Reducing sugarcane irrigation demand through planting date adjustment in Alagoas State, Brazil[1]

Redução da demanda de irrigação da cana-de-açúcar com ajuste na data de plantio, para região de Alagoas

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HIGHLIGHTS:

There is a high potential for reducing irrigation demand through planting date adjustment in the Northeast region of Brazil.
Sugarcane yield has the highest correlation with the precipitation in the dry season rather than in the total crop cycle.
The soil water deficit during the growing cycles of sugarcane showed the tendency to increase from the first to the last planting dates.

ABSTRACT: Sugarcane is both an important crop for the Brazilian Northeast economy, which faces severe water scarcity, and a water-intensive crop. Thus, it is important to develop irrigation strategies to reduce irrigation water demand in the region. This study aims to determine the sugarcane planting date that results in the maximum rainwater availability to the crop in the growing cycle. The crop effective precipitation was estimated from a soil water balance performed during three planting cycles of sugarcane, cultivar 'RB 92579'. The crop was planted under subsurface drip irrigation in five months: October, November, December, January, and February, corresponding to the dry season period of the region. The experiment was conducted at the Açúcar e Álcool Coruripe Mill, located in the Coruripe municipality, State of Alagoas, Brazil, during the years 2012 to 2016. For all planting dates and growing cycles studied, the average effective rainy precipitation was equal to 30% of the total rainfall under irrigated conditions and 54.5% without considering the irrigation component in the soil water balance. November was the planting date that resulted in the minimum irrigation depth for the sugarcane growing cycle, with the potential irrigation water saving ranging from 5 to 129 mm.

Key words: *Saccharum* spp., irrigation management, effective rainy, precipitation, soil water balance

RESUMO: A cana-de açúcar é uma cultura de elevada demanda de água, sendo cultivo importante para o Nordeste do Brasil, região que apresenta limitação hídrica ao longo do ano para as plantas de cana. Assim, torna-se importante desenvolver estratégias para reduzir o volume de água de irrigação para a cultura. Objetivou-se no presente estudo determinar a data de plantio da cana-de-açúcar que coincida com a máxima disponibilidade de água proveniente da precipitação, durante seu ciclo de desenvolvimento. A precipitação efetiva foi estimada a partir do balanço de água do solo efetuado durante três ciclos de cultivo da cana-de açúcar, variedade RB 92579. A cultura foi conduzida sob irrigação por gotejamento subsuperficial, tendo sido plantada em cinco meses: Outubro, Novembro, Dezembro, Janeiro e Fevereiro, correspondentes à estação seca na região. O experimento foi conduzido na Usina Açúcar e Álcool Coruripe S.A., município de Coruripe, Estado de Alagoas, Brasil, durante os anos de 2012 a 2016. Para todas as datas de plantio e ciclos de crescimento avaliados, a precipitação média efetiva foi igual a 30% da precipitação total, na condição de cultivo sob irrigação, e de 54,5% quando não se considerou a irrigação como componente do balanço de água. Novembro foi o mês de plantio com a menor lâmina de irrigação aplicada no ciclo de cultivo da cana-de-açúcar, com economia potencial de água variando de 5 a 129 mm.

Palavras-chave: *Saccharum* spp., manejo da irrigação, precipitação efetiva, precipitação, balanço de água no solo

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INTRODUCTION

To meet the increasing ethanol and sugar demands, the area under sugarcane is rapidly growing worldwide (Rudorff et al., 2010; Cia et al., 2012; Bastidas-Obando et al., 2017). In addition, there has been an expansion of sugarcane cultivation to marginal areas, where water availability is limited or highly variable (Laclau & Laclau, 2009; Azevedo et al., 2011; Carr & Knox, 2011; Cia et al., 2012), that is the case of Brazil.

Sugarcane is a high biomass crop grown mostly in rain-fed environments (Liu et al., 2016). Nevertheless, the crop water supply by rainfall is a climate-dependent variable, so that different maturation periods of the cultivars, associated with different environments, can guarantee better management of the sugarcane harvest and maximum efficiency in the exploitation of the crop (Maule et al., 2001; Pereira, 2012).

