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Productivity and technological quality of sugarcane cultivars fertigated and planted through pre-sprouted seedlings

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Abstract

The increase in sugarcane production in Brazil does not only depend on the increase of cultivated areas. It also needs alternatives to increase productivity. These alternatives include irrigation, planting method, and development of new cultivars. In this scenario, the use of pre-sprouted seedlings is particularly relevant because it ensures high phytosanitary standards and uniform crops. The objective of this work was to evaluate the productivity and technological characteristics of five sugarcane cultivars that were planted through pre-sprouted seedlings and conducted with and without supplementary irrigation in the second growing year. The experiment was conducted at the FCAV/UNESP, in Jaboticabal, São Paulo state, Brazil, from 2015 to 2016. The treatments were distributed in a partially balanced incomplete block design, with three cultivars per block. Supplementary irrigation was performed when there was an accumulated water deficit of 30 mm. Reference evapotranspiration was calculated according to the FAO-56 method. The evaluated sugarcane cultivars were: CTC 4, IACSP 93-3046, RB 86-7515, IACSP 95-5000, and IAC 91-1099. The total irrigation depth applied during the cycle was 360 mm. Supplementary irrigation triggered a decrease in the sugarcane technological indices, mainly for the cultivars CTC 4 and IAC 91-1099, presenting a 15% apparent sucrose (POL%) cane reduction in the non-irrigated treatment, and 14% in the irrigated. Cultivar IAC 91-1099 stood out in the productivity of sugar and stalks, with productivities of 24.16 t ha^{-1} of sugar and 166 t ha^{-1} of stalk under irrigation using pre-sprouted seedlings.

Keywords: Cultivar; Evapotranspiration; Irrigation; *Saccharum* spp.; Water Management.
Abbreviations: PSS_pre-sprouted seedlings; Juice POL_apparent sucrose in juice; POL% cane_apparent sucrose in sugarcane; TRS_total recoverable sugar

Introduction

Sugarcane is cultivated throughout Brazil, with an estimated area for the 2016/17 crop of 9,073.7 10^3 ha (CONAB, 2016). During this crop year, a total stalk production of 690.98 10^6 t is estimated, with a 4.8% increase in relation to 2015/16. Out of this total, 56.7% is for ethanol production, which is estimated to produce 30.3 10^6 m³ of product, and 43.3% will be destined to sugar production. Traditionally, sugarcane planting is carried out through stalks; however, a new planting method of this crop, known as pre-sprouted seedlings (PSS), is currently being developed and improved. The PSS planting system is a multiplication technology, which may contribute to the increase of the cultivated area, associating a high standard of plant sanity, vigor, and planting uniformity. This technique was developed to increase the effectiveness of economic gains in the implantation of nurseries, replanting of commercial areas and, possibly, the renewal and expansion of sugarcane areas (Landell et al., 2013). The greatest advantage of using pre-sprouted seedlings is that fewer seedlings have to be used in the field. For example, to plant sugarcane in an area of 1 hectare, 18-20 tonnes of seedlings are required, compared with only 2 tonnes for pre-sprouted seedlings. The PSS planting system brings changes to the concept applied to sugarcane planting, especially in the areas where the early stages of multiplication occur. The basic change of the new system consists in the use of seedlings as a propagation medium, i.e., pre-sprouted seedlings are used in planting furrows instead of seed stalks (Landell et. al., 2014). Moreover, when pre-sprouted seedlings are used, harvest can take place as early as 90 days in advance, thus saving up to 4950.5 m^3 ha^{-1} of irrigation water (Abd El Mawla et al. 2014). Evaluation experiments of sugarcane cultivars, cultivated with or without water restriction, as well as the planting using pre-sprouted seedlings (PSS), are necessary to indicate to farmers the genetic materials with high productive potentials cultivated under different water regimes, since there are genotypes with higher productive potential under irrigation (Silva et al., 2014a). There are direct and indirect benefits from fertirrigation. Direct benefits include productivity increase above 40% when compared with management without irrigation, as well as higher fertilization efficiency (Uribe et al., 2013). In turn, one of the most important indirect benefits is increased longevity of sugarcane plantations. In Brazil, the current crop expansion occupies areas considered as marginal, mainly in regions with a water deficit. In this case, water may be a limiting factor for the productive crop potential. Thus, evaluation experiments on sugarcane cultivars, conducted under various conditions of water availability in the soil are important to indicate the best management for the crop and to contribute to productivity improvement and maximization of the producers' gain. Two hypotheses were defined for this study: a) there are more productive cultivars for growing under water restriction conditions, and b) there are more responsive cultivars to supplementary irrigation. Thus, the goal of this work was to evaluate the productivity and technological characteristics of five sugarcane cultivars, planted through pre-sprouted seedlings, and conducted with and without supplementary irrigation, in the second growing year.

