Root growth and yield of sugarcane as a function of increasing gypsum doses[1]

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ABSTRACT

Sugarcane plays an important role in the Brazilian agribusiness. However, poor rainfall distribution and soil acidity directly affect its production in the Northeast Brazil. Gypsum improves the soil physical and chemical properties, attenuating the effects of water stress and acidity in the edaphic environment. This study aimed at determining the effect of gypsum doses on sugarcane growth and yield. A field experiment was conducted using a 3 x 5 factorial arrangement organized in a randomized block design, with four replications. Treatments consisted of a combination of three sugarcane varieties (RB011941, RB92579 and RB991536) with five gypsum doses (0 Mg ha^{-1}, 2.5 Mg ha^{-1}, 5.0 Mg ha^{-1}, 10.0 Mg ha^{-1} and 20.0 Mg ha^{-1}). RB92579 exhibited the highest stalk (157.90 Mg ha^{-1}) and sugar (24.10 Mg ha^{-1}) yield. Gypsum did not influence the sugarcane yield or plant growth in the vegetative growth stage, but, in the maturation phase, the leaf area declined and the number of shoots increased with the rise in gypsum doses. Applying gypsum increased the roots density along the soil profile, with a rise of around 1.10 g dm^{-3} at the most technically efficient dose (12.5 Mg ha^{-1}), however, yield was not influenced, maybe due to the effect of high rainfall during the entire crop cycle. Thus, higher gypsum doses are recommended during periods of drought to benefit from the resulting increased root system.

KEYWORDS: *Saccharum* spp.; gipsite; root system.

RESUMO

Crescimento radicular e produção de cana-de-açúcar em função de doses crescentes de gesso

A cana-de-açúcar possui grande expressão no agronegócio brasileiro, entretanto, a má distribuição hídrica e a acidez do solo afetam diretamente sua produção no Nordeste do Brasil. O gesso proporciona melhorias nas propriedades físicas e químicas do solo, atenuando os efeitos da falta de água e acidez no ambiente edáfico. Objetivou-se determinar o efeito de doses de gesso no crescimento e produtividade da cana-de-açúcar. O experimento foi conduzido a campo, utilizando-se delineamento em blocos ao acaso, no esquema fatorial 3 x 5, com quatro repetições. Os tratamentos consistiram da combinação de três variedades de cana-de-açúcar (RB011941, RB92579 e RB991536) com cinco doses de gesso (0 Mg ha^{-1}; 2,5 Mg ha^{-1}; 5,0 Mg ha^{-1}; 10,0 Mg ha^{-1}; e 20,0 Mg ha^{-1}). A RB92579 apresentou maior produtividade de colmos (157,90 Mg ha^{-1}) e de açúcar (24,10 Mg ha^{-1}). O gesso não influenciou na produtividade da cana ou no crescimento das plantas, na fase de crescimento vegetativo. Já na fase de maturação, a área foliar diminuiu e o número de perfilhos aumentou, com o aumento das doses de gesso. A aplicação de gesso aumentou a quantidade de raízes ao longo do perfil do solo, com incremento da ordem de 1,10 g dm^{-3} na dose de maior eficiência técnica (12,5 Mg ha^{-1}), porém, não influenciou na produtividade, talvez pelo efeito da alta pluviosidade durante todo o ciclo da cultura. Portanto, doses de gesso mais elevadas são recomendadas durante períodos de seca, beneficiando-se, assim, do aumento no sistema radicular proporcionado pela sua aplicação.

PALAVRAS-CHAVES: *Saccharum* spp.; gipsita; sistema radicular.

INTRODUCTION

Sugarcane cultivation currently occupies approximately 9 million hectares in Brazil, making it the largest producer in the world, with estimated 691,000 metric tons in the 2016/2017 growing season (Conab 2016).

Studies indicate that the biological production potential of sugarcane exceeds 300 Mg ha^{-1} (Landell et al. 2006). The average Brazilian yield in the 2015/2016 growing season was 76.9 Mg ha^{-1}, while the Northeast region recorded 49.4 Mg ha^{-1} (Conab 2016). Thus, the current Brazilian and northeastern production accounts for less than 25 % of their biological potential.

The lower sugarcane yield in the Northeast, when compared to other regions of Brazil, is primarily due to a poor rainfall distribution. An example is the

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coastal tablelands, where there is ample rainfall in the fall/winter and drought conditions in the spring/summer (Souza et al. 2004), resulting in water deficiency for some of the plant growth phases.

Another fact that corroborates the low yield is the effect of soil acidity linked to the presence of toxic levels of Al^{+3}, in addition to low concentrations of cations such as Ca^{+2}, Mg^{+2} and K^{+} (Souza et al. 2007). This poor nutritional quality directly affects the sugarcane root system and its cane yield potential. The sugarcane root system is fibrous and can reach a depth of up to 3.30 m (Inforzato & Alvarez 1957).

