ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.21, n.3, p.169-174, 2017
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v21n3p169-174

Stalk yield of sugarcane cultivars under different water regimes by subsurface drip irrigation

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Key words:
Saccharum officinarum L.
irrigation management
drip irrigation
cultivar selection

A B S T R A C T

This study aimed to evaluate the stalk yield of ten sugarcane cultivars (RB962962, RB931011, RB931530, RB98710, RB92579, RB867515, RB863129, SP791011, RB72545 and VAT90212) subjected to water deficit, full irrigation and water surplus by subsurface drip irrigation, during three cropping seasons (2011-2014). The experiment was conducted at the Experimental Field of Embrapa Meio-Norte, Teresina, Piauí State, Brazil, in dystrophic Red Yellow Argisol. The cultivars RB962962 (162.3 Mg ha^{-1}) and RB867515 (158.5 Mg ha^{-1}) have better stalk yield compared with other cultivars in all water regimes and cropping seasons.

Palavras-chave:
Saccharum officinarum L.
manejo de irrigação
fertirrigação
seleção de cultivares

Produtividade de colmos de cultivares de cana-de-açúcar submetidas a diferentes regimes hídricos por gotejamento subsuperficial

R E S U M O

Objetivou-se, neste estudo, avaliar a produtividade de colmos de dez cultivares de cana-de-açúcar (RB962962, RB 931011, RB931530, RB98710, RB92579, RB867515, RB863129, SP791011, RB72454 e VAT90212) submetida aos regimes hídricos de deficiência, irrigação plena e excedente hídrico, por gotejamento subsuperficial, durante três ciclos de cultivo (2011-2014). O ensaio foi conduzido no Campo Experimental da Embrapa Meio-Norte, Teresina, PI, em Argissolo Vermelho-Amarelo Distrófico. As cultivares RB962962 (162,3 Mg ha^{-1}) e RB867515 (158,5 Mg ha^{-1}) apresentam melhor produtividade de colmos em comparação às demais cultivares, em todos os regimes hídricos e ciclos de cultivo.

Ref. 047-2016 – Received 4 Apr, 2016 • Accepted 25 Nov, 2016 • Published 6 Feb, 2017

Introduction

In the Northeast region, sugarcane agribusiness is already well consolidated in the states of Alagoas, Paraíba and Pernambuco. However, the crop has occupied areas in non-traditional regions, especially in the states of Tocantins, Maranhão and Piauí, due to their characteristics of soil, topography, climate (solar radiation) and favorable logistic conditions of exportation (MAPA, 2006). However, these potential areas are situated in regions with semi-arid to dry sub-humid climate, with irregular rainfall (800 to 1200 mm per year) (Bastos & Andrade Júnior, 2014) and that do not meet the water demand of the crop during its cycle, requiring the use of irrigation to achieve satisfactory yield levels.

Among the pressurized irrigation methods used in sugarcane cultivation, sprinkler irrigation and the localized methods stand out, such as subsurface drip irrigation (SDI). In the Northeast region, SDI has been widely used because of the greater adaptation to the characteristics of the sugarcane cultivation (Ferreira Júnior et al., 2014) and better water application efficiency (Gil et al., 2008).

Studies conducted in different production environments have demonstrated increment in the stalk yield of sugarcane genotypes in response to irrigation (Carvalho et al., 2009; Gava et al., 2011; Oliveira et al., 2011; Macêdo et al., 2012; Silva et al., 2014). However, for the genotype-environment interaction, it is crucial to conduct tests aiming at the expression of the productive potential of the sugarcane cultivars in different water regimes and production environments (Silva et al., 2008).

Thus, this study aimed to evaluate the stalk yield of ten sugarcane cultivars subjected to different water regimes by subsurface drip irrigation under the edaphoclimatic conditions of Teresina-PI, Brazil, during three cropping seasons.

