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Water use efficiency in the sugarcane cropping in different planting dates in Brazil

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In global terms, irrigation is a human activity with greater demand for fresh water and strategies are needed to minimize this consumption. Therefore, the objective of this study was to establish the sugarcane planting date, which results in a greater water use efficiency, considering the summer planting of the Northeast region of Brazil. The sugarcane cultivar was RB92579, drip irrigated, and the stage of the plant was first ratoon. The experimental design was a randomized complete block design, with four replications and five treatments referring to the planting date (PD) equivalent to the months of October (PD1), November (PD2), December (PD3), 2013, January (PD4) and February (PD5), 2014. Water use efficiency was defined as the ratio of the tonnes of sugar per hectare to the volume of water entering the system, either through irrigation, total rainfall plus irrigation or effective rainfall plus irrigation. The planting dates in October and January showed the highest water use efficiency, as well as higher agro-industry productivity and higher net revenue. Planting in October maximized the use of rainfall and, in November, minimized the use of irrigation water.

Key words: phenology, effective precipitation, evapotranspiration, soluble solids content, irrigation.

INTRODUCTION

The cultivation of sugar cane showed an initial expansion in the Brazilian Northeast, mainly in the Coastal Tablelands region. In this region, 70% of the total annual rainfall occurred in June and July, but this did not affect the growth of the 2014/2015 harvest, with a yield of 6.3%

in relation to the previous harvest, indicating that the culture is adapted to the climate of the region (CONAB, 2014). Compared to other crops, sugarcane is the one that produces the highest amount of dry mass and energy per unit area in only one cut per year (Silva et al.,

2014).

As a result of the population growth, irrigated agriculture is the activity that is growing more and more in Brazil and in the world, consequently having a high consumption of water compared to the other activity sectors, which represents almost 70% of total human blue water use (Gordon et al., 2010; Rost et al., 2008). This is the case of sugarcane that has a relatively high water consumption, and large scale increases in sugarcane farming compared to other crops which may increase overall catchment evapotranspiration (ET) and reduce stream flow (Bastidas-Obando et al., 2017). Thus, for an irrigated agriculture to be environmentally sustainable, an efficient use of water is necessary through an accurate monitoring of water application to provide the optimization of waters resources, which is so important for humanity (Cammalleri et al., 2014, Coelho et al., 2005).

When the input of water in the system (precipitation and/or irrigation) is greater than the output (evapotranspiration and/or percolation), the soil has a greater water availability. Therefore, if the water that enters the system via precipitation is used by the crop in a productive way, the water use efficiency of precipitation in the crop occurs. This will depend on the planting date and the development stages of the crop, that is, if water demand occurs at the stage of crop development that requires more water, there will be a loss in crop yield (Oliveira et al., 2011; Farias et al., 2008).

Therefore, when synchronizing the phenological phase of the crop with higher water requirement with the period of greater rainfall availability, it is possible to reduce the use of irrigation water without decreasing crop productivity. This alternative will either save the water that is spent on irrigation or reduce production costs, with the aim of achieving a good yield of the crop and of a sustainable way for the environment, by maximizing the use of rainfall and minimizing the use of irrigation. Therefore, the objective of this study was to establish the sugarcane planting date which results in a greater water use efficiency, considering irrigated planting in the Northeast region of Brazil.

MATERIALS AND METHODS

The field trials were conducted in an experimental area located in the Coruripe Mill, in the municipality of Coruripe, State of Alagoas, Brazil, with geographic coordinates of 10º01'29.15''S latitude and 35º16'24.86''E longitude, and altitude of 108 m (Figure 1). The climate of the region is rainy tropical type with dry summer and higher precipitations among the months of April and September, according to classification of Köppen. The average annual rainfall was 1,179 mm, with maximum, average and minimum temperature values of 29.5, 24.4 and 21.1°C, respectively. The average annual relative humidity was 82%.The soil of the experiment area was an Ultisol with plan relief, medium to clay texture, formed from the sediment of the Barreiras group, characteristic of the geomorphological unit of the Coastal Tablelands region (Jacomine et al., 1975).

The sugarcane cultivar used in the experiment was the RB92579

at the first ratoon, which shows good expansion and high productivity in the State of Alagoas. The experimental design was a randomized complete block design with four replications, with five planting periods being considered as treatment, totaling 20 experimental plots. The planting dates (PD) were equivalent to the months of October (PD1), November (PD2), December (PD3), January (PD4) and February (PD5), which are adopted by sugar mills in the State of Alagoas. The planting was conducted in double rows, with spacing of 0.5 m between single rows and 1.3 m between double rows.

