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ADAPTATION AND RESPONSIVENESS OF SUGARCANE CULTIVARS UNDER IRRIGATED AND RAINFED PRODUCTION SYSTEMS

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KEYWORDS

Brix, irrigation management, technological quality, yield.

ABSTRACT

Sugarcane is grown in several countries and environmental conditions, and production increases should not only be based on the expansion of the cultivated area. As water is a limiting factor for sugarcane yield, irrigation is crucial to increase its yields. Thus, this study aimed to evaluate the agronomic performance of five sugarcane cultivars under irrigated and rainfed conditions and compare yields in each treatment with those of previous cycles. The experiment was carried out from July 2017 to July 2018, which stands for the fourth sugarcane harvest. It consisted of two irrigation factors (irrigated and rainfed conditions), and five sugarcane cultivars (CTC4, IACSP93-3046, RB86-7515, IACSP95-5000, and IAC91-1099). Irrigation was applied to supply 100% of crop evapotranspiration. Irrigation increased sugarcane yields, and such increases varied with the genotype and crop cycle evaluated. In general, the cultivars most responsive to irrigation were IACSP93-3046 and IACSP95-5000, regardless of the evaluation cycle, and CTC4 from the fourth harvest onwards. Irrigation did not interfere with sugarcane technological quality if harvested after the middle of the crop season (June). Cultivars with higher tillering capacity, such as CTC4, had improved yield stability throughout the cycle when under irrigated conditions.

INTRODUCTION

Sugarcane farming has great economic, environmental, and social importance worldwide. The world's sugarcane cultivated area is around 26 million hectares, with an average yield of 70.2 t ha^{-1} (Faostat, 2017). Such yield is considered low since sugarcane yields can exceed 150 t ha^{-1} (Dias & Sentelhas, 2018; Gonçalves et al., 2017). Sugarcane yield has been recurrently affected by climatic changes. Among them, the concentration of rainfall and drought in a few months can directly impact the yield of this crop. Some studies have pointed out soil water content as the main restriction factor for increases in sugarcane yield (Gonçalves et al., 2017; Costa et al., 2016).

Sugarcane water requirements vary with the phenological stage and are influenced by agricultural management, climate, and the cultivar used. Some studies have shown that sugarcane water demands often decrease as the cycles pass (Jones et al., 2015; Scarpare et al., 2015). For Jones et al. (2015), Sugarcane biomass production can be reduced by up to 35% under water deficit during high evapotranspiration periods.

Combinations of sugarcane cultivars without water restriction and with water restriction in their respective cultivation cycles should be studied to ensure farmers high yield levels and maintain the economic sustainability of the system. In this context, Silva et al. (2016) stated that some cultivars have greater productive potential when under irrigated conditions. Leal et al. (2017) reinforced the need for studies combining different sugarcane genotypes in varied production environments and crop cycles. Assessing just one crop can lead to wrong conclusions about whether cultivars are responsive to irrigation.

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Full, additional, and salvage irrigation strategies are still not widespread in sugarcane crops, but their benefits have proven to be many. The direct benefits of irrigation for sugarcane crops comprise mainly increased agricultural yield and ratoon longevity (Costa et al., 2016). Savings on land leasing and reduction in logistical transport costs can be considered as indirect benefits of irrigation. Currently, the sugarcane production system is under non-irrigated conditions, and water restrictions have been constantly observed (Leal et al., 2017). According to Gonçalves et al. (2017), irrigation emerges as the main alternative for sugarcane expansion towards high drought regions.

Therefore, the hypotheses raised in this study were: (i) some sugarcane cultivars are more adapted to irrigated conditions, and (ii) cultivar responsiveness to irrigation varies over the cropping cycles. This study aimed to evaluate the agronomic performance of five sugarcane cultivars under irrigated and rainfed conditions, in addition to comparing each treatment yield with yields from previous cycles.