The annual water demand for sugarcane ranges from 1100 to 1800 mm (Carr & Knox, 2011). Taking into account that rainfall is the main water supply in most sugarcane growing areas in the world and the nonuniformity of the annual rainy precipitation regime, the response of sugarcane to irrigation becomes dependent on the magnitude and the period of water deficit occurrence, as well the prevailing climatic conditions in this period. In the Northeast region, such a regime is concentrated in the months from March to August. According to Ghiberto et al. (2011), the study of the components of soil water balance provides useful information for managing a crop in both rain-fed and irrigated agriculture.

Therefore, the definition of the proper planting date, by synchronizing the plant phenological stage with the highest water requirement with the period of the year with the highest rainfall, is an important attempt to increase the rainwater and efficiency and reduce the use of irrigation water without decreasing the crop productivity. This study aims to determine the sugarcane planting date that may result in the maximum rainwater availability to the crop in the growing cycle.

MATERIAL AND METHODS

The experiment was conducted in an area belonging to Açúcar e Álcool Coruripe Mill (latitude 10° 01' 29.15" S, longitude 35° 16' 24.86" W, altitude of 108 m), which is a sugar and alcohol-producing plant, located in the Coruripe municipality, State of Alagoas, in the northeastern region of Brazil (Figure 1).

According to Köppen's classification, the climate of the region is As, hot and humid with autumn-winter rains and dry summer. The average annual rain is 1200 mm. The soil of the experimental area is classified as Ultisol, with loamy sandy texture in the top layer and sandy loam in the subsurface.

Sugarcane, cultivar RB 92579, was conducted in double spacing, with 0.5 m between rows in a double line, and 1.3 m between the double lines. The cultivar 'RB 92579' is the most grown in the Brazilian Northeast region (Braga Junior, 2019). Each plot consisted of four double lines, 11.0 m in length and 7.2 m wide, resulting in an area of 79.2 m^2 per plot. The useful area of the plot consisted of the two central double rows, with an area of 39.4 m^2.

A.

B.
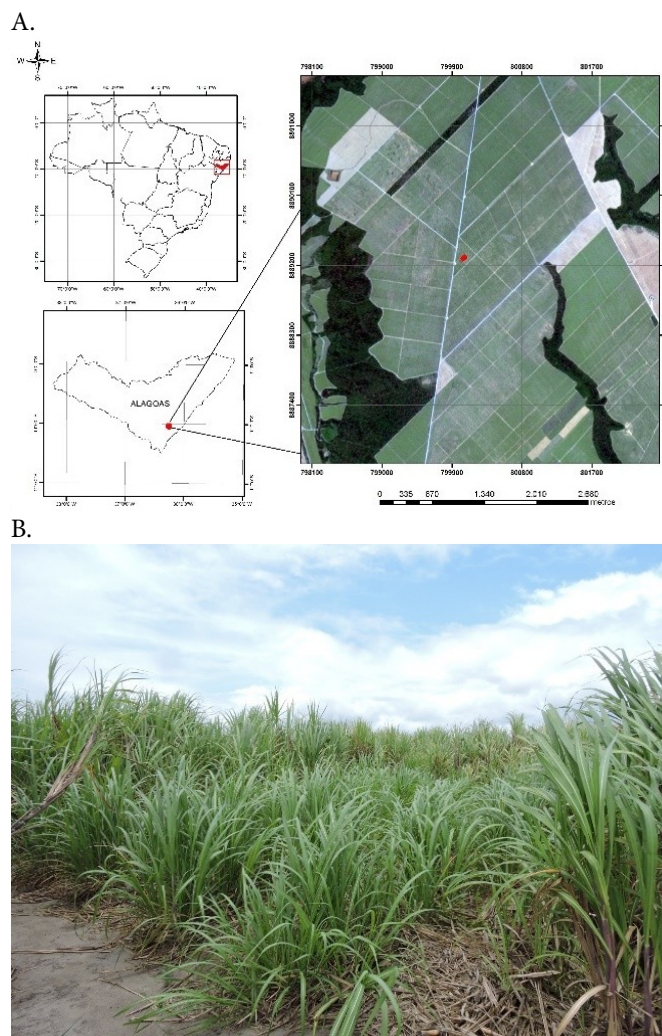
Figure 1. Location of the experimental area, with an aerial view of the sugarcane fields of the Coruripe Mill, State of Alagoas, Brazil (A) and experimental plots (B)

