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Yield and water use efficiency of cauliflower under irrigation different levels in tropical climate

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The aim of the present study is to assess the effects of different irrigation blades on the growth and yield of cauliflower cv. Verona CMS. The plants were cultivated in Red-yellow Latosol during the dry period (winter-spring 2014 and 2015), in the Cerrado-Amazon transition region, Middle-Northern of Mato Grasso State, Brazil. The reference evapotranspiration (ETo) was recorded through the Class A pan method by using tank coefficient of (Kp) 0.7795. We assessed the blades of 40, 60, 80, 100 and 120% evapotranspiration of the culture (ETc) by taking into account the cultivation coefficients (Kc) of 0.70 and 0.95 in the vegetative and reproductive phases. With regard to the morphometric variables of the plants (height, stem diameter and number of leaves) there were no significant interactions between assessment time (days after planting) and irrigation blades throughout the crop years. The hydric response functions presented higher yield at repositions from 80% to 100% of ETc. Variations in the irrigation blade did not influence the thermal demands for the inflorescence differentiation period or the inflorescence shape. Increased irrigated blade reduced water use efficiency: 7.4 and 12.4 kg of fresh mass per m³ of irrigated water.

Key words: Irrigation management, water response function, degree-days, evapotranspiration.

INTRODUCTION

The space distribution of vegetable production centers in Brazil depends on economic, logistical, social and environmental factors (Garcia Filho et al., 2017). Mato Grosso State presents some obstacles for the offer of vegetables due to the high transportation costs and quality losses on products to be consumed *in-natura*,

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mainly in the North of the State. The fast economic growth in some counties (for instance, Sinop: 51.12 and 10.4% population and economic growth in the last decade – IBGE, 2010) led to fast growth of local demands for fruits and vegetables. However, along with the distance from producing centers, knowledge about the yield and physiological features of crops traditionally cultivated in temperate climate regions or in high altitude areas remains poor.

The vegetable production sector has great social importance because of its high demand for man-power and the generation of many direct and indirect job positions in all production stages, including trading. However, the sector faces high risks due to phytosanitary issues, its high sensitivity to weather conditions, its high vulnerability to offer and market seasonality, among others (Zanuzo et al., 2013; Garcia Filho et al., 2017; Ribeiro et al., 2017). The vegetable production sector demands faster development of new technologies than other production systems in order to comply with the different regional conditions in Brazil. Such need results from intrinsic peculiarities of product diversity, production cycle duration, input features and demands, irrigation, fertilization and culture traits.

The aforementioned scenario highlights that the horticultural sector can also have strong environmental impact caused by the use of agricultural pesticides, chemical fertilizers and by the capture of irrigation water. Therefore, the sector has been looking for sustainable management procedures capable of preserving the natural resources and of replacing the conventional production systems (Souza et al., 2013). The absence of appropriate water management is easily observed in irrigated areas, and it results in excessive water and energy use and waste, besides causing environment and plant phytosanitary issues. On the other hand, irrigation deficit impairs the development of culture because it reduces irrigation development and makes the final product unviable for trading and consumption. Therefore, such deficit results in reduced yield and, consequently, in losses to producers (Pereira et al., 2016; Domínguez et al., 2017; Lellis et al., 2017; Koksal et al., 2017; Seidel et al., 2017).

Thus, appropriate irrigation management practices help to increase yield, improve the quality of horticulture products, minimize water use and preserve the water resources, mainly in tropical climate regions facing water restriction periods. Irrigation management sets the time for irrigation and the amount of water based on culture demand, in order to get an efficient irrigation water management. It is essential to know the water needs of the culture in its different phenological phases, which are given by the evapotranspiration potential and water response functions (Sarkar et al., 2009; Souza et al., 2011a, b; Yavuz et al., 2015). Overall, vegetables are extremely dependent on appropriate water input, in all development phases, for biomass production at acceptable amounts and quality. This sector is one of the most demanding in the agricultural sector due to its irrigation water demand (Sousa et al., 2011; Tomassoni et al., 2013; Silva et al., 2014; Léllis et al., 2017; Seidel et al., 2017). Thus, the search for sustainable management ways capable of allowing the preservation of natural resources and the replacement of conventional production systems is growing (Souza et al., 2013).

Among the many vegetables available in Brazil is cauliflower (*Brassica olerac*ea L. var botrytis L.) belonging to Brassicas family; it is included in the group of the most consumed ones, due to its high nutrition and commercial value (May et al., 2007; Torres et al., 2015; Garcia Filho et al., 2017). Light and temperature are among the environmental factors mostly limiting cauliflower cultivation in different times of the year and locations. Vegetables present reduced cultivation cycle when they are grown under temperature conditions above the proper rates recommended for their growth. Such feature reflects on their yield and quality (Puiatti and Finger, 2009) indicating that the weather conditions in some regions can limit their cauliflower production in a part of the year. The ideal environment or time of year, for cauliflower cultivation has been the main focus of countless research (Zanuzo et al., 2013; Ribeiro et al., 2017).

Cauliflower is sensitive to water deficit (Kochler et al., 2007; May et al., 2007; Tomassoni et al., 2013; Pereira et al., 2016). Its yield-response is influenced by irrigation amount and frequency, water application method, culture development stage, water physical and soil conditions, and micro-climatic conditions in the region (Sahin et al., 2009; Sarkar et al., 2009, 2010; Oliveira, 2015; Seidel et al., 2017).

Accordingly, it is essential to know the water needs of this culture and its water response functions in order to achieve efficient irrigation water management (Souza et al., 2011a). Thus, the aim of the present study is to assess the agronomic development of cauliflower cv. Verona CMS under different irrigations blades in Middle-Northern Mato Grosso State, Brazil.

MATERIALS AND METHODS

Study site

The experiment was conducted in the Vegetal Production Sector of UFMT, Sinop Campus (11.85°S and 55.38° W, altitude 371 m). Plants were cultivated in dystrophic Red-yellow Latosol (EMBRAPA, 2013) in two different production cycles at the transition between the dry and the rainy season (from June to November) in 2014 and 2015. The climate in the region was of the Aw type according to the Köppen classification (tropical warm and humid), with two well-defined seasons: rainy (from October to April) and dry (from May to September). These seasons, in their turn, have straight influence on solar radiation transmissivity (Souza et al., 2016) and on other meteorological elements (Table 1). The mean annual potential rainfall and evapotranspiration recorded 1974.77 and 1327.29 mm, respectively, and the mean monthly temperature varied from

Table 1. Mean monthly behavior of the meteorological variables in Middle-Northern Mato Grosso State from 06/1972 to 06/2010.