MATERIAL AND METHODS

The experiment was carried out at the São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences, Jaboticabal Campus, SP, Brazil (21°14'50” S, 48°17'05” W, and altitude of 570 m). According to Koppen's classification, the local climate is type Aw (Alvares et al., 2013), with an average annual temperature above 22 °C, an average temperature in the coldest month above 18 °C, and normal annual rainfall of 1425 mm. This study was carried out between July 2017 and July 2018, which stands for the fourth cycle of sugarcane cutting. The soil in the experimental area was classified as a clayey-textured eutroferric Red Latosol (Oxisol) (Embrapa, 2013). Soil grain-size analysis of the 0.00-0.20 m depth layer shows the following composition: 580 g kg^{-1} clay, 220 g kg^{-1} sand, and 200 g kg^{-1} silt. After the third sugarcane cutting, soil chemical properties were evaluated (Table 1).

TABLE 1. Soil chemical properties after the third sugarcane harvest in July 2017.

Layer	pH	OM	P_{resin}	S	H+Al	Al	K	Ca	Mg	SB	CEC	V%
(m)	$CaCl_2$	(g dm^{-3})	(mg dm^{-3})		(mmol$_c$ dm^{-3})							
0.00-0.20	5.1	24.5	17.0	28.0	27.5	0.5	1.3	19.0	7.0	27.6	55.2	51
0.20-0.40	5.0	24.0	7.5	20.5	28.5	0.0	0.9	16.5	5.0	22.6	21.4	44

OM: organic matter; SB: sum of bases; CEC: cation exchange capacity; V%: base saturation

Sugarcane was planted in November 2014 using pre-sprouted seedlings. The planting lines were spaced at 1.5 m and each seedling 0.50 m apart, at a planting density of 13,333 seedlings ha^{-1}.

The experiment consisted of two irrigation factors (irrigated - I and rainfed - R), and five sugarcane cultivars (CTC4, IACSP93-3046, RB86-7515, IACSP95-5000, and IAC91-1099), arranged in 12 blocks. Irrigation factors were allocated in plots and cultivars in subplots. The experimental design was partially balanced incomplete blocks (PBIB), with three cultivars per plot.

The irrigation factor was allocated in two parallel bands split into 12 blocks, with each block having two irrigation bands. Within the irrigation strips and blocks, the cultivars were arranged in four 4.5-m long rows spaced 1.5 m apart. The outer lines and 0.50 m from the ends of the central rows were discarded as borders.

In 2014, 60 days before planting, 2.0 t ha^{-1} limestone (PRNT = 90) was applied to the experimental area to raise base saturation to 70%. The soil pH corrective was incorporated into the soil by plowing and harrowing. At the beginning of the fourth cycle, in August 2017, 1.0 t ha^{-1} limestone (PRNT = 90) and 1.0 t ha^{-1} agricultural gypsum were applied to the soil surface. Fertilization was established based on soil analysis, recommendations, and doses for high-production systems (Vitti & Mazza, 2002). In each treatment, the following amounts were applied: 180 kg ha^{-1} N, 240 kg ha^{-1} K_2O, 90 kg ha^{-1} P_2O_5, and 45 kg ha^{-1} S. Pests were controlled by spraying Fipronil (Regent®), and weeds were controlled both manually and by application of Dinamic® herbicide.

The irrigation system used was subsurface drip irrigation (SDI), with drip pipes being placed at 0.30 m depth below the planting rows. The system was installed before planting the sugarcane crop, in October 2014. It was operated at a pressure of 100 kPa. To avoid root intrusion in the drippers, 0.05 g trifluralin per dripper was applied via irrigation water at a six-month interval.

Irrigation was managed based on climatic data obtained daily from an automated agrometeorological station, located at the university (Unesp, Jaboticabal Campus). Reference evapotranspiration (ETo) was estimated daily by the Penman-Monteith equation (Allen et al., 1998). Sugarcane crop evapotranspiration (ETc) was estimated by the product of crop coefficients (Kc) and ETo. The Kc values adopted were based on Doorenbos & Kassam (2000), namely: 0.50 (0-30 days after harvest – DAC); 0.60 (31-60 DAC); 0.75 (61-90 DAC); 0.85 (91-120 DAC); 0.95 (121-180 DAC); 1.10 (181-240 DAC); 1.20 (241-335 DAC); and without irrigation (336-365 DAC). Due to the operability of the irrigation system and experimental design, we adopted a single Kc value for all cultivars, as it was not operationally possible to adopt a Kc value for each cultivar.