Material and Methods

The experiments were carried out at the Experimental Field of Embrapa Meio-Norte, in Teresina-PI, Brazil (05° 05’ S; 42° 48’ W and altitude of 74.4 m). The soil of the area is classified as dystrophic Red Yellow Argisol (Melo et al., 2014) and its chemical and physico-hydraulic characteristics (Donagema et al., 2011) are presented in Table 1. The local climate is dry sub-humid, megathermal, with moderate water surplus in the summer and 32.2% of the potential evapotranspiration concentrated from September through November. The extract of the climatological water balance (historic series from 1980 to 2013) records an 8-month period of water deficit, extending from May to December (Bastos & Andrade Júnior, 2014).

The genotypes were evaluated during three crop cycles (plant cane, 1st ratoon and 2nd ratoon), during the cropping seasons of 2011/2012, 2012/2013 and 2013/2014 (Table 2). Ten genotypes were evaluated (RB962962, RB 931011, RB931530, RB98710, RB92579, RB867515, RB863129, SP791011, RB72454 and VAT90212), subjected to three water regimes (WRs), during the stage of full development of the crop: water deficit (WD), full irrigation (FI) and water surplus (WS). The terms WD, FI and WS refer to the partial, full and excess meeting of the sugarcane water demand, in the stage of full development, because the crop coefficient recommended in this phase by FAO is equal to 1.0 (Silva et al., 2012). The WRs were imposed with the application of different irrigation depths, based on the reference evapotranspiration (ETo): WD - replacement of 50% ETo, FI - replacement of 100% ETo and WS - replacement of 150% ETo. The different WRs were always applied on Mondays, Wednesday and Fridays, replacing the ETo accumulated in the period between two consecutive irrigations.

Before and after the period of imposition of the different WRs (DWR), a uniform irrigation depth equivalent to 100% ETo was applied in all treatments. During the rainy season, irrigations were applied only when soil water storage reached 50% of available water capacity (AWC). Irrigation was suspended 30 days before harvest. The reference evapotranspiration (ETo) was calculated through the Penman-Monteith method (Allen et al., 1998), with daily data of air temperature, relative air humidity, wind speed and global solar

Table 1. Chemical and physico-hydraulic characterization of the soil of the experimental area

Parameter	Depth (m)		
	0-0.20	0.20-0.40	0.40-0.60
	Chemical parameters		
OM (g kg^{-1})	17.71	7.06	5.78
pH H_2O	5.21	4.81	4.65
P (mg dm^{-3})	5.93	2.57	2.47
H+Al ($cmol_c$ dm^{-3})	4.06	4.99	5.21
Al ($cmol_c$ dm^{-3})	0.21	0.75	1.20
Ca ($cmol_c$ dm^{-3})	1.58	0.94	0.78
Mg ($cmol_c$ dm^{-3})	0.68	0.73	0.81
K ($cmol_c$ dm^{-3})	0.19	0.15	0.19
CEC ($cmol_c$ dm^{-3})	6.51	6.82	7.00
V (%)	37.79	26.95	25.90
m (%)	7.92	28.87	40.20
	Physico-hydraulic parameters		
Density (Mg m^{-3})	1.63	1.62	1.61
Sand (g kg^{-1})	723.8	674.3	599.8
Silt (g kg^{-1})	140.2	136.3	167.5
Clay (g kg^{-1})	136.0	189.3	232.7
θfc (m^3 m^{-3})[1]	0.209	0.215	0.253
θpwp (m^3 m^{-3})[2]	0.085	0.122	0.148
AWC (mm)[3]	24.8	18.6	21.0
EAW (mm)[4]	12.4	9.3	10.5
Texture	Sandy loam	Sandy loam	Sandy clay loam

[1] Moisture at field capacity measured at -10 kPa
[2] Moisture at permanent wilting point measured at -1500 kPa
[3] AWC – available water capacity
[4] Easily available water (50% of AWC)

Table 2. Dates of beginning and end of planting/emergence, application of the different water regimes, harvest and total crop cycle in each cropping season