The initial soil preparation consisted of a subsoiling, with cutting depth between 0.50 and 0.60 m, followed by crossed plowing and harrowing, with the incorporation of 500 kg ha⁻¹ of Calmix® (70% lime + 30% gypsum), and supplemented by a furrowing at the depth of 0.30 m. Plantings were performed using previously treated sets, with a density of 15-18 sets per meter manually inserted into furrows.

The subsurface drip irrigation system was used with dripline buried at the depth of 0.25 m and spaced at 1.8 m. The daily irrigation depths were determined based on the average daily crop evapotranspiration (ETc). Reference evapotranspiration (ETo) was estimated by the Penman-Monteith method (Allen et al., 1998). The climatic data were collected from an automatic climatological station installed at approximately 5 km from the experimental area, identified as CORURIPE-A355 (WMO Code: 86619) and belongs to the network of the National Institute of Meteorology (INMET). The ETc was estimated from the ETo, using the crop coefficients (Kc) obtained by Silva et al. (2012), and defined in terms of sugarcane age for each treatment. Irrigation was interrupted 30 days before harvest to induce maturation and promote the accumulation of sucrose.

The evaluated treatments consisted of the sugarcane planting dates: October (M1), November (M2), December

Table 1. Soil physical characteristics of the experimental area

Depth (m)	Granulometry (g kg⁻¹)			W_{fc}	W_{pwp}	D_b	Soil texture classification
	Sand	Silt	Clay	(m³ m⁻³)		(Mg m⁻³)	
0-0.2	875.6	66.0	58.4	0.13	0.05	1.57	Loamy sand
0.2-0.4	788.3	106.5	105.2	0.14	0.06	1.65	Sandy loam

W_{fc} - Field capacity (10 kPa); W_{pwp} - Permanent wilting point (1.500 kPa); D_b - Bulk density

(M3), January (M4), and February (M5), related to the summer planting period of the region, and conducted under subsurface drip irrigation. The study was conducted during the year 2012 to 2016, corresponding to plant-cane (2013-2014), first ratoon (2014-2015), and second ratoon (2015-2016) cycles or the three growing cycles, respectively designated as C1, C2, and C3. For each month (M) in each cycle (C), the planting period lasted 12 months from planting to harvest.

For each treatment, daily soil water balance was performed. For this purpose, crop effective root depth (R_d) was considered equal to 0.4 m. According to Cintra et al. (2006), this soil depth holds 83% of total sugarcane roots. The soil moisture at field capacity (W_{fc}, in %) and permanent wilting point (W_{pwp}, in %) were determined from the retention curves obtained for the soils of the experimental area (Table 1).

The components of soil water balance were calculated according to the following equations:

$$AWC = \left[\left(W_{fc} - W_{pwp} \right) R_d \right] 1000 \qquad (1)$$

where:
AWC - available water storage capacity, mm;
W_{fc} - soil moisture at field capacity, m³ m⁻³;
W_{pwp} - soil moisture at permanent wilting point, m³ m⁻³;
R_d - effective root depth, m; and,
1,000 - the conversion factor used to convert m into mm.

As well as

$$SWS_i = \left(SWS_{i-1} + R_i + I_i + ETc_i \right) \qquad (2)$$

where:
SWS_i - soil water storage on day i, mm;
SWS_{i-1} - soil water storage on the previous day, mm;
R_i - total rainfall on day i, mm;
I_i - irrigation depth on day i, mm; and,
ETc_i - crop evapotranspiration on day i, mm.