In this study, irrigation aimed to overcome water deficiencies in sugarcane until the beginning of maturation. It was stopped 30 days before harvest, which is known as dry-off (Inman-Bamber, 2004). This practice is used in sugarcane to stimulate sucrose accumulation by water deficit and mild temperatures below 21 °C. The greater the association between these two factors, the larger the sucrose accumulation in crops (Cardozo et al., 2015).

Irrigated treatments were irrigated when a 20 mm water deficit was accumulated. In other words, the crop was irrigated whenever the sum of crop evapotranspiration minus effective rainfall was equal to 20 mm (Dalri & Cruz, 2002). The effective rainfall was estimated following the method by Ali & Mubarak (2017). Rainfed treatments received rainfall only.

Maximum and minimum average temperatures, as well as the average of the experimental period, were 30.1, 17.1, and 22.9 °C, respectively (Figure 1A). Accumulated rainfall and sugarcane evapotranspiration were 916.9 and 1223.2 mm, respectively (Figure 1B). Mean sugarcane evapotranspiration was 3.35 mm day^{-1}, with a maximum peak of 7.3 mm day^{-1}. Total irrigation depth in the irrigated treatments was 640 mm.

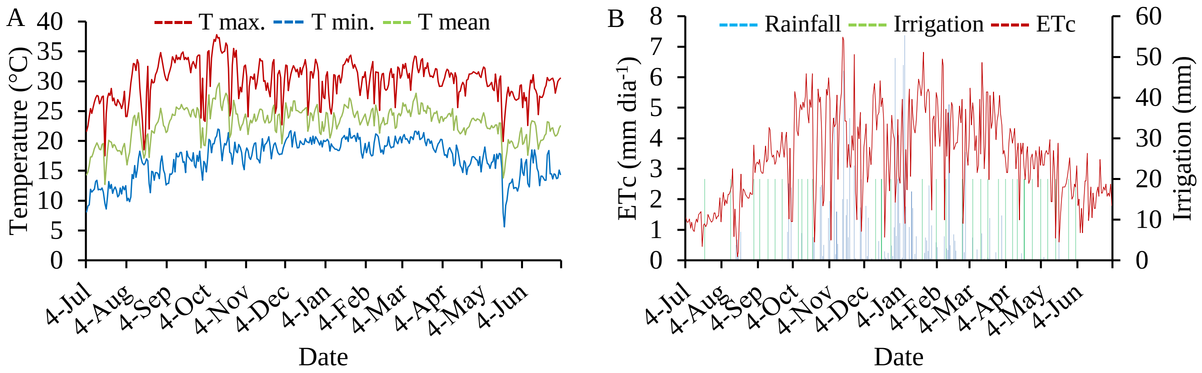

FIGURE 1. Maximum, minimum, and daily average temperatures (A) and crop evapotranspiration (ETc), rainfall and irrigation (B) throughout the cycle of the sugarcane cultivars

Eight stems per subplot were collected for sugarcane technological analysis, according to Consecana (2006). The crop was harvested in the first week of July 2018. Yields were estimated by harvesting the two central meters of each useful row per subplot. Stem yield data from previous cuts of the experiment were plotted (Coelho et al., 2018; Fischer Filho, 2018) to compare yield losses between irrigated and rainfed cultivars over the cycles.

Data were submitted to analysis of variance (F-test) at a 5% probability level. When needed, means were compared by the t-test at 5% probability. The statistical procedures were performed in the SAS© software.

RESULTS AND DISCUSSION

Supplemental irrigation effect on sugarcane yield and technological quality, as well as yield losses under irrigation and rainfed conditions among cultivars, were evaluated throughout the crop cycle. The factor cultivar had a significant effect on stem number per meter (Table 2). Therefore, irrigation did not have any significant effect on such agronomic traits. Both irrigation and cultivar factors, as well as their interaction, had a significant effect on sugarcane yield (TCH). Thus, cultivar and irrigation acted interdependently on TCH, that is, each cultivar had a different response when irrigated or not.