Results and Discussion

There was a significant effect of irrigation on all of the analyzed technological variables ($p<0.05$), with the exception of sugarcane purity (Table 1). The effect of the interaction irrigation versus cultivar (I x C) was not significant ($P<0.05$) for all the analyzed variables, demonstrating that irrigation versus cultivar acts independently. The analysis of total soluble solids (°Brix) (Table 1) revealed that irrigation had a negative effect on the cultivar IAC 91-1099, as shown by a statistically lower mean under the irrigated treatment (19.3%), in relation to the non-irrigated treatment (20.4%). There was no significant difference among cultivars for both water regimes. Dalri et al. (2008), evaluating the effect of irrigation layers on the technological quality of sugarcane, cultivar RB 72 454, concluded that there was no significant difference on ºBrix between irrigated and non-irrigated treatments. Barbosa et al. (2012) observed a significant °Brix increase in the treatment irrigated via a subsurface drip system and fertigated with NPK (20.8 °Brix) compared to the non-irrigated treatment (19.6 °Brix). Oliveira et al. (2011), observed a fall in the °Brix content under the irrigated treatment for the cultivars RB 72 454 and RB763710, which is the same as the one evaluated by Dalri et al. (2008), where the authors did not observe differences for this variable when comparing the cultivation under conditions with and without irrigation. There was a difference between Juice Pol averages of the cultivars under the irrigated and non-irrigated treatments. There was also a significant negative effect for Juice Pol in the irrigated cultivars CTC4 and IAC 91-1099, which presented values of 16.3% and 17.7% and 16.7% and 18.1%, for the irrigated and non-irrigated treatments, respectively (Table 1). Oliveira et al. (2011) obtained similar results for the cultivars RB72454 and RB763710, where the irrigated cultivation caused a fall in the POL5 juice content of the cane. Results on the purity variable showed that cultivar CTC4 under irrigated condition presented a lower average than the cultivars IACSP 95-5000 and IAC 91-1099, but not different from cultivars RB86-7515 and IAC91-1099. This was due to the lower Juice Pol content, compared to the other treatments, directly interfering with the purity variable, since this is obtained by the ratio between Juice Pol and °Brix. Therefore, the treatments in this research had no restrictions for this technological quality. According to Ahmed et al. (2010), the juice purity of sugarcane is not related to other characteristics of the crop, which is interfered with almost exclusively by vegetative and climatic conditions. There was no statistically significant difference among cultivars for the TRS technological analysis when it was compared within the irrigated and non-irrigated treatment (Table 1). When the TRS of the cultivar is compared between the water regimes, irrigation affected negatively this index for the cultivars CTC4 and IAC 91-1099. Reductions were 7.52% and 6.62%, respectively. Farias et al. (2009), evaluating irrigation depths in the technological quality of sugarcane, observed higher TRS quantity when 100% ETc was provided, obtaining 147.47 kg t^{-1} for the cultivar 79-1011. Deon et al. (2010) obtained 135.9 kg t^{-1} of TRS for the cultivar SP 90-3414; this value is lower than the averages of this experiment. Cultivars presented similar POL% cane averages, both in the irrigated and non-irrigated management. This is similar to Juice Pol and TRS analyses. Irrigation promoted a significant decrease ($p<0.05$) in the POL% cane averages of cultivars CTC4 and IAC 91-1099. There was no statistically significant difference in the fiber content among the cultivars, and irrigation provided lower fiber content only for the cultivar IACSP 95-5000, in relation to the non-irrigated treatment. All cultivars under the irrigated treatment presented fiber averages below 10.5%; this is undesirable for the energetic balance of the plants, since 10.5% to 12.5% are considered ideal fiber average contents (Fernandes, 2003). Low fiber contents in the cane increase the effectiveness of juice extraction in the processing units, since there is no need to reabsorb the juice in the mills. The fiber content is quite variable, according to the crop year. Silva et al. (2014a) obtained fiber contents close to 15% for the cultivar IAC91-1099 in a crop year and, in the immediate following year, this value got close to 13%.