The soil preparation consisted of sub soiling with a depth of 0.50 m to 0.60 m. The irrigation depths were applied daily by means of a subsurface drip system. The drippers were spaced 0.5 m from each other and buried at 0.25 m of soil depth, with a nominal flow rate of 1.0 L h^{-1}. The irrigation depths were applied according to the average of the daily reference evapotranspiration estimated in the previous week.

In order to estimate the reference evapotranspiration, the Penman-Monteith equation (Allen et al., 1998) was used, based on data obtained from an automatic climatological station located 5 km from the experiment site and named CORURIPE-A355, belonging to National Institute of Meteorology (INMET). The crop evapotranspiration (ETc) was estimated from reference evapotranspiration (ETo). For this, appropriate crop coefficients (Kc) were used for each stage of crop development and planting dates. The crop coefficients (Kc) were obtained by Silva et al. (2012). Soil water balance was performed daily and from this, it was possible to estimate the effective precipitation (EP) and the precipitation efficiency (PE), which is the ratio between EP and total precipitation (TP).

After each crop cycle, the physical productivity (tonnes of industrializable stalks per hectare - TISH) and the sugarcane quality parameters: sucrose content of the broth - SCB (%), industrial fiber content - Fiber(%), soluble solids content - ºBrix(%), total recoverable sugar - TRS (kg Mg^{-1}) and tonnes of sugar per hectare - TSH (Mg ha^{-1}) were determined. The water use efficiency of each treatment based on TISH or TSH was determined by Equations 1, 2 and 3.

$$WUE(i) = \frac{TISH\ or\ TSH}{I} = Kgm^{-3} \tag{1}$$

$$WUE(p+i) = \frac{TISH\ or\ TSH}{P+I} = Kgm^{-3} \tag{2}$$

$$WUE(ep+i) = \frac{TISH\ or\ TSH}{EP+I} = Kgm^{-3} \tag{3}$$

Where, WUE(i) is the water use efficiency of the irrigation (i); WUE(p+i) is the water use efficiency of precipitation plus irrigation(p + i); WUE(ep+i) is the water use efficiency of effective precipitation plus irrigation (ep + i); TISH is the tonnes of industrializable stalks per hectare (Mg ha^{-1}); TSH is the tonnes of sugar per hectare (Mgha^{-1}); I is the irrigation (m^3 ha^{-1}); P is the precipitation (m^3 ha^{-1}) and EP is the effective precipitation (m^3 ha^{-1}).

A preliminary economic analysis was carried out to determine the gross revenue (GR) for the month of each harvest, the total cost of water by subsurface drip irrigation (C) and the net revenue (NR). The total cost of water is the product of the cost of irrigation water by the irrigation depth applied. The cost of irrigation water was defined based on information on average operational costs of irrigation provided by the Talles Machado Mill, State of São Paulo, and Coruripe Mill, State of Alagoas, Brazil, whose value was US$ 0.75 per mm. Gross income is the product of TISH by TRS and by the value of kg of TRS (CONSECANA-AL 2015). Net income is the result of subtracting the total cost of water from gross income.