TABLE 2. Summary of the analysis of variance for the number of stems per meter and yield (TCH) of sugarcane.

---------------------Stem number m^{-1}------------------			--------------------TCH-------------------		
Factor	F	*p*-value	Factor	F	*p*-value
Cultivar (C)	12.45	0.001	Cultivar (C)	4.06	0.01
Irrigation (I)	2.53	0.12	Irrigation (I)	35.66	0.0001
C*I	0.51	0.73	C*I	2.98	0.0093
C.V. (%)	19.14		C.V. (%)	14.93	

TCH – tons of cane per hectare; C.V. – coefficient of variation

The cultivar with the highest stem number per meter was CTC4 and the lowest was RB86-7515 (Figure 2A). This difference was 77%, so this trait has a high genetic influence, which can be confirmed by the non-significant effect of irrigation on this parameter. Tillering is a factor that affects sugarcane production and is linked to the genetic potential of each variety (Benett et al., 2011; Costa et al., 2016). As for TCH, the cultivars RB86-7515 and IACSP95-5000 had no significant increases when irrigated (Figure 2B). When irrigated, the cultivars CTC4, IACSP93-3046, and IAC91-1099 had yield increments of 50%, 42%, and 24%, respectively. For each water management, the cultivar with the highest yield was CTC4 in both cases. Notably, for non-irrigated management, the cultivar IACSP93-3046 had the lowest yield.

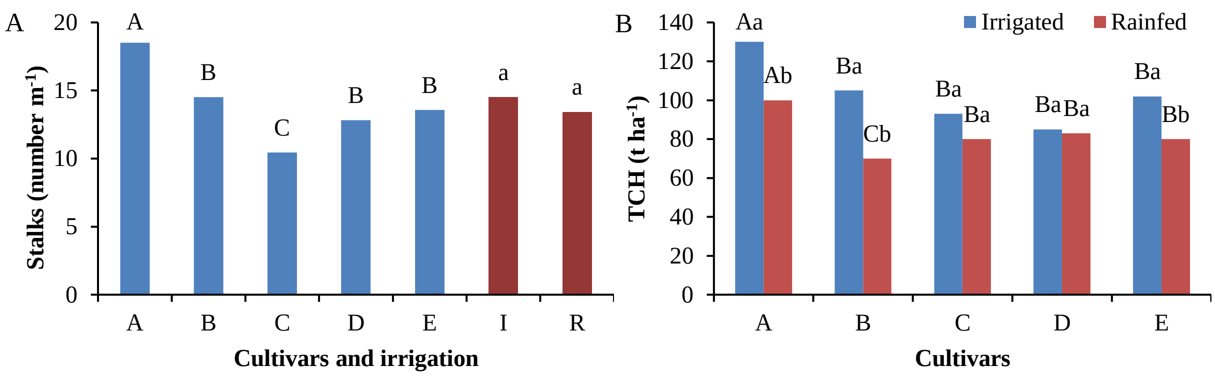

FIGURE 2. Averages of stalk number per meter (A) and yield (TCH) (B) for sugarcane cultivars under supplementary irrigation and rainfed. A: CTC4, B: IACSP93-3046, C: RB86-7515, D: IACSP95-5000, E: IAC91-1099. I: irrigated; R: rainfed. Uppercase and lowercase letters compare cultivars and water management, respectively.

Technological analysis of sugarcane showed no significant effect of cultivar and irrigation on any of the traits evaluated (Table 3). When evaluating sugarcane productive behavior (RB92-579), Costa et al. (2019) found that high irrigation depth can reduce fiber contents and soluble solids (Brix), but does not affect total recoverable sugars (TRS) and polarizable sugars (Pol) of the cane and the juice. Furthermore, the interaction between the factors was also not significant for any trait. Therefore, irrigation does not reduce sugarcane technological quality. Likewise, the genetic variability of the evaluated cultivars was null for the technological traits of sugarcane.

TABLE 3. Summary of the analysis of variance for the traits of sugarcane technological quality.