Months	Rainfall (mm)	Insolation (hours)	Maximum temp. (°C)	Average temp. (°C)	Minimum temp. (°C)	Relative humidity (%)	Wind speed ($m\ s^{-1}$)	Cloudiness time (hours)	Atmospheric pressure (hPa)
January	310.85	124.98	31.53	24.89	20.74	85.54	1.31	5.45	967.09
February	348.39	117.77	31.62	24.90	20.61	85.34	1.27	5.43	968.56
March	288.19	138.50	32.09	25.13	20.68	84.37	1.20	5.24	967.67
April	120.75	181.79	32.68	25.31	20.27	81.39	1.23	4.56	967.87
May	25.90	224.62	32.41	24.49	18.57	77.01	1.34	3.86	969.70
June	7.99	248.88	32.62	23.20	15.99	72.68	1.41	2.48	970.65
July	4.88	263.22	33.06	22.96	15.26	67.98	1.45	2.01	971.66
August	9.50	229.44	34.43	24.12	16.42	65.99	1.43	2.30	969.86
September	60.21	154.08	34.35	25.43	18.90	71.18	1.31	3.80	968.71
October	182.23	160.98	33.47	25.76	20.52	78.31	1.39	5.16	967.68
November	271.04	128.58	32.30	25.28	20.64	83.45	1.30	5.50	966.60
December	344.54	120.09	31.46	24.93	20.69	85.04	1.32	5.50	966.64

The conventional meteorological station belonged to the National Meteorology Institute (INMET), the so-called "Gleba Celeste", located at 12.29° S and 55.29° W, altitude 415.0m.

23.2 to 28.8°C (Souza et al., 2013). Meteorological data were collected by an automatic station through the CR 1000 data acquisition system during the experimental period, and through global solar radiation (piranometer CS300), wind speed and direction (anemometer, 03002-L RM YOUNG) sensors, as well as through a psychrometer with thermometer shelter (CS 215) and a rain sensor (TE 525).

Experimental design

The two experiments were conducted in the same site; however, millet (*Pennisetum americanum* L. cv. ANm 17) was pre-cultivated (further cutting, fragmentation and incorporation to the soil through harrowing) in order to improve the amount of organic matter in the rainy season of the 2015 crop. A completely randomized block design, with four repetitions (20 useful plants) and 5 daily irrigation-blade treatments were adopted. The drip irrigation system with self-compensating emitters, at flow rate of 7.0 L h^{-1} m^{-1} and service pressure of 10mca was employed.

The irrigation blades in 2014 (from July to November) were 60, 80, 100 and 120% of the evapotranspiration expected for the culture (Tec); in 2015, the blade was adjusted to 40% of ETC. The cultivation coefficients (kc) of 0.70 and 0.95 were used in the two production cycles in the vegetative and reproductive phases, respectively (Allen et al., 1998). The reference evapotranspiration (ETo) was recorded through the Class A tank method by taking into consideration the correction coefficients (kp) described by Souza et al. (2015) and Pedrosa et al. (2017).

$$ETo = ECA * Kp \quad (1)$$

$$ETc = ETo * Kc \quad (2)$$

where: ET_0 is the daily reference evapotranspiration (L m^{-2}); ETc is the evapotranspiration of daily culture (L m^{-2}); ECA is the evaporation of the daily class A pan (L m^{2}); Kp is the pan coefficient; Kc is the crop coefficient, which depends on the development stage.

Agronomic practices

Verona CMS (the assessed hybrid) has a good commercial acceptance and is recommended for cultivation in summer, since it is resistant to black rot. It has a white color inflorescence from 1.2 to 1.5 kg, besides presenting an approximate 100-day cycle (May et al., 2007; Zanuzzo et al., 2013;). The seedlings were produced in trays (128 cells) under 50%-shade black polyester fabric and capillary root zone irrigation. The transplantations were performed when plants presented between 4 and 5 expanded leaves (at August 1st, 2014 and July 11th, 2015) at spacing of 1.0 × 0.6 m (between rows and between plants). The soil in the experimental site presented 340, 170 and 495, 300, 188 and 512 g dm^{-3} of sand, silt and clay, at layers of 0-20 and 20-40 cm down the soil, respectively. The observed chemical features in the two cultivation years are shown in Table 2. In addition, values of 30.51 and 42.84 g dm^{-3} of total organic matter in the soil were found at 0-20 and 20-40 cm layers, respectively.

Cultivations were carried out under full sun light, without using dead cover on soil surface. Based on Filgueira (2005), 80, 350 and 200 kg ha^{-1} of N, P_2O_5 and K_2O, respectively were applied in the transplantation pit (base fertilization). Next, complementation with 150 kg ha^{-1} of N was conducted at 20, 40 and 60 days after transplantation (DAT). The application of 2.4 kg ha^{-1} of boron (borax – at 11% boron concentration) was performed on soil surface, close to the root system. Spontaneous vegetation control (weeds) was conducted through mechanical fashion and constant manual weeding in order to minimize competition with the culture. The phytosanitary treatments were performed whenever necessary, based on Figueira (2005) and May et al. (2007).

Crop observations

Non-destructive fortnight evaluations were conducted up to 120 DAT as a way to set plant height, stem diameter and number of leaves. The equatorial and longitudinal diameters, leaf area, fresh mass at inflorescence and shoot dry mass were obtained during the harvest (Hortibrasil, 2018). The yield performance was assessed through water use efficiency, by taking into account the water

Table 2. Chemical features of the soil in the experimental site at the two assessed depths in two production cycles.