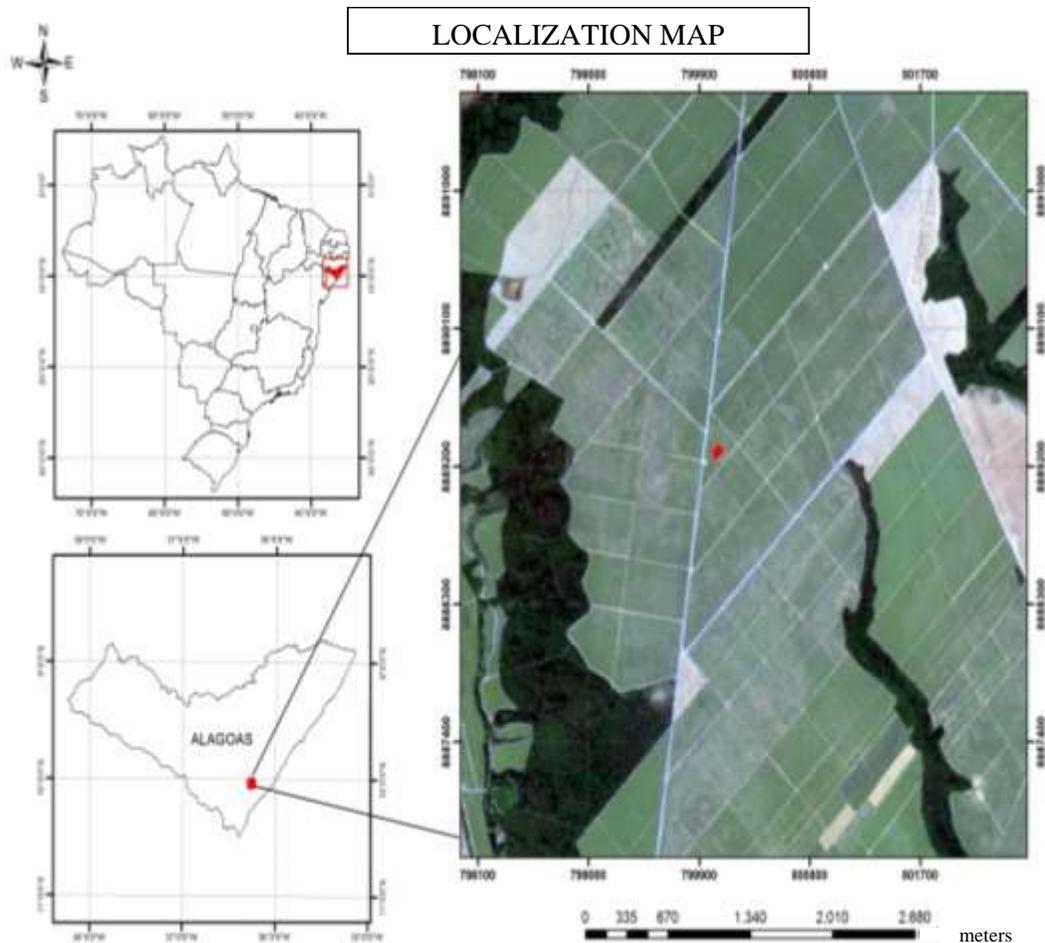The physical and technological productivity data were submitted

Figure 1. Location of the experimental area, with aerial view of the sugarcane fields of the Coruripe Plant, State of Alagoas.

to analysis of variance using the F test. The averages were compared by the Tukey test at 5% probability. For the analyzes, the statistical software SISVAR was used.

RESULTS AND DISCUSSION

In Figure 2, the water demand of sugarcane during its growing cycle was observed for each planting date, in relation to the precipitation distribution.

It was observed that the climate found in the region for the experimental period was favorable to the good development of the crop in its different stages of growth and different planting dates (Figure 2).

Most of the precipitation occurred in development phase 3 in all date of planting, mainly in PD2, PD3 and PD4 (Figure 2). In this development phase of the crop, high amounts of water were required to favor the maximum growth of the stalk, consequently being the phase of higher crop water demand. The period of greatest precipitation was between the months of April to September, exactly in the phase that the crop requires

more water. Similar results were obtained by Silva et al. (2011) with the RB92-579 cultivar in the Juazeiro Municipality, State of Bahia, Brazil. Dantas Neto et al. (2006), in an experiment with the SP79-1011 cultivar conducted in the State of Paraíba, Brazil, found a higher concentration of precipitations from March to June, being within a characteristic range of months for the Northeast of Brazilian which period has a greater water availability of rains.