----------------Brix--------------			----------------Pol----------------			---------------Purity-------------		
Trait	F	*p*-value	Trait	F	*p*-value	Trait	F	*p*-value
Cultivar (C)	0.89	0.48	Cultivar (C)	0.93	0.46	Cultivar (C)	1,79	0,15
Irrigation (I)	4.14	0.06	Irrigation (I)	2.67	0.11	Irrigation (I)	3,23	0,08
C*I	0.77	0.55	C*I	0.59	0.67	C*I	2,07	0,11
C.V. (%)	4.36		C.V. (%)	5.72		C.V. (%)	1.02	
----------------Fiber-------------			-----------------PC--------------			----------------ATR-------------		
Trait	F	*p*-value	Trait	F	*p*-value	Trait	F	*p*-value
Cultivar (C)	1.2	0.33	Cultivar (C)	1.04	0.4	Cultivar (C)	1,06	0,39
Irrigation (I)	0.9	0.17	Irrigation (I)	3.84	0.06	Irrigation (I)	3,88	0,06
C*I	0.38	0.82	C*I	0.64	0.63	C*I	0,62	0,65
C.V. (%)	4.38		C.V. (%)	5.49		C.V. (%)	5.08	

C.V. – coefficient of variation; Pol – Pol of the sugarcane juice; PC – Pol of the sugarcane; ATR – total recoverable sugars

Although no significant result was obtained for either of the two factors (cultivation and irrigation), all technological traits had values above the minimum recommended for sugarcane industrialization (Consecana, 2006) (Figure 3). All cultivars had Brix greater than 18°, POL above 15%, Purity greater than 75%, Fiber between 10.5 and 12.5%, and PC higher than 13% (Consecana, 2006; Matsuoka et al., 2015).

The average cumulative yield reduction over the cycles was 39% for irrigated cultivars and 40% for rainfed ones (Table 4). The highest was observed for IAC91-1099 (57%), and the smallest for CTC4 (19%). Under irrigated management, the smallest cumulative yield reduction was recorded for the cultivar CTC4, whereas under rainfed it was for IACSP95-5000.