Year	Depht of soil (cm)	pH (H_2O)	P (mg/dm³)	K	Ca	Mg	Al	H	S	T	V (%)
				cmol/dm³							
2014	0-20	5.7	2.44	0.14	1.9	1.16	0	3.1	3.2	6.3	50.78
	20-40	5.4	3.85	0.31	2.19	0.78	0.15	4.85	3.28	8.28	39.6
2015	0-20	6.1	2.09	0.06	1.97	0.78	0	3.63	2.81	6.44	43.63
	20-40	5.5	1.18	0.05	0.62	0.31	0.1	4.03	0.99	5.12	19.27

S: sum of the bases; T: CTC at pH 7.0; V: saturation of the bases (%).

volume of the irrigation blade, the rainfall records in inflorescence fresh mass production (EUA^1) and the water volume applied through irrigation (EUA^2). The meteorological measurements were collected every 5 min and stored, based on hourly and daily scales. The minimum (T_b) and maximum (TB) basal temperatures of 14 and 36°C (Nowbuth and Pearson, 1998) were applied in order to find the thermal sums (accumulated degree-days) for cauliflower plants. The proposal by Ometto (1981) was applied to cases suitable for it which depends on the local weather conditions, according to Souza et al. (2011b).

i) Case 1: Tm > Tb; TB > TM

$$GDD = ((TM – TB)^2)/2 + (Tm – Tb) \quad (3)$$

ii) Case 2: Tm ≤ Tb < TM ; TB > TM

$$GDD = ((TM – TB)^2)/(2(TM-Tm)) \quad (4)$$

iii) Case 3: Tb < Tm; TB < TM

$$GDD = 2[(TM\ Tm)\ (Tm – Tb)] + ((TM – Tm)^2) – ((TM – TB)^2) / (2(TM – Tm)) \quad (5)$$

iv) Case 4: Tb > Tm; TB < TM

$$GDD = 0.5 [((TM – Tb)^2) – ((TM – TB)^2)] / (TM – Tm) \quad (6)$$

Where: TM and Tm = maximum and minimum daily temperatures (°C). Tb and TB = minimum and maximum basal temperature

Statistical analysis

Data were subjected to analysis of variance; means were compared through the Tukey test at 5% probability whenever they were significant. Regressions were adjusted by taking into consideration the irrigated blade as independent variable. The statistical package Sisvar 5.5 Build 82 was used in the calculations.

RESULTS AND DISCUSSION

Meteorological dates

The climatic seasonality in the Sinop-MT region (Table 1) showed that the time to conduct the experiment was appropriate to assess the effect of irrigation blades, regardless of the year. Accumulated rainfall recorded 424.6 and 88.0 mm in 2014 and 2015, respectively. However, in 2014 only 50 mm was recorded up to 80 DAT (10/19th/14) (Figure 1). Such behavior was essential to minimize soil humidity homogenization (due to rainfall), mainly during culture vegetative development, which, in turn, would have direct influence on the hydric deficit effect over the productive components.

According to Santos et al. (2013), there are wider thermal amplitudes in winter in Sinop-MT region, since water steam has great potential to mitigate radiation in the atmosphere. Thus, the differences between night and daylight temperature in the rainy months was caused by radiation transmissivity reduction (daylight cycle) and by radiation incidence increase in long waves emitted by the atmosphere (night cycle). There was mitigation of the maximum temperature due to changes in the total of direct and diffuse components, caused by cloudiness and minimum temperature increase. This outcome resulted from balance of night long-waves (Souza et al., 2016). Accordingly, they recorded daily mean temperatures of 26.38, 27.32, 27.27 and 25.88°C between August and November 2014, and 25.17, 26.49, 28.38, 27.92 and 26.52°C between July and November, 2015, respectively.

Another significant effect of rainfall could be observed on the global radiation incidence (short waves) between the 2 production cycles. In 2014, the daily means were 27.16, 19.82, 20.53 and 18.32 MJ m^{-2} day^{-1} between August and November, whereas in 2015 (lower accumulated rainfall throughout the cultivation cycle), the daily means were 21.15, 22.34, 21.35, 21.88 and 18.63 MJ m^{-2} day^{-1} between July and November, respectively. If one takes into consideration that global radiation is formed by visible and infrared ultra-violet radiation, it was possible indicating more availability of photosynthetically active radiation in the winter of 2015, fact that led to better yield performance at the same water-reposition level. The daily thermal amplitudes varied from 14.7 to 20.0°C in August and from 4.94 to 14.4°C in November, 2014, whereas, in 2015, they varied from 15.1 to 21.5°C in July and from 7.9 to 14.0°C in November.

Cauliflowers grown under Brazilian conditions were recommended for typically temperate climate; however, nowadays it has been gaining space in tropical climate regions. The difficulty in producing winter cultivars in hot weather regions was based on the need of mild temperatures (14-20°C) to pass from the vegetative to the reproductive stage (Filgueira, 2005). Genetic enhancement made it possible to select cultivars capable