The analysis of variance for cane sugar productivity (Table 2) demonstrated that there is a significant effect from irrigation and cultivars ($p<0.05$). The effect of the interaction irrigation versus cultivar was not significant, demonstrating that this interaction acts independently over sugar productivity. Irrigation promoted a significant increase in TRS values for cultivars IACSP 93-3046 and IACSP 95-5000, presenting increments of 49.5% and 31.6%, respectively (Table 2). Among the cultivars, in the irrigated management, CTC 4, IACSP 91-1099, RB 86-7515, IACSP 93-3046 and IAC 95-5000 stand out. In the non-irrigated management, the cultivars presenting higher sugar productivity were IAC 91-1099, CTC 4 and RB 86-7515. Considering the general average, it is possible to notice higher sugar productivity in the irrigated management; it is statistically higher that the non-irrigated one, presenting a 17.7% increase in sugar productivity. Irrigation did not promote a significant stalk productivity increase for the cultivars CTC4 and RB 86-7515 (Table 2). As for the cultivars IACSP 93-3046, IACSP 95-5000, and IAC 91-1099, TCH relative increases were 54.78%, 37.93%, and 24.53%, respectively. Considering the general average, irrigation promoted a 23.3% increment in sugarcane stalk productivity. Gava et al. (2011), for the cultivar RB 86-7515, obtained 118.8 t ha^{-1} under the irrigated treatment and 84.9 t ha^{-1} without irrigation. Oliveira et al. (2014), while evaluating different irrigation layers in the cultivar RB 855453, observed a productivity of up to 249.02 t ha^{-1} in the layer providing 100% of the ETc. Silva et al. (2014a), while

Table 1. Mean comparison and analysis of variance (ANOVA) for technological variables of five sugarcane cultivars cultivated under irrigated and non-irrigated treatments.