The total volume of water precipitation during the sugarcane cycle did not varied significantly among the evaluated planting dates, with the percentage difference between the highest and the lowest rain height of 3.6%; for the effective precipitation, the difference was 40% (Table 1). The low utilization of rainfall by the plant may be related to the type of soil and its low water storage capacity. Lima Neto et al. (2009), in their study of soil characterization in the Coastal Tablelands, verified that there is a compacted layer present in the depths of the soil of this region. This layer prevents the deepening of the roots, thus restricting the efficient use of water by
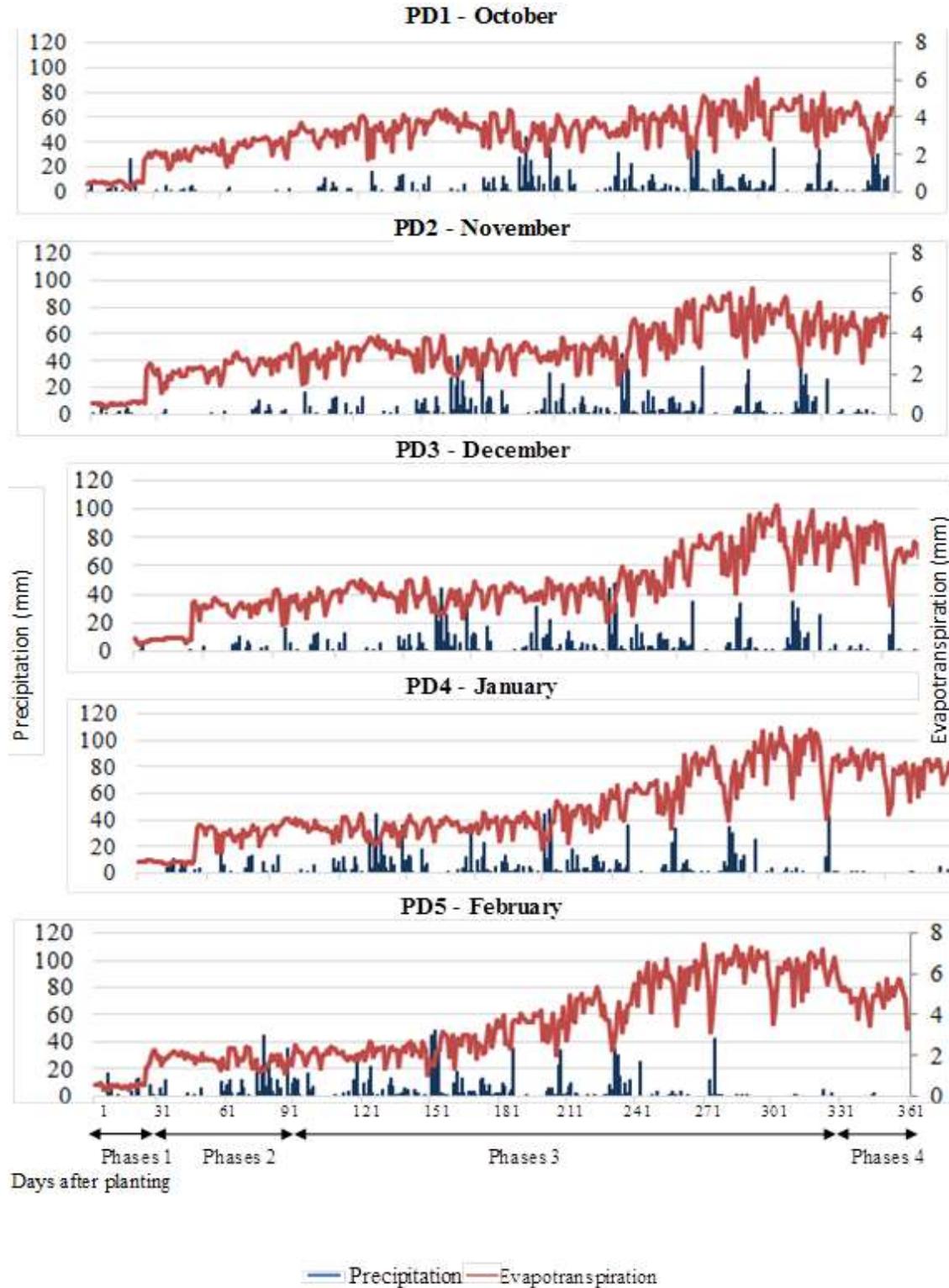
Figure 2. Behavior of precipitation and ETc during the growing cycle of sugarcane and the planting dates of October (PD1), November (PD2), December (PD3), January (PD4) and February (PD5).

them.
There was no statistically significant difference in

relation to TISH and TSH; however, a trend of reduction of yield per hectare was observed during the harvest

Table 1. Amount of total precipitation (P), effective precipitation (EP), reference evapotranspiration (ETo), crop evapotranspiration (ETc), precipitation efficiency (PE) and accumulated irrigation depth (mm) for each planting date (PD) studied.