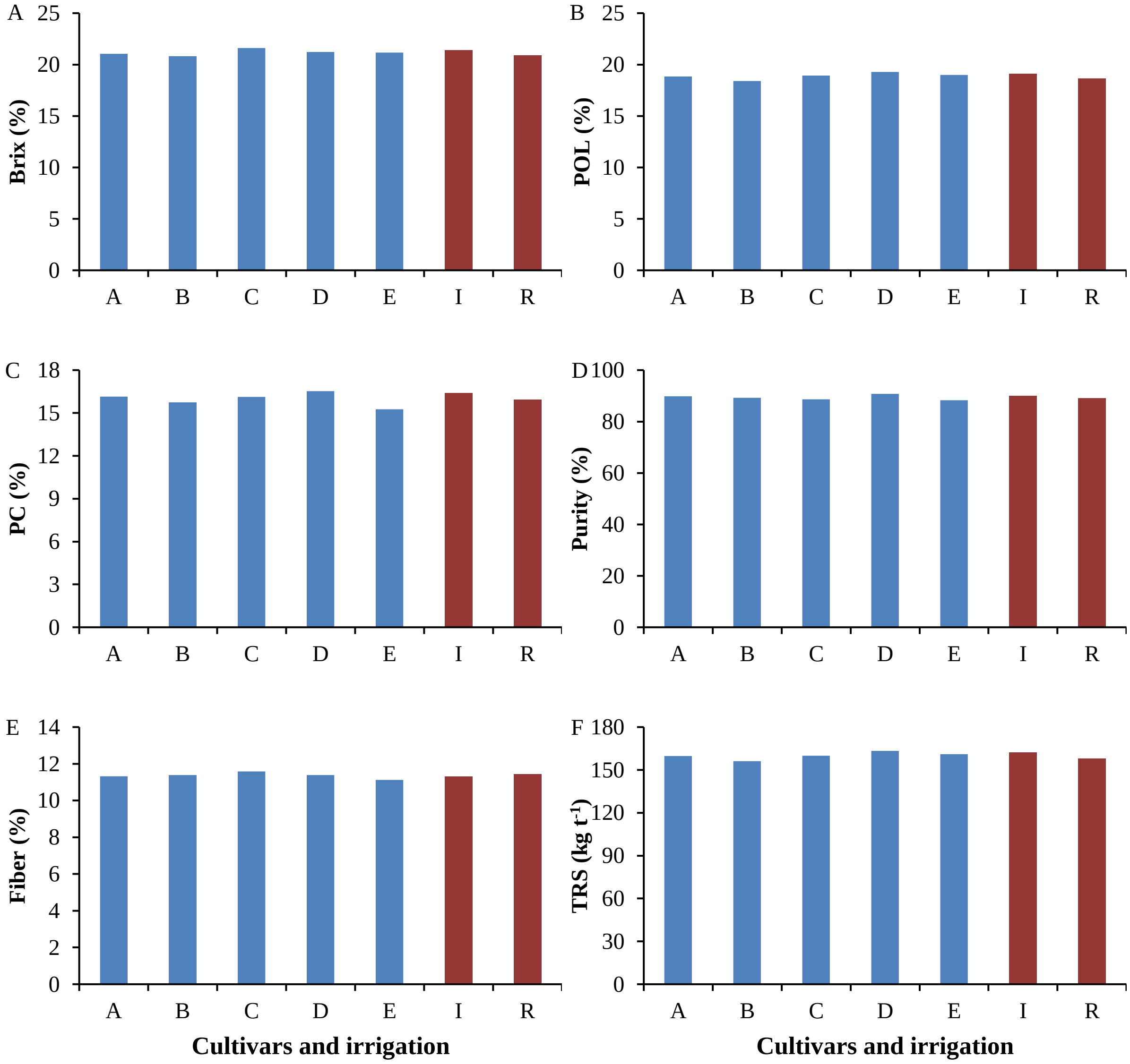

FIGURE 3. Means of technological quality traits for the sugarcane cultivars under supplementary irrigation and rainfed. Brix (A), Pol – Pol of the sugarcane juice (B), PC – Pol of the sugarcane (C), Purity (D), Fiber (E), and TRS – total recoverable sugars (F). A: CTC4, B: IACSP93-3046, C: RB86-7515, D: IACSP95-5000, E: IAC91-1099. I: irrigated; R: rainfed.

Our results demonstrate the importance of long-term studies to indicate the best sugarcane genotype for irrigated and rainfed systems. In this regard, by comparing CTC4 and IAC91-1099, we observed that, in 2016, when irrigated, the cultivar IAC91-1099 had a yield 39 tons per hectare higher than did CTC4. Yet, in 2018, this was reversed, and the yield of the cultivar CTC4 was almost 30 tons per hectare higher than that of IAC91-1099. Simões et al. (2018) observed an increase in yield by 16.49% in the second cycle compared to the first for the cultivar VAT 90212. The authors claimed that such yield increase in the second cycle was due to proper post-harvest management.

TABLE 4. Yield variation (TCH) of sugarcane cultivars grown under supplementary irrigation and rainfed conditions over the harvest cycles.

Cultivar	Management	2016[1]	2017[2]		2018		Total variation (%)
		1st ratoon	2nd ratoon	Var (%)	3rd ratoon	Var (%)	
CTC4	Irrigated	127	122	-3.1	130	5.6	2.5
	Rainfed	126	112	-11.1	86	-30.3	-41.3
IACSP93-3046	Irrigated	158	145	-7.8	104	-39.9	-47.7
	Rainfed	102	96	-5.8	73	-31.1	-36.9
RB86-7515	Irrigated	120	132	10.7	93	-42.1	-31.4
	Rainfed	114	112	-2.1	81	-38.0	-40.1
IACSP95-5000	Irrigated	150	131	-12.2	89	-47.5	-59.7
	Rainfed	109	105	-3.1	85	-23.8	-27.0
IAC91-1099	Irrigated	166	157	-5.4	103	-52.6	-58.0
	Rainfed	133	121	-9.1	83	-46.0	-55.2