Mean comparison	°Brix		Juice Pol (%)		Purity (%)	
Cultivar	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated
CTC 4	19.54Aa	20.59Aa	16.29Ab	17.72Aa	85.03Bb	86.66Aa
IACSP 93-3046	19.91Aa	20.77Aa	17.32Aa	18.25Aa	87.42Aa	87.67Aa
RB 86-7515	19.42Aa	20.27Aa	16.83Aa	17.57Aa	86.16ABa	87.25Aa
IAC 95-5000	19.86Aa	20.13Aa	17.24Aa	17.58Aa	87.49Aa	86.88Aa
IAC 91-1099	19.28Ab	20.41Aa	16.70Ab	18.12Aa	86.24ABa	86.94Aa
Mean	19.60b	20.43a	16.87b	17.84a	86.47ª	87.09a
ANOVA			F			
Irrigation (I)	17.25**		17.97**		3.83	
Cultivar (C)	0.69		1.04		2.72*	
I x C	0.54		0.7		1.13	
V.C. (%)	3.83		5.14		1.39	
	TRS (kg t^{-1})		POL % cane		Fiber (%)	
Cultivars	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated
CTC 4	142.32Ab	153.89Aa	14.17Ab	15.42Aa	10.43Aa	10.84Aa
IACSP 93-3046	150.60Aa	156.90Aa	15.10Aa	15.73Aa	10.27Aa	10.76Aa
RB 86-7515	146.24Aa	150.23Aa	14.62Aa	15.05Aa	10.48Aa	11.14Aa
IAC 95-5000	150.35Aa	148.8Aa	15.06Aa	14.90Aa	10.08Ab	10.77Aa
IAC 91-1099	145.59Ab	155.91Aa	14.55Ab	15.69Aa	10.32Aa	10.68Aa
Average	147.02b	153.08a	14.7b	15.36a	10.31b	10.84a
Irrigation (I)	10.16**		0.0033**		15.14**	
Cultivar (C)	0.92		0.96		0.8	
I x C	1.42		1.42		0.23	
V.C. (%)	4.99		5.45		5.00	

*averages followed by the same capital letter, in the column, and lowercase letter on the line, do not statistically differ by t-test at 5% probability; *significant at 5% level; ** significant at 1% level.
TRS: Total sugar recoverable.

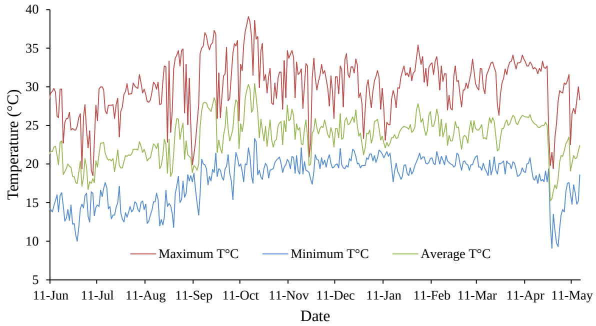

Fig 1. Maximum, minimum and average temperatures during the experimental period in Jaboticabal, São Paulo state.

Table 2. Comparison of productivity averages of stalks (t ha^{-1}) and sugar (t ha^{-1}) for the five sugarcane cultivars under irrigated and non-irrigated treatments.

	Cultivar	Stalk productivity (t ha^{-1})		Sugar productivity (t ha^{-1})	
		Irrigated	Non-irrigated	Irrigated	Non-irrigated
	CTC 4	127.17 Ba	126.41 ABa	18.62 Ba	19.37 ABa
	IACSP 93-3046	157.64 Aa	101.85 Bb	23.69 Aa	15.85 Bb
	RB 86-7515	119.65 Ba	113.94 ABa	17.32 Ba	17.15 ABa
	IACSP 95-5000	149.67 ABa	108.51 ABb	21.39 ABa	16.25 Bb
	IAC 91-1099	165.99 Aa	133.29 Ab	24.16 Aa	20.75 Aa
	Average	144.02 a	116.80 b	21.04 a	17.88 b
F	Irrigation (I)	22.46**		11.87**	
	Cultivar (C)	0.0413*		2.88*	
	I x C	0.045*		2.44	
	V.C. (%)	16.95		18.11	

*averages followed by the same capital letter, in the column, and lowercase letter on the line, do not statistically differ by t test at 5% probability; *significant at 5% level; ** significant at 1% level.