Both daily soil water surplus (WS_i) and soil water deficit (WD_i) were determined according to Allen et al. (1998) from the following relationships:

$$WS_i = \left(R_i + I_i - ETc_i \right) - \left(AWC - SWS_{i-1} \right) > 0, \qquad (3)$$

$$\text{If } SWS_{i-1} < AWC \left(1 - f \right), \text{ then } WD_i = \left| R_i - ETC_i \right|, \qquad (4)$$

$$\text{and If } SWS_{i-1} > AWA \left(1 - f \right), \text{ then } WD_i = 0, \qquad (5)$$

where:
f - water depletion factor; and,

$$R_e = R - WS \qquad (6)$$

where:
R_e - total effective precipitation in the growing cycle, mm;
R - total rainfall in the growing cycle, mm; and,
WS - total soil water surplus in the growing cycle, mm,

$$P_e = \left(\frac{R_e}{R} \right) 100 \qquad (7)$$

where:
P_e - rainy precipitation efficiency, mm.

The soil water balance was conducted considering two conditions: 1) rainfall and irrigation as water input components (named here water balance with irrigation) and 2) only rainfall as water input component (named water balance without irrigation). The total soil water deficit was obtained from the sum of WD_i that occurred during the crop growing cycle. The f value of 0.5 was considered. Rainy precipitation efficiency (P_e) and irrigation depth applied (I) were used to establish the sugarcane planting date that may result in the maximum rainwater availability to the crop in the growing cycle.

RESULTS AND DISCUSSION

Based on climatological data from 1981 to 2010 for the municipality of Coruripe, State of Alagoas, Brazil (INMET, 2020), the climatic water balance method showed two distinct seasons: a rainy period from May to August, in which a soil water surplus occurs, and a dry period from September to February, with a soil water deficit. The rainfall distribution for all planting dates and growing cycles of sugarcane is shown in Figure 2.

For the five planting months evaluated (M1, M2, M3, M4, and M5), the average rainfall values relating to the planting period were 1,435, 1,310, and 1,247 mm, respectively, whereas the average ETo values were 1,560, 1,527, and 1,623 mm, respectively, from the first (C1) to the third (C3) growing cycle (Table 2).

Cycle C3 was the driest among the three evaluated growing cycles, with a climatic water deficit (R - ETo) of 376 mm. In the first and the second growing cycles, no dramatic differences were observed in rainfall volumes for the five studied planting months. During cycle C3, February (M5), which accumulated approximately 300 mm of water more than the other planting months, was an exception.

During the three growing cycles, no notable differences were verified for ETo values among the planting dates. For ETc, the differences among the values were greater than that
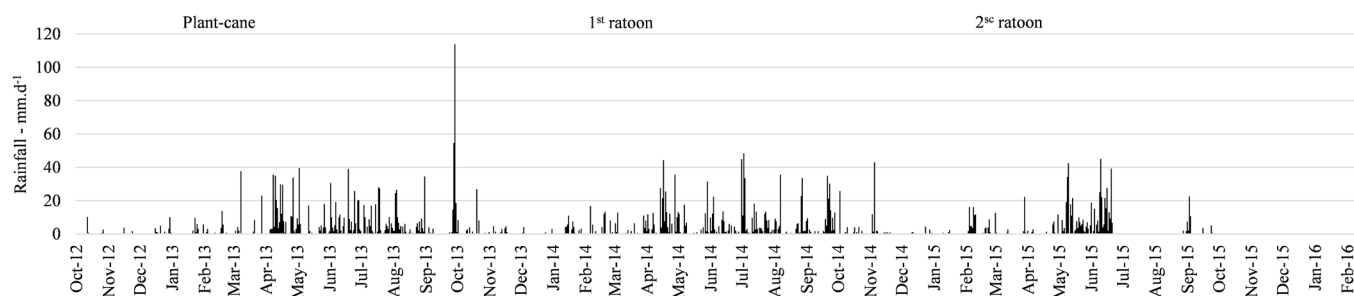
Figure 2. Rainfall distribution for all planting dates and sugarcane growing cycles: plant cane, first ratoon, and second ratoon

Table 2. Rainfall, reference (ETo), and crop (ETc) evapotranspiration, for each planting month and sugarcane growing cycle

