cultura do milho*. Brazilian Agricultural Research Corporation - Embrapa Milho e Sorgo. 1st ed. Sete Lagoas, Brazil.
- [33] 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. <http://dx.doi.org/10.51359/2238-6211.2017.229254>
- [34] Bergamaschi, H., Matzenauer, R. (2014): *O milho e o clima*. Emater/RS-Ascar. Porto Alegre, Brazil. (In Brazilian Portuguese)
- [35] Pegorare, A. B., Fedatto, E., Pereira, S. B., Souza, L. C. F., Fietz, C. R. (2009): Supplemental irrigation in the cycle of "safrinha" corn under no-tillage system. *Revista Brasileira de Engenharia Agrícola e Ambiental* 13(3): 262-271. <https://doi.org/10.1590/S1415-43662009000300007>
- [36] Fietz, C. R., Comunello, É., Garcia, R. A., Flumignam, D. L., Ceccon, G. (2019): Demanda hídrica e coeficientes de cultivo de milho safrinha consorciado com braquiária. *Agrometeoros* 27(2): 325-330. <http://dx.doi.org/10.31062/agrom.v27i2.26447> (In Brazilian Portuguese)
- [37] Souza, A. P. de, Lima, M. E. de, Carvalho, D. F. de. (2012): Evapotranspiration and crop coefficients of corn in monoculture and intercropping system with gray mucuna, using weighing lysimeters. *Revista Brasileira de Ciências Agrárias* 7(1): 142-149. <http://dx.doi.org/10.5039/agraria.v7i1a802>
- [38] Araújo, M. S. P. de, Sousa, E. F. de, Pereira, V. R., Ferreira, F. H. A., Carvalho, D. F. de (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>

- [39] Ceccon, G. (2013): Consórcio Milho-Braquiária. Brazilian Agricultural Research Corporation - Embrapa Agropecuária Oeste. Brasília, Brazil. (In Brazilian Portuguese)
- [40] Souza, L. S. B. de, Moura, M. S. B. de, Sedyama, G. C., Silva, T. G. F. d.a (2015): Water requirement and crop coefficient of maize and cowpea in sole and intercropping systems. *Revista Caatinga* 28(4): 151-160. <https://doi.org/10.1590/1983-21252015v28n417rc>
- [41] Sampaio, P. R. F., Miranda, N. de O., Medeiros, J. F. de, Lima, R. M. de S., Santos, W. de O. (2016): Water requirement of *Crotalaria juncea* L. as a response to soil residual salinity. *Irriga* 21(2): 211-225. <https://doi.org/10.15809/irriga.2016v21n2p211-225>
- [42] Sanches, A. C., Souza, D. P. de, Jesus, F. L. de F., Mendonça, F. C., Maffei, R. G. (2017): Water consumption of tropical forage grasses in the period of pasture formation. *Revista Brasileira de Agricultura Irrigada* 11(2): 1291-1301. <http://dx.doi.org/10.7127/rbai.v11n200606>
- [43] Dehghanisani, H., Kanani, E., Akhavan, S. (2020): Evapotranspiration and components of corn (*Zea mays* L.) under micro irrigation systems in a semi-arid environment. *Spanish Journal of Agricultural Research* 18(2): e1202. <http://dx.doi.org/10.5424/sjar/2020182-15647>
- [44] Faria Junior, C. A., Dallacort, R., Freitas, P. S. L. de, Barbieri, J. D., Rezende, R., Fenner, W. (2019): Dual crop coefficient of maize corn of Tangará da Serra-MT. *Irriga* 24(3): 473-485. <http://dx.doi.org/10.15809/irriga.2019v24n3p473-485>
- [45] Valentín, F., Nortés, P. A., Domínguez, A., Sánchez, J. M., Intrigliolo, D. S., Alarcón, J. J., López-Urrea, R. (2020): Comparing evapotranspiration and yield performance of maize under sprinkler, superficial and subsurface drip irrigation in a semi-arid environment. *Irrigation Science* 38(1): 105-115. <https://doi.org/10.1007/s00271-019-00657-z>
- [46] Andrea, M. C. da S., Vieira, F. F., Dallacort, R., Barbieri, J. D., Freitas, P. S. L. de, Tieppo, R. C., Zolin, C. A., Krause, W., 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>
- [47] Zhang, B., Liu, Y., Xu, D., Zhao, N., Lei, B., Rosa, R. D., Paredes, P., Pereira, L. S. (2013): The dual crop coefficient approach to estimate and partitioning evapotranspiration of the winter wheat–summer maize crop sequence in North China Plain. *Irrigation Science* 31(6): 1303-1316. <https://doi.org/10.1007/s00271-013-0405-1>
- [48] Wang, Y., Cai, H., Yu, L., Peng, X., Xu, J., Wang, X. (2020): Evapotranspiration partitioning and crop coefficient of maize in dry semi-humid climate regime. *Agricultural Water Management* 236: 106164. <https://doi.org/10.1016/j.agwat.2020.106164>
- [49] Cortez, J. W., Furlani, C. E. A., Silva, R. P. da (2009): Fertilization system and intercalating crops consortium and their effects on variables of corn crop harvest. *Engenharia Agrícola* 29(2): 277-287. <https://doi.org/10.1590/S0100-69162009000200011>
- [50] Pereira, L. C., Fontanetti, A., Batista, J. N., Galvão, J. C.C., Goulart, P. L. (2011): Behavior of corn cultivars when intercropped with *Crotalaria juncea*: preliminary study. *Revista Brasileira de Agroecologia* 6(3): 191-200.
- [51] Kappes, C., Zancanaro, L. (2015): Intercrop systems of brachiaria and crotalarias with maize crop. *Brazilian Journal of Maize and Sorghum* 14(2): 219-234. <http://dx.doi.org/10.18512/1980-6477/rbms.v14n2p219-234>