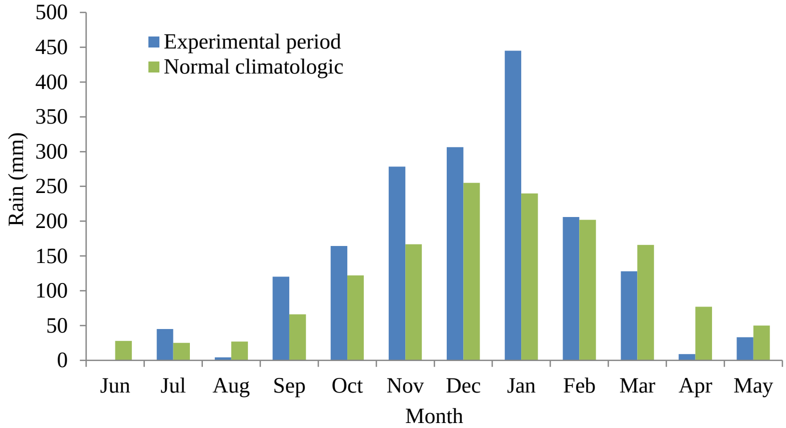

Fig 2. Normal climatologic monthly (1971 until 2000) and monthly rainfalls during the experimental period (June-16 to May-17) in Jaboticabal, São Paulo state.

Table 3. Physical characteristics of soil in the experimental area

Depth (cm)	Soil density (g cm^{-3})	Sand (g kg^{-1})	Clay (g kg^{-1})	Silt (g kg^{-1})	Soil texture
0 – 20	1.29	220	580	200	Clay
20 – 40	1.20	190	600	210	Clay
40 – 60	1.07	160	650	190	Very clay

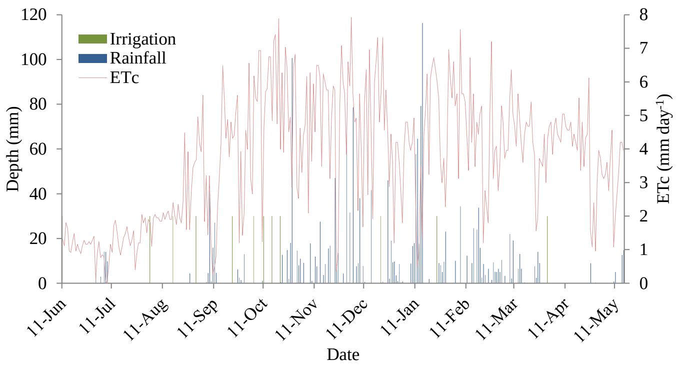

Fig 3. Rainfall and sugarcane evapotranspiration during the experimental period in Jaboticabal, São Paulo state.

Table 4. Chemical characteristics of soil in the experimental area.

Depth (cm)	pH $CaCl_2$	Organic Matter (g dm^{-3})	P_{resin} (mg dm^{-3})	S	H+Al	Al	K	Ca	Mg	BS	CEC	BS%
					(mmol$_c$ dm^{-3})							
0-20	5.4	25	41	45	32	1	1.8	51	21	73.6	105.4	70
20-40	5.2	18	19	53	34	0	1.6	31	13	45.4	79.4	56

Table 5. Sugarcane growth periods and crop coefficients (kc).

Periods	kc
From planting to 0.25 covering	0.5
From 0.25 to 0.50 covering	0.8
From 0.50 to 0.75 covering	0.95
From 0.75 to complete covering	1.1
Maximum usage	1.2

analyzing the effects of irrigation in the average productivity of the stalks for two productive cycles, report values of 126.04 t ha^{-1}, 100.92 t ha^{-1}, and 127.86 t ha^{-1} for the cultivars IAC 91-1099, IACSP 93-3046, and RB86-7515, respectively. These values are different from the ones found in this work, indicating that the productivity of cultivars is variable, according to the cutting purpose, region, and even to the production environment, since they are more adapted to certain production environments.

Campos et al. (2014) obtained productivities from sugarcanes cultivated under supplementary irrigation, in the region of Goianésia, Goiás state, of 140.68 t ha^{-1}, 168.59 t ha^{-1}, 144.57 t ha^{-1} and 154.98 t ha^{-1} for the cultivars CTC 4, IAC 91-1099, IACSP 95-5000, and RB 86-7515, respectively. The values found by these authors for the cultivars IAC 91-1099 and IAC 95-5000 were very close to the ones observed in this work under the irrigated treatment.