Months	Rainfall (mm)			ETo (mm)			ETc (mm)		
	C1	C2	C3	C1	C2	C3	C1	C2	C3
October	1,396	1,300	1,235	1,564	1,517	1,611	1,164	1,136	1,206
November	1,438	1,288	1,198	1,566	1,524	1,629	1,166	1,151	1,175
December	1,451	1,333	1,134	1,559	1,519	1,654	1,186	1,170	1,204
January	1,435	1,335	1,187	1,558	1,535	1,622	1,212	1,215	1,206
February	1,454	1,293	1,481	1,551	1,542	1,598	1,249	1,267	1,219
Mean	1,435	1,310	1,247	1,560	1,527	1,623	1,195	1,188	1,202

C1 - Plant cane; C2 - 1st ratoon; C3 - 2nd ratoon

observed for ETo values, with the tendency to increase from the first to the last planting dates. This trend occurred particularly during the first and the second growing cycle of the study (Table 2), where the differences between the lowest and the highest water demand by the sugarcane were around 85 and 131 mm, respectively, for growing cycles C1 and C2.

The ETc and R during the third sugarcane cycle (C3) are shown in Figures 3 for different months. The first (C1) and second (C2) growing cycles were reported by Meneses & Resende (2016) and by Carvalho et al. (2019), respectively, and showed a similar pattern as presented in Figure 3.
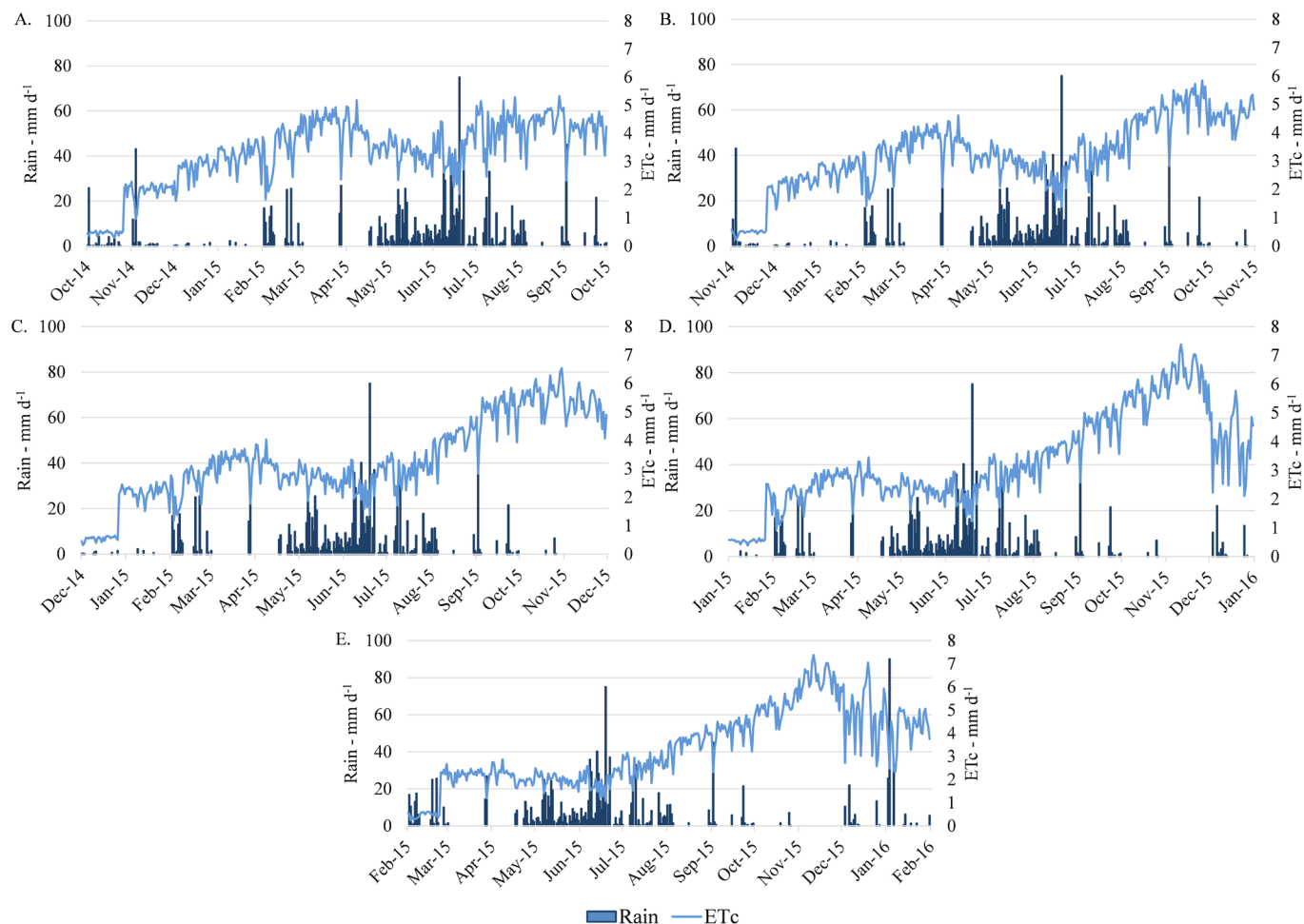
Figure 3. The daily mean of crop evapotranspiration (ETc) and the total rainfall during the third growing cycle of sugarcane in five planting months, A - October, B - November, C - December, D - January, E - February