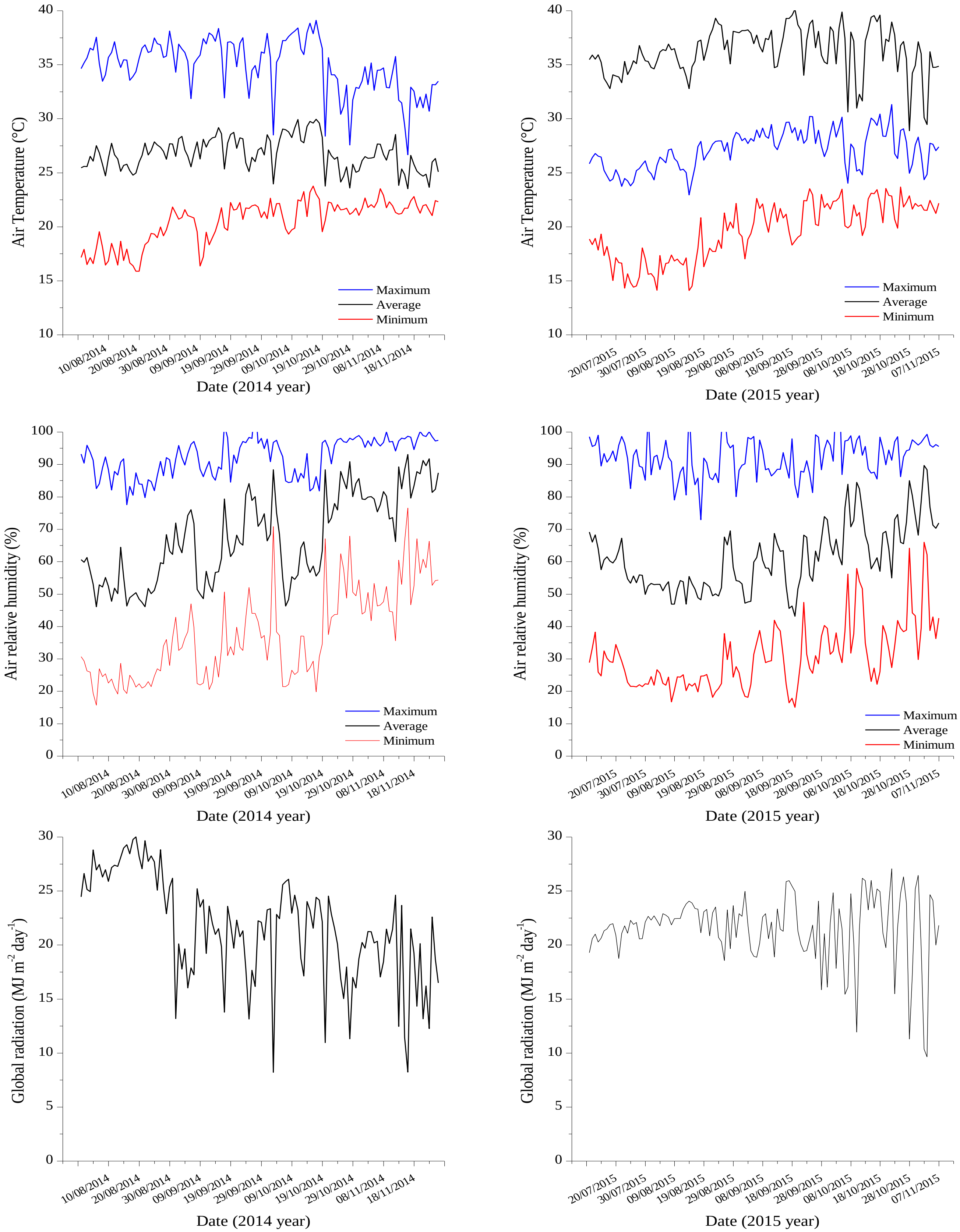

Figure 1. Air temperature variations, relative air humidity, global radiation, rainfall and reference evapotranspiration in Sinop-MT, from August to November, 2014 and 2015.

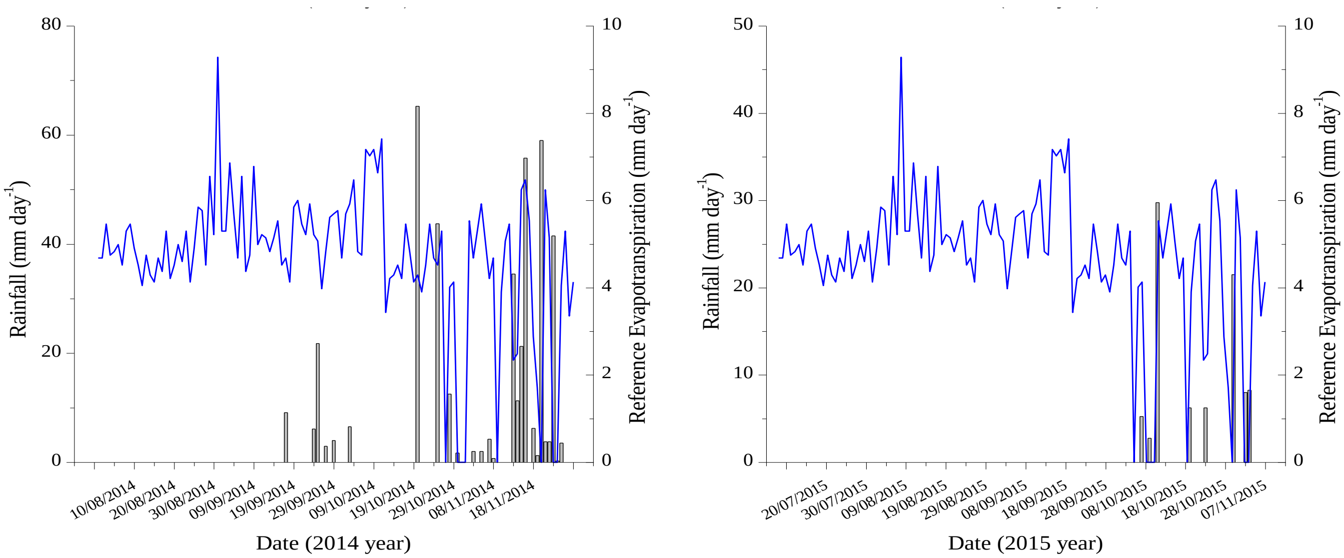

Figure 1. Contd.

of tolerating temperatures above 30°C (May et al., 2007) and it enabled cultivating this vegetable in tropical climate regions, as long as cultivars presenting wide adaptability were selected. Such process allowed these cultivars to be grown all year long (Claudio, 2013).

According to Filgueira (2005), there are cultivars with different thermo-climatic demands in Brazil, which can be gathered in two groups: the first one comprises cultivars adapted to plantation in fall-winter and the second one covers spring-summer cultivars, which do not demand cold, as well as develop and produce under higher temperatures. There are few open pollination cultivars in the second group, and the current trend is to replace them by hybrids (Cardoso and Silva, 2009). Zanuzo et al. (2013) assessed 8 genetic materials from different thermo-climatic demands in Sinop-Mt region. They concluded that hybrids belonging to group Verona present wide adaptability to regional conditions. Accordingly, despite the wide thermal amplitude in winter, due to rainfall, there was maximal temperature reduction and minimal temperature increase, so that temperatures within the ideal rate for the cultivation of hybrids belonging to group Verona were reached. These species were recommended for summer cultivation (Morais Junior et al., 2012; Zanuzo et al., 2013).