To mitigate the effects of poor rainfall distribution and chemical impediment not only in the soil surface layer, but also in the subsurface (depth below 20 cm), a series of agricultural techniques have been applied to improve soil physicochemical properties (Rocha et al. 2008, Oliveira et al. 2010a), including liming, which is efficient in raising calcium content and in reducing the exchangeable aluminum levels in the soil. However, its reaction is restricted to the application site, not achieving acidity correction at deeper soil layers (Caires et al. 2004). Gypsum has been used as an alternative, since its greater mobility in soils improves the chemical and physical properties of the subsurface layers, reducing Al^{3+} saturation at depth and increasing cations contents, primarily of calcium (Quaggio 2000).

The effect of gypsum on soil occurs because of the dissociation of dihydrate calcium sulfate ($CaSO_4.2H_2O$). The leaching of Ca^{+2} and SO_4^{-2} result in the ionic exchange of toxic aluminum on the surface with Ca^{+2} and formation of the $AlSO_4^{+}$ ionic pair, which is not toxic to plants (Pavan & Volkweiss 1986). As such, applying gypsum enables deeper rooting, with greater exploration of soil volume, increasing water and nutrient extraction by the sugarcane (Morelli et al. 1992). This increased root system results in greater resistance to water stress.

Studies conducted at different regions of Brazil have demonstrated that the use of gypsum at doses below 5 Mg ha^{-1} in soils planted with sugarcane has increased yield and deepened roots (Morelli et al. 1992, Rocha et al. 2008).

For coffee cultivation, high doses of gypsum (exceeding 20 Mg ha^{-1}), when compared to the conventional recommended dose of at most 4 Mg ha^{-1}, have been suggested (Ramos et al. 2013). These authors report that this treatment has expanded the root system and increased yield, mainly in the Brazilian Savannah regions, where crops experience periods of severe drought. For sugarcane, studies that assess the effect of very high doses of gypsum on growth and yield are in the early stages, primarily investigating recent varieties.

Our hypothesis is that high doses of gypsum favor the growth and relative distribution of roots across the soil profile, thereby raising the sugarcane production of current varieties. Based on that, the present study aimed to assess the effect of gypsum on the yield and development of shoots and root systems of three varieties of sugarcane.

MATERIAL AND METHODS

The study was conducted in the field, between late 2011 and early 2013, in São Luiz do Quitunde (9º22'S, 35º32'W), Alagoas State, Brazil, in a soil classified as Fluvic Neosol (Fluvisol) (Embrapa 2013). According to the Köppen climate classification system, the climate is tropical monsoon with dry summers. The average temperature in the region was 27.5 ºC, with maximum and minimum of 32 ºC and 23 ºC, respectively, and average rainfall of 1,681 mm, during the study period (Figure 1).

The chemical analysis of the soil was conducted before the study (Table 1), at three depths (0-20 cm, 20-40 cm and 40-60 cm) (Embrapa 2009).

The soil was prepared using a heavy grader, followed by leveling and furrow opening. Next, a chemical fertilizer was applied using 700 kg ha^{-1} of the formula 14-00-18 (ammonium sulfate - 20 % N and potassium chloride - 58 % K_2O), based on the recommendations of local mills.

The experiment had a 3 x 5 factorial scheme, organized in a randomized block design, with four replications. The first factor consisted of three sugarcane varieties (RB011941, RB92579 and RB991536) and the second of five gypsum doses (0 Mg ha^{-1}, 2.5 Mg ha^{-1}, 5.0 Mg ha^{-1}, 10.0 Mg ha^{-1} and 20.0 Mg ha^{-1}). Each plot consisted of five 10-meter rows, spaced 1.10 m apart, totaling 55 m². Only three central rows were used for assessments, disregarding 1 m at the extremities. Thereby, the useful area of each plot had 33 m^2.

The gypsum used in the experiment had a mineral origin and was obtained from gypsite deposits ($CaSO_4.2H_2O$) in the Araripe gypsum deposit, in the Pernambuco State. Gypsum characterization was conducted at the Universidade Estadual Paulista, in Botucatu, São Paulo State, Brazil, and contained 45.86 % of CaO, 20.30 % of S and 19.18 % of moisture.

The gypsum doses were uniformly applied to the bottom of the furrow, at a depth of approximately 20 cm, over a length of 10 m. Next, the stalks were distributed along the rows, using 15 buds per meter. Manual weed control was carried out only up to 30 days after plant emergence. Irrigation (30 mm) was carried out at 2 and 20 days after the beginning of the experiment.

Plant development was assessed at 116 and 395 days after planting (DAP). For that, plant height, stalk diameter, number of leaves (totally expanded, with at least 20 % of green area, counted from the leaf + 1), length and width of leaf + 3 and number of shoots were quantified in 10 plants per plot. Leaf area was calculated based on their dimensions and the number of leaves using the method proposed by Hermann & Câmara (1999).