Cropping season	Planting/Emergence		Application of the different water regimes			Harvest		Cycle (d)[1]
	Beginning	End	Beginning	End	Duration (d)	Beginning	End	
2011/2012	06.20.11	07.20.11	10.03.11	12.30.11	88	06.23.12	07.08.12	354
2012/2013	-----	07.24.12	09.03.12	11.29.12	87	07.01.13	07.18.13	359
2013/2014	-----	08.01.13	09.22.13	11.29.13	68	07.07.14	07.11.14	344

[1]Cycle (d), number of days between the end of planting/emergence and the end of harvest

radiation, obtained by an automatic agrometeorological station close to the experiment.

A subsurface drip irrigation system was used, with polyethylene drip lines and emitters with nominal flow rate of 2 L h^{-1}, spaced by 0.5 m. The laterals were spaced by 2 m and buried at depth of 0.25 m. Each drip line was buried in the center of two sugarcane rows, spaced by 0.5 m. Water meters were installed to control and measure the water volume applied in each regime.

The adopted experimental design was randomized blocks, with four replicates, and treatments arranged in split plots (WRs in the plots and cultivars in the subplots). The plots consisted of one 10-m-long double row of each cultivar. The evaluated area of the plot comprehended the same 10 m in the central length of the plot.

Soil tillage consisted of one plowing and two cross harrowings. Two months before planting, soil liming was performed through the application of 1 Mg ha^{-1} of dolomitic limestone. Planting was manually performed. The seed-stalks were cut, maintaining three buds per set, which were distributed in the planting furrows, to achieve 15 buds m^{-1}.

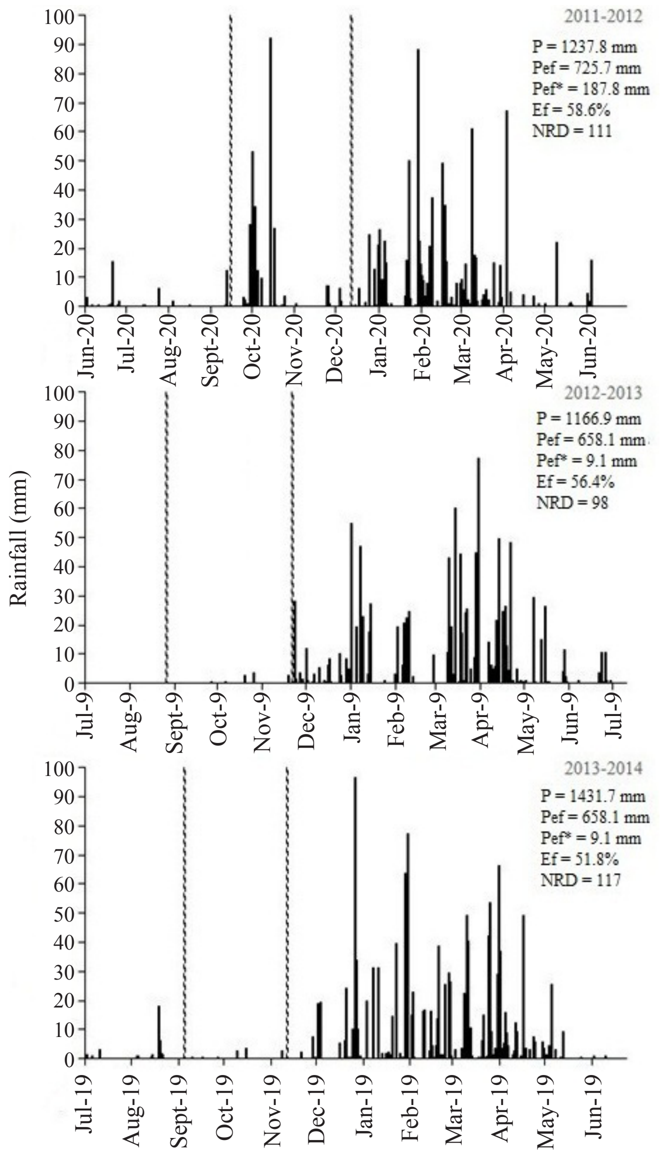
The fertilizers (macro- and micronutrients), in the three crop cycles, were applied totally through fertigation, with weekly frequency for macronutrients and monthly frequency for micronutrients, based on the following recommendation: 120 kg ha^{-1} of N (urea), 120 kg ha^{-1} of P_2O_5 (MAP), 100 kg ha^{-1} of K_2O (potassium chloride) and a formulation of micronutrients composed of 6.5 kg ha^{-1} of boric acid, 7 kg ha^{-1} of zinc oxide, 6 kg ha^{-1} of copper oxide, 11 kg ha^{-1} of manganese oxide and 1 kg ha^{-1} of sodium molybdate (Andrade Júnior et al., 2012).