Table 3 synthesizes information encompassed in the monthly scale, total rainfall, evapotranspiration and the blade applied throughout the 117 (1149 degrees-days accumulated - GDA) and 119 (1396.4 GDA) cultivation days in 2014 and 2015. Such periods-of-time corresponded to the accumulation of 1449 and 1396.4 degrees-day, respectively. In Table 2, the effective rained blade was only higher than ETo in October and November 2014. Therefore, there was need of water reposition for 277.62 and 282 mm irrigation throughout the productive cycles. These values were references for the treatment with blade reposition of 100% ETc.

Rainfall changed the applied blade in the treatments because the experiment was conducted under field conditions. Thus, after irrigation (I) was added to the effective rainfall (Ef Ra), it was possible to verify the blades corresponding to 84.92 and 108% of ETc applied to treatments T1, T2 and T4 in 2014; to 54, 70, 85 and 115% of ETc to treatments T1, T2, T3 and T5 in 2015. However, all analyses linked to water use efficiency were taken into account, based on the initial % of the applied blade, since the differences between the two cultivation cycles were lower than 5.0mm when the treatments were defined.

The analysis of variance (ANOVA) did not show significant interactions between evaluation time (DAT) and the irrigation blade, regardless of the crop year. Isolated factors presented significant differences, and the effects throughout time (DAT) were assessed through regression based on the thermal sum (GDA) (Figure 2). The irrigation blades influenced plant height and the number of leaves from the 103 DAT and after on, in the 2014 production cycle. However, plants presented from 22.4 to 28.6 leaves between 89 h and 117 DAT (Table 4). The decreased number of leaves recorded at the end of the cycles resulted from the senescence of leaves closer to the soil (first leaves emitted by the plants).

On the other hand, the irrigation blades had an influence after the 109 DAT in the 2014 cycle. They led to higher mean height, wider stem diameters and larger number of leaves in the blades of 60 and 100% ETc reposition treatments. There was reduced growth and plant height in this production cycle, regardless of the

Table 3. Total mean values of effective rainfall (Ef Ra), reference evapotranspiration (ETo) and total blade applied through irrigation + effective rainfall (ETreal) during the evaluation periods, with treatment using 100% ETc reposition.

Year	Mês	Efective rainfall (Ef Ra) (mm)	Reference evapotranspiration (mm)	Applied wather depth (mm)	ETreal (mm)
2014	July	-	-	-	-
	August	0	161.2	80.6	80.6
	September	43.9	128.2	73.7	117.7
	October	129.7	119.6	83.9	213.6
	November	251.0	56.4	39.5	290.4
	Total	424.6	465.4	277.7	702.3
2015	July	0	99.4	49.7	49.7
	August	0	167.9	84.0	84.0
	September	0	158.3	79.2	79.2
	October	71.8	116.3	58.2	129.9
	November	16.3	22.0	11.0	27.2
	Total	88.0	563.9	282.0	370.0

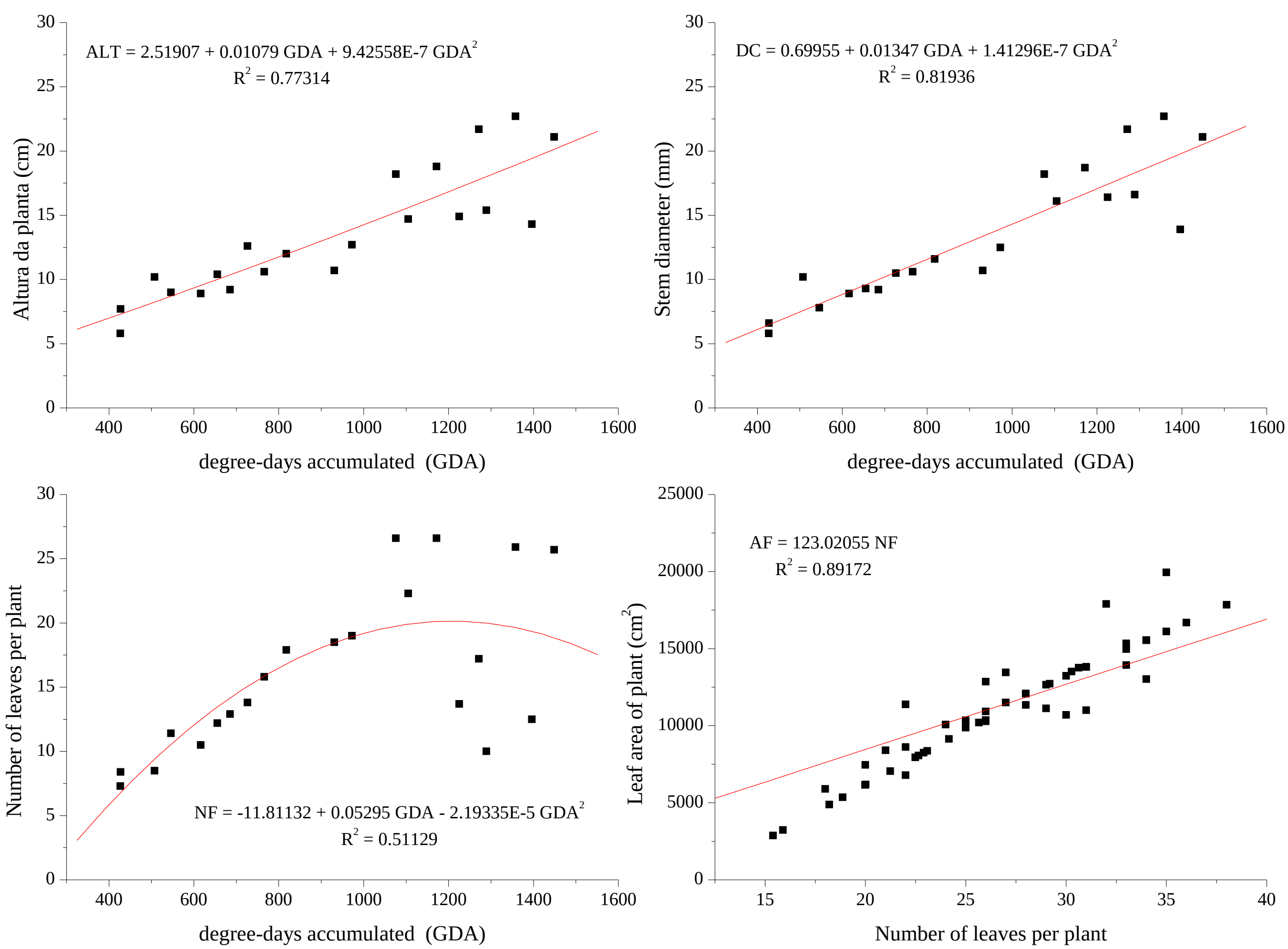

Figure 2. Estimates of the morphometric variables of cauliflower plants cv. Verona based on the accumulated thermal sum, by taking into consideration the two cultivation cycles (2014 and 2015) in Sinop-MT, Brazil.