For plantings in October and November (Figures 3A and B), the initial phase of the growing cycle, with lower values of Kc, coincides with the period of lower rainfall. Specifically, for planting in October (Figure 3A), the end of the growing cycle coincides with the end of the rainy season, when a certain amount of water deficit would be desirable for favoring a maturation of sugarcane during harvest.

By its turn, for planting in January and February (Figures 3D and E), the phases of higher evapotranspirometric demands of the crop coincide with the dry season and, consequently, higher irrigation requirements. For the months of October, November, December, January, and February, the values of water daily consumption by sugarcane ranged from 1.0 to 5.3, 1.3 to 5.8, 1.2 to 6.5, 0.9 to 7.4, and 1.1 to 7.4 mm d^{-1}, respectively, during the growing cycle.

Considering the planting dates of all growing cycles evaluated, the ETc average daily value ranged from 3.42 to 3.54 mm d^{-1} and the maximum daily rate ranged from 5.32 to 7.38 mm. In a review performed by Carr & Knox (2011) that was based on lysimeter data from different parts of the world, the annual sugarcane water requirements are between 1,100 and 1,800 mm, with maximum daily rates of 6 to 15 mm d^{-1}.

The ETc behavior in function of planting months showed that the synchronization of the phenological stage of the plant with the rainfall availability results in remarkable differences in the water demand of sugarcane during its growing cycle. This fact has a direct impact on the crop requirement for irrigation water and the consequent potential for saving water.

The behavior of soil water surplus, soil water deficit, effective precipitation (R$_e$), and rainfall efficiency for the conditions of soil water balance with and without irrigation are shown in Figure 4.

For the two conditions, the level of soil water surplus increased from the first to the last planting date in all the growing cycles (Figures 4A and B). Despite the lowest volume of rain occurred in the cycle C3, the highest soil water surplus values in each planting date were obtained in this growing cycle under irrigated condition. The difference compared to other cycles was more pronounced in February (M5), in which the occurrence of more intense summer rains at the final phase of the growing cycle (Figure 2) contributed to this result.

Similarly to the soil water surplus, the water deficit in the soil for both irrigated conditions (Figures 4C and D), increased from the first to the last planting date in all growing cycles, except for cycle C3 with irrigation (Figure 4C). The rainfall occurrence in January and February (Figure 2) explains this behavior for cycle C3.

Under irrigated conditions, the water deficit differences among the planting dates are related mostly to the month in which the irrigation was suspended to promote the maturation of sugarcane. Thus, sugarcane planted in the initial months of the growing cycle benefited from the residual moisture from the end of the rainy season, whereas no benefit occurred when sugarcane was planted in January and February.