At harvest, the stalks of the evaluated area of each experimental plot were weighed using a PR30-3000 dynamometer, with precision of 500 g, to determine stalk yield (tons of cane per hectare - TCH, in Mg ha^{-1}). The daily records of total rainfall were obtained from an automatic agrometeorological station close to the experiment. The effective rainfall was estimated by the methodology of the Soil Conservation Service of the United States (USDA), available in the software Cropwat v. 8.0 (FAO, 2009).

Stalk yield data were subjected to the joint analysis of variance and compared by the Scott-Knott test, at 0.05 probability level. The joint analysis of the data is possible, because the relationship between the highest and lowest residual mean squares of the individual tests was not higher than seven (Gomes, 2000).

Results and Discussion

The total rainfalls (P) were equal to 1,237.8 mm (2011-2012), 1,166.9 mm (2012-2013) and 1,431.7 mm (2013-2014). Since there was not an accentuated variation in the number of rainy days (NRD) in the three cropping seasons (from 98 to 117 days), the rainfall efficiency (Ef) was very similar, with values of 58.5% (2011-2012), 56.4% (2012-2013) and 51.8% (2013-2014) (Figure 1). In the cropping season of 2011-2012, during the period of imposition of the different water regimes (DWRs), there was an effective rainfall (Pef) of 187.8 mm, which particularly damaged the application of the water deficit (WD) regime for the evaluated varieties. In the 1st and 2nd ratoons, the effective rainfall contributed equally to the expression of the productive potential and biometry of the evaluated cultivars, and the probable detected differences were due to the greater contribution of the irrigation applied notably in the period prior to the rainy season.



Period of application of the different water regimes (DWR) between dotted lines; P, total rainfall; Pef, effective rainfall; Pef*, effective rainfall during the application of the DWR; Ef, rainfall efficiency; NRD, number of rainy days

Figure 1. Daily rainfall recorded during the three crop cycles

The total water depth (TWD) (effective rainfall + irrigation), in the evaluated WRs, did not vary in an accentuated way in the three cropping seasons (Table 3). In the WD regime, the total water depth applied oscillated from 1,156.5 mm (2013-2014) to 1,248.2 mm (2011-2012), while in the WS regime this oscillation was from 1,462.1 mm (2011-2012) to 1,579.1 mm (2012-2013) (Table 3). In percent terms, the mean TWD applied in the WS regime (1,510 mm) was only 24.4% higher than that applied in the WD regime (1,213.7 mm). These TWD values were lower than those recommended for 12-month-old sugarcane (1,500 to 2,000 mm) (Silva et al., 2014), a reflex of the better water application efficiency of the subsurface drip irrigation (Oliveira et al., 2011).