Table 4. Morphometric variables of cauliflower plants cv. Verona under different irrigation blades and development phases, between August 21st and November 26th, 2014, in Sinop-MT, Brazil.

DAT	GDA	Plant height (cm)				Stem diameter (mm)				Number of leaves			
		L60*	L80*	L100*	L120*	L60	L80	L100	L120	L60	L80	L100	L120
32	426.9	7.1 [a]	6.6 [a]	3.8 [a]	5.6 [a]	3.9 [a]	3.9 [a]	3.7 [a]	3.2 [a]	8.1 [a]	7.3 [a]	6.7 [a]	6.9 [a]
39	507.6	9.6 [ab]	8.0 [b]	11.8 [a]	11.4 [a]	4.2 [a]	4.4 [a]	4.1 [a]	4.0 [a]	8.4 [a]	8.3 [a]	8.5 [a]	8.6 [a]
47	616.2	10.0 [a]	8.5 [a]	9.0 [a]	8.3 [a]	7.9 [a]	7.4 [a]	7.5 [a]	6.6 [a]	10.7 [a]	10.6 [a]	11.0 [a]	9.7 [a]
54	685.2	9.7 [a]	8.8 [a]	9.5 [a]	8.9 [a]	10.0 [a]	8.8 [a]	9.1 [a]	8.4 [a]	13.3 [a]	12.8 [a]	13.2 [a]	12.4 [a]
61	766.1	11.7 [a]	9.6 [a]	11.2 [a]	9.9 [a]	11.9 [a]	11.7 [a]	12.1 [a]	10.8 [a]	17.2 [a]	15.4 [a]	16.2 [a]	14.2 [a]
77	931.0	12.5 [a]	9.4 [a]	11.6 [a]	9.6 [a]	14.7 [a]	12.7 [a]	14.3 [a]	12.1 [a]	20.4 [a]	18.6 [a]	17.5 [a]	17.6 [a]
89	1076.0	19.3 [a]	17.6 [a]	18.9 [a]	17.2 [a]	23.6 [a]	20.4 [a]	21.6 [a]	19.2 [a]	28.5 [a]	26.4 [a]	27.0 [a]	24.6 [a]
96	1171.8	19.7 [a]	19.9 [a]	19.1 [a]	16.4 [a]	26.9 [a]	23.1 [a]	25.1 [a]	22.3 [a]	25.6 [a]	26.7 [a]	28.4 [a]	25.5 [a]
103	1271.6	24.2 [a]	20.8 [ab]	23.1 [a]	18.6 [b]	28.9 [a]	26.8 [a]	27.9 [a]	23.7 [a]	29.2 [a]	26.7 [ab]	28.6 [ab]	24.2 [b]
110	1357.9	24.3 [a]	22.1 [a]	22.6 [a]	21.7 [a]	36.3 [a]	31.7 [a]	34.2 [a]	30.8 [a]	26.8 [a]	26.2 [a]	24.8 [a]	25.8 [a]
117	1449.0	23.5 [a]	20.6 [ab]	18.4 [b]	21.8 [ab]	29.6 [a]	27.7 [a]	29.6 [a]	25.1 [a]	26.3 [ab]	27.0 [a]	22.4 [b]	26.9 [a]

*L60, L80, L100 and L120 correspond to the evapotranspiration reposition rate (irrigated blade) of the culture (ETc). Means followed by the same letter on the line (analysis of irrigation blade influence at the same evaluation day) did not differ from each other in the Tukey test at 5% probability.

morphometric variable or treatment, when values were compared to that of 2014; however, such result did not indicate yield decrease. Thus, such performance can be explained by the significant increase in cloudiness and i rainfall rates from October, 2014 and after. A significant change in the number of leaves between 77 and 89 DAT was observed. It is worth highlighting that solar radiation incidence on the surface of Earth is the main energy source for vegetal development, mainly for leaves, which need PAR (photosynthetic active radiation – one of the global radiation components) to make photosynthesis as the primary metabolism process in plants.

The irrigation blades led to significant differences in plant height, stem diameter and number of leaves at 5% probability (Table 5) in the 2015 crop, from the 73, 87 and 100 DAT and after, respectively. There was increase in the number of leaves, up to the 87 DAT, and further reduction (senescence) was noticed due to the beginning of the reproductive phase. Such performance is inherent to the cycle of this vegetable, which presents fast leaf-surface growth in order to allow greater production of photo-assimilates in the reproductive phases, and subsequent decrease after this phase.

The stem can be considered as an essential partition for plants, since it holds the conducting beams (xylem and phloem) responsible for taking water from the root system to the shoot, as well as for distributing the photo-assimilates to the entire body of the plant, besides being the support structure to the shoot. Thus, there was initial growth up to the 109 DAT and subsequent reduction due to wilting at the end of the plant cycle. The increase in stem diameter, and in plant height, highlight the lack of high plant densities; therefore, the adopted spacing, and the association of the local micro-meteorological conditions with the employed culture management, did not favor the outspread of the main physiological diseases and disorders such as hollow stalk and tenderness.

Oliveira (2015) analyzed the irrigation blades and the N fertilization for the cauliflower cultivar Barcelone and found stronger irrigation blade effect than fertilization effect. He recorded higher culture development indices by using irrigation equivalent to 132.4% Tec in Minas Gerais State. Similar results were recorded by Seidel et al. (2017), who observed that the maintenance of the field capacity until the end of the final formation of cabbage head (*Brassica oleracea* L. var. Capitata) was favorable to good culture yield; however, stress caused by water deficit reduced the plant height and the size of the heads. Results of both cultivation cycles showed that the initial effects of possible water stress could be compensated by plant adaptive responses to the cultivation environment. Plants can have different responses to different water deficits, since there are the tolerant ones, which overcome stress by changing their morphological and biochemical features, and the susceptible ones, which develop symptoms resulting in lower yield (Chakraborty et al., 2015).