[1] Data from the study by Coelho et al. (2018); [2] Data from the study by Fischer Filho (2018); Var: variation

In the same experimental area, but the second cutting, Coelho et al. (2018) concluded that irrigation promoted a decrease in the technological quality of cultivars. In the following year (third cutting), Fisher Filho (2018) observed that the technological quality of sugarcane was not reduced with irrigation, as in the present study. Both in our study and Fisher Filho (2018), sugarcane was harvested in the middle of the season (July). In the study of Coelho et al. (2018), sugarcane was harvested at the beginning of the crop season (May). Therefore, when under irrigation, sugarcane should be harvested from the middle of the crop season onwards. This occurs because warmer regions, as in our study, have higher temperatures at the beginning of the sugarcane season. Such a fact, together with high soil moisture, reduces stem sucrose accumulation at the expense of crop vegetative growth (Cardozo et al., 2015; Muñoz & Trujillo, 2020).

By studying water relations and yield for sugarcane under subsurface drip irrigation with wastewater, Gonçalves et al. (2017) observed values of technological quality traits close to those in our study, with no significant differences between treatments for any of them. Therefore, if irrigation is performed properly, it does not reduce stem sucrose concentration, thus increasing yield and sucrose contents in irrigated areas.

Moreover, irrigation did not promote a significant effect on the average tillering of the cultivars evaluated. However, variance analysis indicated a significant difference between cultivars, therefore, stem number is more influenced by genotype than by environment (Silva et al., 2016). Only in regions with an annual rainfall below 1,000 mm and low-fertility sandy soils, there is an increase in sugarcane tillering when sugarcane is irrigated (Surendran et al., 2016).

In the two cuttings before our study, annual rainfall was above 1400 mm, and irrigation also did not increase the number of tillers of the cultivars (Coelho et al., 2018; Fischer Filho, 2018). In our study (fourth cutting), even though it was a year with low rainfall (917 mm), irrigation also did not promote a significant increase in the number of stems per meter for the cultivars. This is because the soil in this study has a high clay content (58%) and high fertility (Table 1).

In years before our experiment, the cultivar CTC4 was tolerant to water deficit, with no differences in yield between irrigated and rainfed systems (Coelho et al., 2018; Fischer Filho, 2018). In those years (second and third cuttings), annual rainfall was 1740 and 1498 mm, respectively, surpassing the normal annual average for the region. In turn, in our study (fourth cutting), the same cultivar (CTC4) had a higher yield under irrigation since annual rainfall was only 917 mm, which may have affected its yield in the rainfed system.

Soil water content is essential at all sugarcane phenological stages. In this sense, rainfall of at least 1100 mm regularly distributed throughout the year is crucial to meet sugarcane water needs (Teixeira et al., 2016). Accordingly, CTC4 was tolerant to water deficit only in regions where its minimum water requirement was reached.

In the studies by Coelho et al. (2018) and Fisher Filho (2018), the cultivar with the highest average yield was the IAC91-1099, with values of 166 t ha^{-1} and 157 t ha^{-1} in the second and third cuttings and under irrigation, respectively. In the fourth cutting, it decreased by 58% (Table 4) and was 103 t ha^{-1}. During the cycles, yield variation for the cultivar CTC4 was almost null and was 127, 130, and 130 t ha^{-1} in the second, third, and fourth cuts, respectively. This was probably due to its high tillering capacity (Figure 2A), a trait that may indicate the high adaptability of cultivars in irrigated and rainfed systems (Silva et al., 2008). This demonstrates that long-term studies are needed to indicate the best cultivars to be used in irrigated and rainfed systems, showing yield stability over the years.

CONCLUSIONS

Irrigation promotes an increase in sugarcane yield as a function of genotype and cutting cycle evaluated. In general, the most responsive cultivars to irrigation are IACSP93-3046 and IACSP95-5000, regardless of the evaluated cycle, and CTC4 from the fourth cutting cycle onwards. Irrigation does not interfere with sugarcane technological quality if harvested from mid-season onwards (from July). Cultivars with higher tillering, such as CTC4, have greater yield stability throughout the cycle under irrigated conditions.

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