On the other hand, the TWD applied during the period of DWR imposition varied substantially between the WRs applied

Table 3. Irrigation depths (ID) applied in response to the imposed water regimes (WR) and effective rainfall (Pef) recorded during the cultivation cycle of the sugarcane cultivars in the three cropping seasons (2011-2014)

Cropping season	WR	Depths (mm) / Application period (DWR)						Total (mm)
		Before		During		After		
		Pe	ID	Pe	ID	Pe	ID	
2011-2012	WD	31.3	199.5	187.8	138.7	506.6	184.3	1248.2
	FI	31.3	199.5	187.8	244.0	506.6	184.3	1353.5
	WS	31.3	199.5	187.8	352.6	506.6	184.3	1462.1
2012-2013	WD	0.0	76.8	9.1	171.4	649.0	330.1	1236.4
	FI	0.0	76.8	9.1	342.7	649.0	330.1	1407.7
	WS	0.0	76.8	9.1	514.1	649.0	330.1	1579.1
2013-2014	WD	33.5	58.1	9.1	166.1	699.4	171.6	1156.5
	FI	33.5	58.1	9.1	332.3	699.4	171.6	1322.7
	WS	33.5	58.1	9.1	498.4	699.4	171.6	1488.8

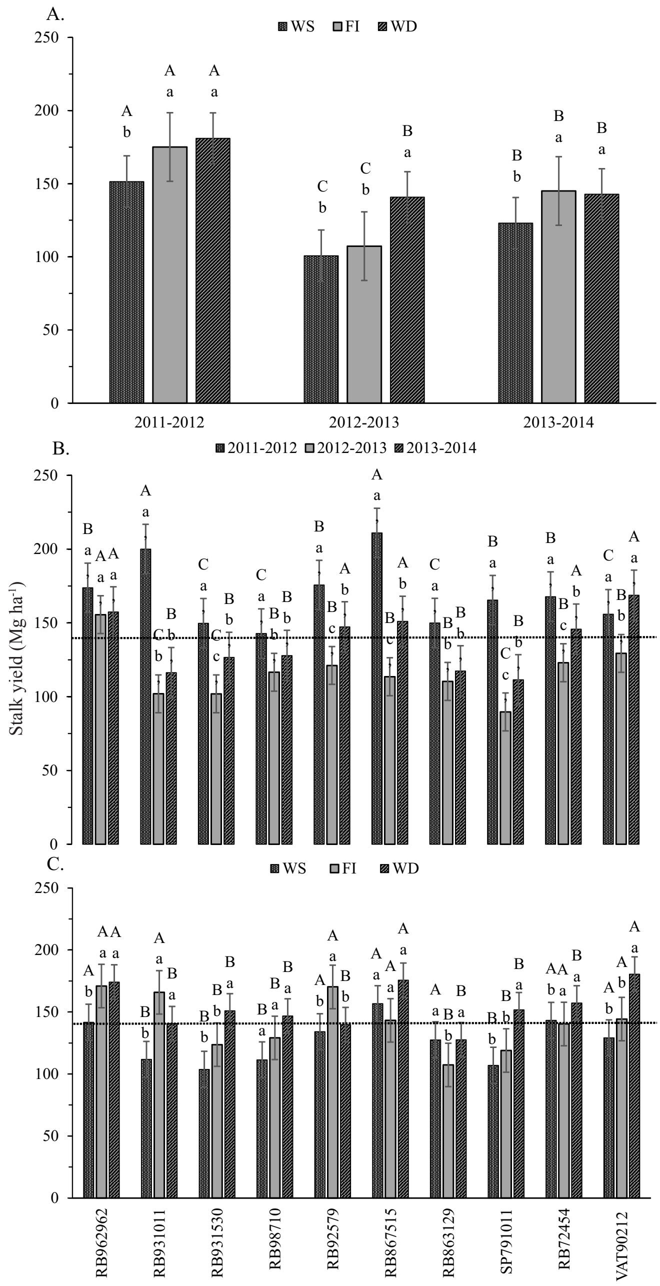
DWR, different water regimes; Pef, effective rainfall; I, irrigation; WR, water regime; WD, water deficit; FI, full irrigation; WS, water surplus