On the other hand, effective precipitation showed an inverse tendency compared to that observed for water surplus and water deficit in the soil, with a reduction of its values from the first to the last planting date (Figures 4E and F), except for the
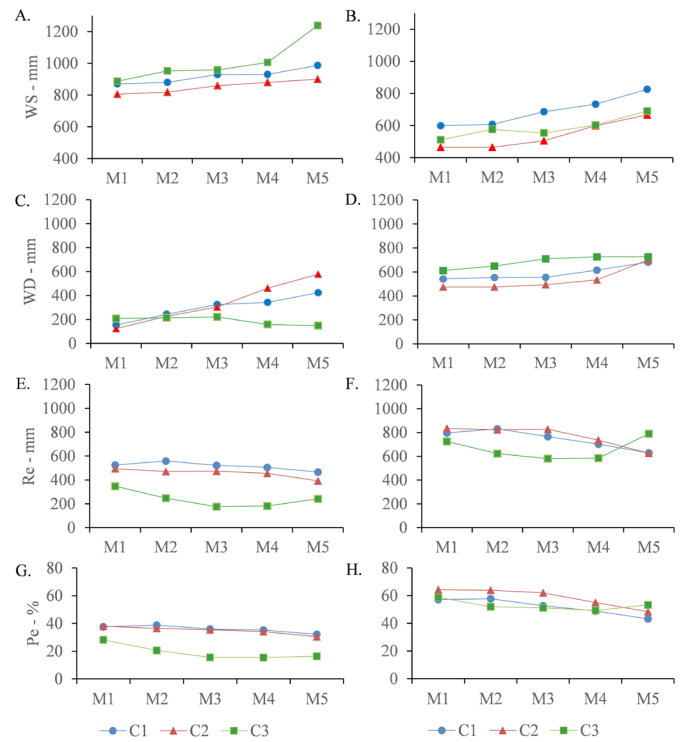
M1 - October; M2 - November; M3 - December; M4 - January; M5 - February; C1 - Plant cane; C2 - First ratoon; C3 - Second ratoon

Figure 4. Soil water surplus - WS (A and B), soil water deficit - WD (C and D), effective precipitation - R$_e$ (E and F), and rainfall efficiency - P$_e$ (G and H) in function of planting months, in three cycles, with and without irrigation

last month (February) in growing cycle C3, especially without irrigation (Figure 4F).

As a result of the behavior of the variables R, WS, and R$_e$ in the three growing cycles of sugarcane studied, the rainy precipitation efficiency (P$_e$) also showed a general tendency of reduction from the first to the last planting date for both irrigated and not irrigated conditions (Figures 4G and H), with the same exception for the growing cycle C3.

For all planting dates and growing cycles, considering the options with and without irrigation, the average values of soil water surplus were 927 and 606 mm, while the average water deficits were 275 and 603 mm, respectively (Table 3). When they performed soil water balance in similar environmental conditions to this study, Abreu et al. (2013) estimated an average soil water deficit in three growing cycles of sugarcane cultivated in September and under rain-fed conditions of 869 mm for the period of September to March and a soil water surplus of 837 mm for the period of April to August. However, in a study with sugarcane conducted in a milder weather region (Jaboticabal Municipality, State of São Paulo, Brazil), where the control section was considered the soil layer equivalent to 1.0 m depth with a silty clay loam texture, Ghiberto et al. (2011) reported values of soil surplus water ranging from 192 to 340 mm and lower than the values obtained herein.

The value of the average soil water surplus accounted for approximately 44% of irrigation depth plus rainy precipitation, a value notably higher than 15% found by Silva et al. (2014), when studying the water demand of sugarcane by the water balance method in the State of Paraíba, Brazil, although the rainfall value of the study period was a third of the historical average value of the region.