Planting date	P (mm)	EP (mm)	Eto (mm)	Etc (mm)	PE (%)	I (mm)
PD1	1,300.0	469.8	1,517.2	1,136.1	36.2	687.7
PD2	1,288.0	405.9	1,523.5	1,150.7	31.6	652.7
PD3	1,333.0	405.6	1,518.6	1,170.2	30.5	670.4
PD4	1,335.2	390.9	1,535.0	1,215.4	29.3	672.3
PD5	1,292.8	334.8	1,542.3	1,267.1	25.9	771.0
Mean	1,309.8	401.4	1,527.3	1,187,9	30.7	690.8

Table 2. Tonnes of industrializable stalks per hectare (TISH), total recoverable sugar (TRS), tonnes of sugar per hectare (TSH), sucrose content of the broth (SCB), sucrose content of cane (SCC), soluble solids content (^{o}Brix) and industrial fiber content (Fibre) of the RB92579 sugarcane cultivar under different planting dates (PD).

Planting date	TISH (Mg ha^{-1})	TRS (Kg Mg^{-1})	TSH(Mg ha^{-1})	SCB (%)	SCC (%)	°Brix (%)	Fiber (%)
PD1	140.63[a1]	143.79[c]	20.24[a]	17.65[b]	14.76[b]	19.49[c]	12.75[b]
PD2	125.82[a]	142.36[c]	17.89[a]	18.32[b]	14.56[b]	19.93[c]	13.25[ab]
PD3	106.62[a]	152.06[cb]	16.25[a]	18.90[ab]	15.67[ab]	20.71[cb]	13.38[ab]
PD4	126.92[a]	160.75[ab]	20.42[a]	20.30[a]	16.61[a]	22.07[a]	13.95[a]
PD5	118.56[a]	162.71[a]	19.26[a]	20.29[a]	16.82[a]	21.90[ab]	13.20[ab]
Mean	123.71	152.33	18.81	18.95	15.68	20.82	13.31
F[2]	ns	**	ns	**	**	**	*
CV%[2]	13.94	2.70	14.43	3.11	3.00	2.39	2.76
MSD[2]	40.11	10.29	6.43	1.53	1.17	1.25	1.00

[1]Means followed by the same letter in the column do not differ significantly from each other by the Tukey test. [2]**significant at 1% probability; *significant at 5%; ns: not significant by the F test (ANOVA). [3]CV, Coefficient of variation; MSD, Minimum significant difference.

time, due to the low availability of rainfall that occurred in phase 3 of the crop from the PD2, as could be observed in Table 2. The planting date PD2 resulted in lower irrigation water consumption, with a slide water application of 652.7 mm in the crop cycle, while PD1 and PD5 showed the greatest irrigation requirements. Thus, comparing the planting dates with lower and higher irrigation demand, it was observed that PD2 represented water saving of 118.3 mm in relation to PD5. The irrigation depths applied in PD4 and PD5 occurred due to the low effective precipitation found for them, in which it was necessary to supply the water deficit using irrigation water.

PD1 (140.63 Mg ha^{-1}) had the highest stalk yield, followed by PD4 (126.92 Mg ha^{-1}). PD1 and PD4 (20.44 and 20.22 Mg ha^{-1}) showed higher values of tonnes of sugar per hectare (TSH), while PD3 had lower yields of stems and sugarcane (Table 2).

In general, Meneses (2015) observed that there was a trend of decreasing productivity during the harvest time for the RB 92579 cultivar. This tendency was not clearly established in the cropping cycle of sugarcane in this study, due to an increase in yield in the last two planting dates (PD4 and PD5). Almeida et al. (2008) found the highest final production of stalk (136.22 t ha^{-1}) at the planting in October in the Coastal Table lands region of the State of Alagoas, and observed that it was a favorable month for good sugarcane management, since it is a period of favorable yield, as it was found in the this study.

The values of SCB, SCC and °Brix showed increase during the harvests. This fact was due to the relation between the maturation phase in the last three planting dates (PD3, PD4, and PD5) and the lack of rainfall in this period, since the water deficit in the maturation phase of sugarcane decreases the vegetative development, avoiding that the sugar translocates to the crop leaves, maintaining concentration in the stalks and favoring the final production of sugar.

It was observed in Table 3 that the planting date PD1 resulted in maximum water use efficiency on the basis of TISH, and the PD4 in the base of TSH, considering all the water intakes. The planting dates PD3 and PD5 were the ones that showed lower efficiency of water use in both water inputs and crop productive bases.

The highest water use efficiency of irrigation based on the TISH was observed in PD1 (20.45 kg m^{-3}) followed by PD2 (19.28 kg m^{-3}) and PD4 (18.88 kg m^{-3}). Silva et al.

Table 3. Values of water use efficiency (WUE) in the sugarcane cycle, RB 92579 cultivar, in five planting dates (PD): October (PD1), November (PD2), December (PD3), January (PD4) and February (PD5).