in the three cropping seasons. In 2011-2012, the contribution of irrigation to the TWD applied in the three WRs was lower than those in the other cropping seasons, due to the greater contribution of Pef (187.8 mm), which particularly damaged the imposition of the WR regime. Because of that, the lowest irrigation depths were recorded in this cropping season, which varied from 138.7 mm (WD) to 352.6 mm (WS). However, in 2012-2013 and 2013-2014, the contribution of Pef was very small (9.1 mm), which increased the contribution of the irrigation depth (ID), in all WRs (Figure 1). The values of ID in 2012-2013 were higher than those in 2013-2014, due to the superiority of the daily ETo (6.1 mm) and the longer period of DWR imposition (87 days) (Table 2).

In the period after DWR application, the ID applied in 2012-2013 was 330.1 mm, superior to those applied in 2011-2012 (184.3 mm) and 2013-2014 (171.6 mm), precisely to complement the greater ETo–Pef difference of 363.4 mm occurred in this period (Figure 1). In addition, the rainfall concentrated in only 98 days, with an effectivity of 56.4% (Figure 1). This combined effect of the variation of Pef and ID, especially during DWR application, promoted high oscillation in soil water storage between the WRs, affecting the expression of the productive potential of the evaluated cultivars.

The joint analysis of the TCH data revealed that there was no significant interaction ($p > 0.05$) between the periods, water regimes and cultivars, indicating that the interannual variability of the imposed WRs was not able to promote alteration in the productive performance of the evaluated cultivars (Gava et al., 2011; Oliveira et al., 2011). The TCH of the cultivars showed significant interaction ($p < 0.05$) of periods versus water regimes (Figure 2A), periods versus cultivars (Figure 2B) and water regimes versus cultivars (Figure 2C), a reflex of the different application of the WRs in each cropping season.

For all cultivars, the means of TCH in the cropping season of 2011-2012 were superior to those of 2012-2013 and 2013-2014, a consequence of the better water availability in the soil in this season, especially due to the occurrence of rainfalls that totaled 187.8 mm during the period of DWR imposition (Figure 1). On the other hand, in the cropping season of 2012-2013, the means of TCH were lower because of the strong water restriction in the soil, particularly under WD and FI regimes, during the period of DWR imposition (Figure 2A). The mean values of TCH under the water regimes of FI (142.5 Mg ha^{-1}) and WS (154.9 Mg ha^{-1}) were higher than those of



Means followed by the same letter, lowercase for the same cultivar and uppercase between cultivars, do not differ by Scott-Knott test at 0.05 probability level

Figure 2 . Stalk yield (TCH) of the evaluated cultivars in response to the water regimes (WR) in the three crop cycles. (A) interaction WR versus PP; (B) interaction PP versus C; (C) interaction WR versus C. PP: Planting period; C: Cultivar; WD: water deficit, FI: full irrigation, WS: water surplus

WD (125.1 Mg ha^{-1}) in all crop cycles evaluated (Figure 2A), reinforcing the importance of adequate water supplementation to sugarcane, to achieve high stalk yields (Silva et al., 2014).

The cultivars with best performances were RB867515 (210.9 Mg ha^{-1}) and RB931011 (200.0 Mg ha^{-1}), which produced 24.7 and 18.2% more stalks in comparison to the mean yield of the experiment in 2011-2012 (169.2 Mg ha^{-1}). However, in 2012-2013, the most critical cropping season with respect to the water availability in the soil, the cultivar RB962962 (155.6 Mg ha^{-1}) produced 33.7 and 10.5% more stalks than the mean TCH of 2012-2013 (116.3 Mg ha^{-1}) and the overall mean of the experiment (140.8 Mg ha^{-1}) (Figure 2B).