Table 3. Mean values of WS, WD, R_e, and P_e in three growing cycles of sugarcane with and without considering the irrigation component in the soil water balance

Month	WS (mm)		WD (mm)		Re (mm)		Pe (%)	
	With	Without	With	Without	With	Without	With	Without
October	854	525	161	542	456	785	34.6	60.0
November	883	549	228	559	425	759	32.0	57.9
December	915	582	283	586	391	724	29.0	55.3
January	938	645	321	625	381	674	28.2	51.1
February	1,042	728	384	702	367	681	26.3	48.3
Mean	927	606	275	603	404	725	30.0	54.5

WS - Soil water surplus; WD - soil water deficit; R_e - Effective precipitation; P_e - Rainfall efficiency

Table 4. Soil water deficit in irrigation season - WS_{dry} and irrigation depth - I for each planting month and sugarcane growing cycle

Months	WS$_{dry}$ (mm)				I (mm)			
	C1	C2	C3	Mean	C1[1]	C2[2]	C3	Mean
October	233	196	412	277	556	669	923	716
November	110	150	310	190	458	653	840	650
December	81	156	503	247	470	670	825	655
January	179	193	579	317	508	672	948	710
February	303	356	693	451	636	771	930	779
Mean	179	210	500	296	526	687	893	702

C1 - Plant cane; C2 - First ratoon; C3 - Second ratoon; WS$_{dry}$ - Water deficit only considering irrigation season. Does not include the sugarcane ripening period; References: [1] Meneses & Resende (2016); [2] Carvalho et al., (2019)

Under irrigated conditions, the average P_e for all planting dates and growing cycles was 30%; while without considering the irrigation component in the soil water balance, the value was 54.5 (Table 3). When evaluating three cycles of sugarcane planting dates in the same region, Silva et al. (2015) found higher values of P_e. The average P_e values obtained using an irrigation depth corresponding to 100% of ETo were estimated at 34.1%, and for the sugarcane growing without irrigation, it was estimated at 40.1%. Cardoso et al. (2015) reported that 45% of the water volume equivalent to the sum of rainfall with irrigation depth was lost by drainage when cultivating sugarcane in lysimeters.

Dias & Sentelhas (2018), using the FAO-AZM simulation model for climatic conditions in the Northeast region of Brazil and sugarcane cultivation under full irrigation, found that the lowest irrigation responsiveness occurred in the planting carried out in October; therefore, it is inferred that this is the month with the greatest utilization of precipitation, which corroborates with the results obtained in the present study.

By evaluating two cycles of sugarcane planting dates without the use of irrigation, Teodoro et al. (2015) reported values of 689 mm for soil water surplus and -665 mm for soil water deficit close to mean values estimated in this study, which were respectively 606 and -603 mm.

The results found in this study are close to the ones found by Wiedenfeld (2004), who states that frequent irrigation, as performed in this study, maintains a wetter (filled) soil profile, resulting in a lower soil capacity to store water from rainfall. Furthermore, rainfall efficiency is a result of the characteristic of the precipitation annual distribution. In the experimental area of Coruripe Mill, approximately 70% of the total annual rainfall is in the period from April to August (Carvalho et al., 2013). The low observed rainfall efficiency is also related to the sandy soil texture of the planting area, which results in a small soil water storage capacity, and with the small deepening of the sugarcane root system, which is aggravated by the existence of a soil layer that impedes root development. This soil layer is cohesive, has a pedogenetic origin, and is characterized by a hard setting soil horizon that is very hard or extremely hard when dry and generally friable when wet (Bezerra et al., 2015).

When considering the entire sugarcane growing cycle, planting in October resulted in lower WS, WD, ETc, and higher Re and Pe values. However, when considering only the local dry season, the planting date in November and December were the months with minimum soil water deficit (Table 4). It could be that sugarcane yield has the highest correlation with the precipitation in the dry season rather than in the total crop cycle.

In consequence, for these months, the applied irrigation depth was lower. According to the results, there is a high potential for reducing irrigation demand through planting date adjustment in the Northeast region of Brazil. Planting sugarcane in November resulted in the minimum irrigation depth for the sugarcane growing cycle, with a potential irrigation water depth saving from 5 to 129 mm relative to the other evaluated planting dates.

Conclusions

1. The synchronization of crop phenological stage with rainfall decreases the irrigation water demand of sugarcane during its growing cycle.

2. For all planting dates and growing cycles, the average effective precipitation was equal to 30.0% of the total rainfall under irrigated conditions and 54.5% without considering the irrigation component in the soil water balance.

3. November was the planting date that resulted in the minimum irrigation depth for the sugarcane growing cycle, with a potential irrigation water depth savings from 5 to 129 mm.

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