Cultivar	WUE (Kg m^{-3})	Planting date				
		PD1	PD2	PD3	PD4	PD5
	WUE(i) on a basis of TISH	20.45	19.28	15.90	18.88	15.38
	WUE(ep+i) on a basis of TISH	12.15	11.89	9.91	11.94	10.72
RB92579	WUE(p+i) on a basis of TISH	7.08	6.48	5.32	6.32	5.74
	WUE(i) on a basis of TSH	2.94	2.74	2.42	3.04	2.50
	WUE(ep+i) on a basis of TSH	1.75	1.69	1.51	1.92	1.74
	WUE(p+i) on a basis of TSH	1.02	0.92	0.81	1.02	0.93

Table 4. Economic performance of the sugarcane, RB 92579 cultivar, as a function of the planting dates.

Planting date	TISH[1] (Mg ha^{-1})	TRS[1] (Kg Mg^{-1})	TRS/ha[1]	US$/TRS[1]	GR[1] (US$/ha)	I[1] (mm)	TCI[1] (US$)	NR[1] (US$/ha)
PD1	140.63	143.79	20,221.0	0.1477	2,986.35	687.7	1,447.79	1,538.56
PD2	125.82	142.36	17,912.0	0.1454	2,603.80	652.7	1,374.11	1,229.69
PD3	106.62	152.06	16,213,0	0.1301	2,108.92	670.4	1,411.37	0,697.56
PD4	126.92	160.75	20,402.0	0.1300	2,654.85	672.3	1,415.37	1,237.48
PD5	118.56	162.71	19,291.0	0.1417	2,732.71	771.0	1,623.16	1,109.55
Mean	123.71	152.33	18,808.0	0.1390	2,617.33	690.8	1,454.36	1,162.57

[1]TISH, tonnes of industrializable stalks per hectare; TRS, total recoverable sugar; TRS/ha, total recoverable sugar per hectare; US$/TRS , amount paid to total recoverable sugar; GR, gross revenue; I , irrigation depth applied; TCI, Total cost of irrigation water; NR, net revenue.

(2013), using a randomized block design and two central pivots, found lower values of WUE(i) for the same cultivar. This fact was a result of lower sugarcane productivity and higher irrigation water consumption found by that author. In this study, the highest WUE(pe + i) on the basis of HCT was found in the planting date PD1 and on the basis of TAH in the PD4 (Table 3).

Oliveira et al. (2011), when developing an experiment with 11 sugarcane cultivars in the State of Pernambuco in the planting date of October 2006 with full irrigation, verified that the RB 92579 cultivar had a high water use efficiency of 18.3 kg m^{-3}, corroborating with the result obtained in this study for planting date in January (PD1).

The parameters used in the economic analysis to determine the planting date that provided the best financial return are shown in Table 4. The average net revenue was US$ 1,162.57 per hectare. In economic terms, the October and January planting dates resulted in higher net revenues.

Regarding the cost of irrigation, the difference between the highest and lowest costs was US$ 249.05. This cost was high due to the increase in the unit cost of water (US$ 0.75 mm^{-1}) in the study year, compared to that used by Resende (2013) who conducted similar analysis, however with values corrected for US$ 0.79 mm^{-1} of water.

Meneses (2015), studying planting dates for RB 92579 cultivar, found a net average income per hectare four times higher when compared to the value obtained in this study. This fact was due to the higher yield of stalk and sugar with lower irrigated depth (mean of 641.20 mm) and mainly due to the lower water cost (R$ 0.79 m^{-3}).

According to Vieira et al. (2014), in order to quantify the economic benefits of irrigation, it is necessary to know how to quantify the expected increase in productivity due to the increase in water applied. In this study, the highest irrigation depth was applied in the planting date PD5 and the lowest in the PD2, thus having a difference of 118.30 mm.

Conclusion

The planting date in October provided the maximization of the precipitation water use by the sugarcane, while planting date in November had minimized the crop use of irrigation water. Plantings carried out in October and January contributed to the crop showed higher yields of sugarcane stalk and sugar, respectively; as well as, when planted in October and January, sugarcane showed a greater efficiency in water use efficiency for all water intakes for both the tonnes of stalks per hectare and the tonnes of sugar per hectare. In summary, planting dates in October and January provided the maximization of the net revenue obtained with the cultivation of the sugarcane crop.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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