The cultivars VAT90212, RB92579 and RB72454 form a group with intermediate behavior regarding stalk production, with mean TCH of three crop cycles of 151.3, 148.0 and 145.5 Mg ha^{-1}, respectively, which are 7.4, 5.1 and 3.3% higher than the overall mean of TCH of the experiment (Figure 2B). Oliveira et al. (2011) also found superior performance of TCH for the cultivars RB92579 (255.6 Mg ha^{-1}) and RB72454 (191.6 Mg ha^{-1}), in cultivation under conventional big gun sprinkler irrigation (total water depth of 1,396.6 mm), plant-cane cycle and full irrigation, under the conditions of soil (dystrophic Yellow Argisol) and climate (rainy tropical) of Carpina-PE.

On the other hand, the cultivars SP791011 (122.2 Mg ha^{-1}), RB863129 (125.9 Mg ha^{-1}), RB931530 (126.1 Mg ha^{-1}) and RB98710 (129.1 Mg ha^{-1}) showed the lowest performance regarding stalk production and the TCH values were 13.3, 10.6, 10.4 and 8.3% lower in relation to the overall mean of the experiment (140.8 Mg ha^{-1}), respectively (Figure 2B). The overall performance of these cultivars was substantially affected by the low yields in TCH under the condition of water deficit in the soil. Lower performances in TCH for the cultivars SP791011 (155.0 Mg ha^{-1}) and RB863129 (181.5 Mg ha^{-1}) were also reported by Oliveira et al. (2011), in cultivation irrigated by conventional big gun sprinklers (total water depth of 1,396.6 mm), plant-cane cycle, under the conditions of soil (dystrophic Yellow Argisol) and climate (rainy tropical) of Carpina-PE. The values of TCH of these cultivars were superior to those of the present study, because they were not subjected to periods of water deficit in the soil.

The cultivars RB962962 (162.3 Mg ha^{-1}) and RB867515 (158.5 Mg ha^{-1}) showed higher productive performance in relation to the others, in all cropping seasons and WRs evaluated (Figures 2B and 2C). Under conditions of both low and high water availability in the soil, the cultivars RB867515 (156.7 Mg ha^{-1}, under WD, and 175.6 Mg ha^{-1}, under WS) and RB962962 (141.7 Mg ha^{-1}, under WD, and 174.1 Mg ha^{-1}, under WS) showed similar productive behavior (Figure 2C), which is a desirable characteristic, considering the high rainfall instability of the Northeast region. Silva et al. (2014) also obtained superior performance in terms of TCH for the cultivar RB867515, in the cycles of plant cane (140.9 Mg ha^{-1}) and 1st ratoon (118.8 Mg ha^{-1}), under subsurface drip irrigation (total water depths of 1,880 mm, in plant cane and 1,714 mm, in 1st ratoon), under the conditions of soil (eutrophic Red Latosol) and climate of Jaú-SP. On the other hand, the cultivars RB931530 (103.7 Mg ha^{-1}), SP791011 (107.3 Mg ha^{-1}), RB931011 (111.7 Mg ha^{-1}) and RB98710 (111.4 Mg ha^{-1}) should not be recommended for cultivation in the region of Teresina-PI, because of the low capacity of stalk production, notably under the condition of reduced water availability in the soil. Sugarcane plants subjected to water deficit exhibited reduced daytime CO_2 assimilation, due to the decrease in stomatal conductance (diffusive factor), reduction in the activity of PEPcase and RuBisCO (biochemical factors) and lower photochemical activity (Machado et al., 2013), with negative effects on stalk production.

Increments in stalk yield under regimes of FI and WS can be attributed to the adequate water availability during the growth period, which promotes greater availability of nutrients to the sugarcane root system (Oliveira et al., 2011). Under this condition, there is an increase in tillering and elongation of the stalks due to the large transport of carbohydrates from the roots to the shoots (Inman-Bamber & Smith, 2005; Singh et al., 2007).

Conclusion

The cultivars RB962962 (162.3 Mg ha^{-1}) and RB867515 (158.5 Mg ha^{-1}) showed better performance of stalk yield in comparison to the others, in all water regimes, in the three cropping seasons.

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