Materials and Methods

Characteristics of the area and experimental design

The experiment was conducted at the FCAV, UNESP, Jaboticabal Campus, São Paulo state, Brazil (latitude 21º14'50'' S, longitude 48º17'5'' and altitude 570 m). The climate is Cwa-type (Köppen), characterized by average annual rainfall of 1416 mm (1975-2015), with a total average for the most rainy month of 255 mm (December) and 25 mm for the driest month (July) (Alvares et al., 2013). The soil of the experimental area is classified as Eutroferric Red Latosol. The physical characteristics of soil are presented on Table 3 and the chemical characteristics, on Table 4.

Preparation of pre-sprouted seedlings

Pre-sprouted sugarcane seedlings were planted on November 14, 2014, and harvested on May 16, 2015 to start the experimental period that extended up to May 16, 2016. Production of PSS starts by selection of micro seed pieces, which are propagules which contain only one bud. Before sowing, the micro seed pieces were thermally treated, immersed in water at 52 ° C for 30 minutes and sprayed with fungicide and insecticide, thus ensuring high phytosanitary standards. After that, they were placed in tubes filled with the substrate and then stored in a protected environment. They were irrigated three times a day, and humidity in the substrate was kept suitable for seedling development. After 30 days, acclimatization of the seedlings was started. They were exposed to direct sunlight and irrigation was suppressed gradually, thus increasing seedling establishment capacity in the field (Pinto et al., 2016). Seedling production time until planting in the field was approximately 60 days.

Management of irrigation and fertilization

Irrigation was applied by a subsurface drip system, installed before sugarcane planting. The dripping pipe (Petroisa, mode Durazio®) had a diameter of 16 mm, pipe wall of 500 micron and emitters spaced 0.3 m apart. The water from a well was filtered by a 125 micron disc filter. The pressure of the irrigation system was stabilized by a flow regulator and monitored by a pressure gauge; it was kept at 100 kPa. The dipper flow rate was 5 L h^{-1} m^{-1}.

Irrigation was applied from planting until 45 days before harvesting, when a 30 mm water deficit was accumulated after a previous irrigation. The crop water deficit was calculated as the difference between daily crop evapotranspiration and rainfall. This criterion was based on experiment of Dalri & Cruz (2002), in which significant difference in stalk sugarcane productivity did not occur when irrigation depths of 10, 2,0 and 30 mm were applied. Crop evapotranspiration was calculated by the product of crop coefficient (Table 5) and reference evapotranspiration during the growing season (Doorenbos and Kassam, 1979). Reference evapotranspiration was calculated by the Penman-Monteith equation, parameterized according to the FAO-56 method (Allen et al., 1998), using daily climate data from the FCAV/UNESP automated agrometeorological station. Irrigation efficiency was assumed as 90%.

Fertilization was performed with the application of 130 kg ha^{-1} of K_2O and 180 kg N; sources were potassium chlorate and ammonium sulfate, respectively. There was no need for phosphate fertilizers due to the high phosphorus contents obtained through the chemical analysis of the soil. In the irrigated plots, fertilization was performed through fertirrigation; the dose was divided into eight equal applications. In the non-irrigated management, fertilizers were applied in July 2015, 30 days after cutting.

Climate conditions

In the first months of sugarcane growth, the average air temperature varied between 16.7 °C and 23 °C, close to the normal averages for the location (Fig 1), but below the ideal temperature range for the sprout of sugarcane buds, which is between 27°C and 36°C (Pierre et al., 2014). According to Bonnet et al. (2006), as the air temperature increases up to 30°C, there is a considerable increase in tillering and height growth, helping the vegetative propagation of sugarcane.