Overall, when plants are exposed to water deficit conditions, there are physiological responses that can indirectly result in water conservation in the soil due to decrease in the transpiration surface through senescence, reduced expansion or leaf elongation, which in their turn, depend on water turgescence and availability to the plants. Bergamaschi and Bergonci (2017) state that low water availability in the soil can cause leaf area reduction and lead to decreased photosynthetic capacity and to lower growth and yield rates. The regressions were adjusted based on thermal sums as independent variables in order to assess the effect of cultivation cycle duration ("time" as quantitative variable) (Figure 2). In this case, regardless of the assessed morphological

Table 5. Morphometric variables of cauliflower plants cv. Verona under different irrigation blades and development phases between July 11^{th} and November. 07th, 2015, Sinop-MT, Brazil.

DAT	GDA	L40*	L60*	L80*	L100*	L120*
			Plant height (cm)			
32	427.2	7.7^{a}	8.1^{a}	7.5^{a}	7.5^{a}	7.7^{a}
41	546.0	9.5^{a}	9.3^{a}	8.6^{a}	9.1^{a}	9.6^{a}
48	655.2	10.7^{a}	11.2^{a}	9.8^{a}	11.2^{a}	9.1^{a}
53	726.4	12.4^{a}	11.6^{a}	12.0^{a}	11.0^{a}	11.9^{a}
62	818.1	12.2^{a}	11.5^{a}	11.5^{a}	12.4^{a}	12.5^{a}
73	972.5	12.2^{a}	12.9^{a}	11.8^{a}	13.5^{a}	13.1^{a}
87	1105.2	13.7^{a}	15.0^{a}	13.7^{a}	16.1^{a}	14.8^{a}
100	1225.1	13.1^{a}	15.9^{a}	13.4^{a}	16.4^{a}	15.5^{a}
109	1288.9	12.0^{b}	16.7^{a}	14.3^{ab}	17.6^{a}	16.6^{a}
119	1396.4	11.5^{b}	15.6^{a}	10.6^{b}	17.0^{a}	16.8^{a}
			Stem diameter (mm)			
32	427.2	6.5^{a}	$6.67^{a\ a}$	6.44^{a}	6.89^{a}	6.65^{a}
41	546.0	8.3^{a}	7.78^{a}	7.25^{a}	7.81^{a}	8.05^{a}
48	655.2	9.6^{a}	9.57^{a}	8.61^{a}	9.56^{a}	8.99^{a}
53	726.4	10.7^{a}	10.97^{a}	11.18^{a}	9.21^{a}	10.65^{a}
62	818.1	12.2^{a}	11.6^{a}	10.85^{a}	12.26^{a}	11.33^{a}
73	972.5	12.5^{a}	11.94^{a}	12.04^{a}	13.58^{a}	12.21^{a}
87	1105.2	15.0^{a}	17.6^{a}	14.93^{a}	17.96^{a}	15.11^{a}
100	1225.1	14.2^{b}	18.42^{a}	16.37^{ab}	17.17^{ab}	15.86^{ab}
109	1288.9	14.2^{b}	19.2^{a}	18.44^{a}	18.75^{a}	15.33^{b}
119	1396.4	11.7^{b}	16.21^{a}	10.65^{c}	16.58^{a}	14.66^{ab}
			Number of leaves			
32	427.2	8.1^{a}	8.4^{a}	8.0^{a}	8.9^{a}	8.9^{a}
41	546.0	11.3^{a}	11.6^{a}	10.3^{a}	12.2^{a}	11.5^{a}
48	655.2	12.0^{a}	12.4^{a}	11.3^{a}	12.6^{a}	12.9^{a}
53	726.4	12.9^{a}	15.6^{a}	14.7^{a}	12.5^{a}	13.6^{a}
62	818.1	17.8^{a}	18.6^{a}	17.4^{a}	18.0^{a}	17.9^{a}
73	972.5	17.0^{b}	21.5^{a}	18.0^{ab}	20.5^{ab}	18.2^{ab}
87	1105.2	22.2^{ab}	24.0^{a}	19.8^{b}	22.3^{ab}	23.4^{ab}
100	1225.1	10.6^{b}	15.9^{a}	13.3^{ab}	15.0^{a}	13.6^{ab}
109	1288.9	6.4^{b}	12.0^{a}	9.4^{ab}	11.7^{a}	10.5^{a}
119	1396.4	6.5^{c}	13.0^{a}	11.0^{ab}	10.5^{b}	10.5^{b}

*L40, L60, L80, L100 and L120 correspond to the evapotranspiration reposition rate (irrigated blade) of the culture (ETc). Means followed by the same letter on the line (influence analysis of irrigation blades in a single development phase) did not differ from each other in the Tukey test at 5% probability.

variables, the coefficients adjusted at the linear (Figure 2) and quadratic (Figure 2) functions were significant at 1.0% probability; correlation coefficients (r) were higher than 71.5%.

The cauliflower cv. Verona presented inflorescence variation from 41 to 53 DAT under Sinop-MT weather conditions, regardless of the applied irrigation management. Inflorescences presented diametric ratios (ratio between equatorial and longitudinal diameter) varying from 1.01 and 1.0; thus, indicating flat shapes (Table 6). There were significant differences in the equatorial and longitudinal diameters of inflorescences under the different irrigation blades, and it allowed assuming that there was harvest point standardization. Silva et al. (2014) found inflorescence diameter from 19.86±0.82 to 21.49±0.30 cm in cauliflowers cultivated under the different irrigation systems. Similar results were also recorded by Kudela et al., (2011), who assessed the quality of cauliflower under 2 different irrigation blades and found ID from 19.35 to 20.05 cm. Overall, bigger inflorescences are more valorized in the market, for they comply with the higher classes in the

Table 6. Productive components of cauliflower plants cv. Verona under different irrigation blades and development phases, by taking into consideration the two cultivation cycles (2014 and 2015) in Sinop-MT, Brazil.