At the end of the crop productive cycle, the average temperatures were low, mainly at the end of April and the beginning of May, enhancing the accumulation of saccharine in the stalks, since there is no vegetative growth of the culture at this stage. At temperatures lower than 20°C, stalk growth is practically null (Pierre et al., 2014).

Rainfall was lower than the normal annual average, indicating a growth reduction of the culture in June and August 2015 (Fig 2). From September 2015 to February 2016, rainfalls were above the normal average for the region in the initial sugarcane growth period, indicating high productive potential in the non-irrigated treatments.

Evapotranspiration and rainfall accumulated during the experimental period were 1260 and 1740 mm, respectively (Fig 3), and mean crop evapotranspiration was 3.7 mm day^{-1}. Daily crop evapotranspiration remained around 2 mm day^{-1} from June to August, varied from 3 to 7 mm day^{-1} from September to February and from 2 to 6 mm day^{-1} from March to May. According to Olivier & Singels (2012), sugarcane crop requires by 2.8 to 3.7 mm day^{-1} to attain 120 to 130 t ha^{-1}. According to Silva et al. (2012), mean daily evapotranspiration for sugarcane crop in the semi-arid region of the São Francisco river valley, Brazil, is 4.7 mm day^{-}

[1]. In another study in the same region, Silva et al. (2014b) found sugarcane evapotranspiration of 4.3 mm day^{-1}.
In the irrigated treatments, 360 mm were applied in 12 events of 30 mm (Fig 3). Irrigations were concentrated between August and October, as a result of the water deficit, resulting from lower rainfalls in relation to the high evapotranspiration of the culture, coming from its higher vegetative growth.

Technological quality and production

The crop was harvested in May 2016. The technological analyses were the following (CONSECANA, 2006): total soluble solids (Brix), Juice POL, purity, fiber, and total recoverable sugar (TRS) (kg t^{-1}). The stalk productivity was determined by harvesting 5 m per line from each sub-plot. Sugar productivity (t ha^{-1} of TRS) was calculated by the product of TRS (kg t^{-1}) by the stalk productivity (t ha^{-1}) divided by 1,000. After harvesting and weighing, ten stalks per sugarcane sub-plot were sent to the laboratory to perform the technological analysis.

Statistical analysis

The experiment consisted in treatments with two factors: irrigation, allocated in the plot, and sugarcane cultivar allocated in the sub-plot (Split-plot). The irrigation factor had two levels (irrigated and non-irrigated) and the cultivar factor had five levels (CTC 4, IAC 93-3046, RB 86-7515, IAC 95-5000 and IAC 91-1099), with 12 replicates. The sub-plots included four sugarcane lines with 4.5 m length, spaced 1.5 m apart and with seedlings spaced 0.5 m apart (13,333 seedlings ha^{-1}). The two side lines as well as 1 m at each edge of the central lines were considered as a buffer, so the usable area corresponded at 2.5 m in each central line.
The treatments were distributed in a partially balanced incomplete block design, with three cultivars per block. This design is considered a good option to evaluate a great number of treatments, without increase the magnitude of the experiment (Bose & Nair, 1939). The analysis of variance and the comparison of means were performed by SAS®. The productivity and technological quality data were submitted to analysis of variance and t test (5% of probability) of means comparison.

Conclusions

1- Supplementary irrigation promoted a significant fall in POL % juice, TRS (kg t^{-1}) and POL % cane in the cultivars CTC4 and IAC 91-1099, reduced °Brix for the cultivar IAC 91-1099 and reduced fibers for the cultivar IACSP 95-5000. 2– Supplementary irrigation increased the sugar productivity of cultivars IACSP 93-3046 (23.69 t ha^{-1}) and IAC 91-1099 (24.16 t ha^{-1}). 3- Cultivars IACSP 93-3046, IACSP 95-5000 and IAC 91-1099 presented higher stalk productivity under irrigated treatment when compared to the non-irrigated management, with increases of 54.78%, 37.93%, and 24.53%, respectively.

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