Year	Irrigation blades	DINF (days)	DEq (cm)	DLo (cm)	IFM (g plant^{-1})	AF (cm²)
2015	L40	46.3 ^{a}	20.6 ^{a}	19.63 ^{a}	488.75 ^{b}	11041.4 ^{b}
	L60	46.9 ^{a}	21.4 ^{a}	20.25 ^{a}	563.98 ^{b}	12800.2 ^{ab}
	L80	43.6 ^{a}	24.0 ^{a}	21.94 ^{a}	730.66 ^{a}	11727.2 ^{b}
	L100	49.9 ^{a}	24.8 ^{a}	22.75 ^{a}	871.51 ^{a}	14678.0 ^{a}
	L120	41.3 ^{a}	22.7 ^{a}	20.5 ^{a}	751.4 ^{a}	14733.7 ^{a}
	DMS	15.2	5.0	5.18	157.4	3214.7
	CV(%)	23.1	16.3	20.74	16.1	27.91
2014	L60	50.0 ^{a}	20.5 ^{a}	20.20 ^{a}	435.7 ^{a}	8368.1 ^{a}
	L80	46.0 ^{a}	20.8 ^{a}	20.29 ^{a}	470.1 ^{a}	8763.3 ^{a}
	L100	53.0 ^{a}	21.1 ^{a}	20.42 ^{a}	514.3 ^{a}	7746.5 ^{a}
	L120	44.0 ^{a}	20.8 ^{a}	20.31 ^{a}	477.03 ^{a}	7048.8 ^{a}
	DMS	12.4	2.4	0.82	286.9	2638.5
	CV(%)	20.4	5.4	1.91	28.8	25.57

normal Brazilian classifications for trading standards (Hortibrasil, 2018). However, there is great variability in this feature in the same cultivar (Monteiro et al., 2010; Torres et al., 2015; Ribeiro et al., 2017).

The inflorescence fresh mass (IFM) presented significant difference between irrigation blades in the 2015 cultivation cycle: variations higher than 380 g at 40% irrigated blade increase. This behavior highlights that although there were no diametric differences, the irrigated blade influenced the density of immature inflorescences. Regardless of cultivation cycle and irrigated blade, there were inflorescences presenting white-milky color and formed cover (2 leaves tight to the edges). These features are bond to the assessed cultivar. Ribeiro et al. (2017) found that in tropical conditions Verona CMS is more tolerant to high temperature than cvs. Sarah and Sharon, exhibiting more marketable products on postharvest by reducing hollow stem and physiological disorder. It is also possible to highlight the record of less than 5% severe defects, such as the presence of leaves in the head (leaf emergence in the internal part of the inflorescence), hairiness (opened flowers in the head, similar to hair), purple spots (pinkish spots resembling wine on the inflorescence) and hollow stalk. Monteiro et al. (2010) assessed the water performance of summer cauliflowers and found IFM from 0.73 to 1.11 kg.

With regard to inflorescence commercial yield, there was quadratic performance with the irrigated blades in the 2 cultivation cycles. In 2014, the generated functions were $Prod = 2326.58 + 35615.3\ LI – 17917.5\ LI^2$; and in 2015 they were $Prod = 2735.28 + 64257.7\ LI – 29750.7\ LI^2$. The determination coefficients (R^2) were 0.86 and 0.88 (in this case, LI is the irrigated blade in decimals L40, L60, L80, L100 and L120, which corresponded to 0.4, 0.6, 0.8, 1.0 and 1.2, respectively). The maximum points for water reposition at 99.34 and 107.8% of ETc were found by applying the derivative of these polynomials, that is, irrigation management with daily reposition close to the 100% ETc recommended by the Class A tank method. Such values allow better yield results for cauliflower cv. Verona (Table 7). It is also possible to mention that the increased rainfall after 60 DAT in 2014 in comparison to 2015 enabled significant reduction in water use efficiency (EUA), even when only irrigation was taken into account. Air temperature variations and global radiation (Figure 1) indicated that it is possible to find positive correlation between commercial yield and the micro-meteorological elements in this genetic material, that is more stable thermal amplitudes through the cycle tend to favor better inflorescence development and, consequently, more fresh weight (Zanuzo et al., 2013). The recorded yields are similar to that recorded by Monteiro et al. (2010): mean yield between 14.56 and 23.76 t ha^{-1} in different genetic materials of the summer cycle. Zanuzo et al., (2013) found mean yield of 18.9 and 18.7 t ha $^{-1}$ for hybrids Verona 184 and Verona 284 in the Sinop region. Pereira et al. (2016) noted that desert hybrid (summer cultivar, with a cycle varying between 80 and 90 days) is promising for cultivation in the soil and climatic conditions of the region Amazon; its productivity is 17.1 t ha^{-1}, it has inflorescence fresh mass of 0.85 kg plant^{-1}, inflorescence diameter of 18 cm, and 38 kPa tension of soil water content.

Conclusion

It is recommended to adopt daily water reposition

Table 7. Mean yield and water use efficiency (kg m^{-3}) of cauliflower cv. Verona CMS, subjected to different irrigation blades in Sinop-MT, Brazil.

Year	Irrigation blades	Productivity (kg ha^{-1})	Irrigation depth - I (mm)	I + Pef	EUA[1*]	EUA[2*]
2015	L40	19,550.0	112.8	200.8	17.33	9.74
	L60	22,559.2	169.2	257.2	13.33	8.77
	L80	29,226.4	225.6	313.6	12.95	9.32
	L100	34,860.4	282.0	370.0	12.36	9.42
	L120	30,056.0	338.4	426.4	8.88	7.05
2014	L60	17,428.0	166.7	591.5	10.45	2.95
	L80	18,804.0	222.2	647.0	8.46	2.91
	L100	20,572.0	277.8	702.6	7.41	2.93
	L120	19,081.2	333.3	758.1	5.72	2.52

EUA[1] and EUA[2] take into consideration the irrigation blade and the irrigation blade + effective rainfall, respectively.

between 80 and 100% of the evapotranspiration of the culture in winter-fall cauliflower crops in Middle-Northern Mato Grosso State. The irrigation blade variations did not influence the duration and thermal demands of the differentiation period of cauliflower cv. Verona CMS inflorescences. Increased irrigated blades reduced water use efficiency, regardless of cultivation cycle: it produced from 7.4 to 12.4 kg of inflorescence fresh mass per m³ of irrigated water.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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