Plant height was measured from the level of soil up to the ligule of the leaf + 1, which is the first leaf from the apex with the ligule totally visible. Stalk diameter was measured with a caliper in the middle third of the plant. In addition to these measurements, the mean tillering of each row was quantified, counting the number of plants per meter of furrow, on the three central rows of the plot.

Harvest occurred at 402 DAP. All the shoots collected in each plot were weighed with a dynamometer. Metric tons of pol per hectare were calculated based on metric tons of cane per hectare and analysis of sucrose content (Fernandes 2000).

After the sugarcane was harvested and the entire experimental area was cleaned, a soil sample was collected from each plot, including roots, using a hollow-stem auger (volume of 1.62 dm^3), at three depths (0-20 cm, 20-40 cm and 40-60 cm), to assess the sugarcane root development. The evaluation of roots followed the methodology recommended by Vasconcelos & Landell (2003), with modifications. Collections were carried out along the central row of each plot, 25 cm from the sugarcane line. The soil samples containing the roots were washed in 2 mm mesh sieves and the roots were dried in a forced-air oven at 65 ºC, for 96 h. They were then weighed on a semi-analytical scale to determine the weight of roots collected from each plot.

The results obtained were submitted to analysis of variance at 5 %, using the F-test, and the means compared by the Tukey test, for the qualitative factor (sugarcane varieties). Regression was applied to the quantitative factor (gypsum dose) and the results presented in graph form.

RESULTS AND DISCUSSION

The analyses of variance detected no interaction effects between the varieties and gypsum doses in the sugarcane biometry, at the two assessment times (Table 2).

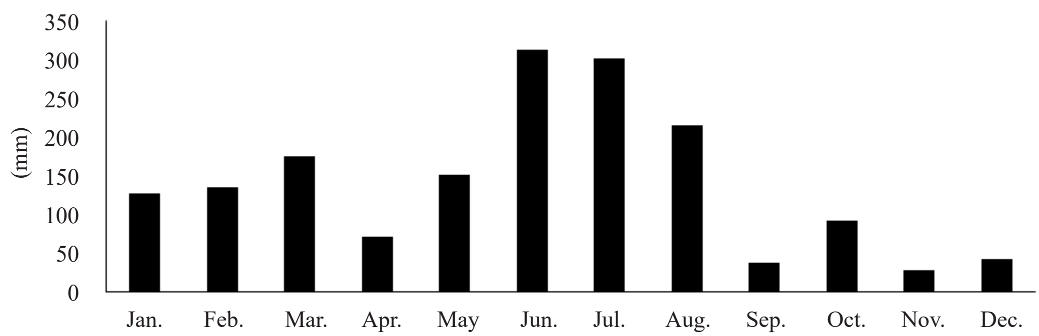

Figure 1. Average monthly rainfall in São Luiz do Quitunde, Alagoas State, Brazil, in 2013.

Table 1. Soil chemical characteristics.

Depth	pH	Ca	Mg	K	Al	H + Al	CEC	SB	P	S	Fe	Cu	Mn	Zn	B	V	m	OM
cm	(H_2O)	cmol$_c$ dm^{-3}							mg dm^{-3}							%		dag kg^{-1}
0-20	5.8	2.0	1.4	0.65	0.00	2.0	6.05	4.05	46.6	37	75	3.5	4.4	2.1	0.23	67	0	3.1
20-40	5.1	1.1	0.6	0.34	0.03	2.7	4.74	2.04	38.1	37	74	2.9	1.6	1.2	0.20	43	13	2.4
40-60	4.8	0.9	0.5	0.23	0.60	3.2	4.83	1.63	14.8	36	64	2.1	1.0	0.8	0.18	34	27	2.1

Gypsum doses affected the number of shoots and leaf area in the maturation phase, at 395 DAP. The varieties were significantly different in terms of height, number of leaves and leaf area (Table 2).

The RB92579 variety exhibited a greater height at 395 DAP (Table 2). Similar results were found by Almeida et al. (2008) and Oliveira et al. (2010b), where RB92579 was the tallest of the varieties cultivated. The genotypic characteristics of the sugarcane varieties determine the height and diameter of the stalk, as well as other morphological aspects of the plant. The expression of these traits is also influenced by the edaphoclimatic factors and management techniques used (Costa et al. 2011).

Stalk diameter did not differ between the varieties studied, at both the vegetative growth and maturation phases (Table 2). However, there was an increase of 31.0 %, 37.0 % and 55.0 % in the stalk diameter of the varieties RB011941, RB92579 and RB991536, respectively, from the first to the second assessment (Table 3). According to Costa et al. (2011), these increases in diameter occur after the maximum growth phase, when vertical growth is decreased, followed by the sugar accumulation phase.

The number of leaves of young plants (116 DAP) differed between varieties. In the maturation phase (395 DAP), there was a decline of 28.5 %, 22.0 % and 43.0 % in the number of leaves of the varieties RB011941, RB92579 and RB991536, respectively, in relation to the previous assessment. However, no difference was observed in the number of leaves between varieties (Table 3). This reduction is attributed to a strategy of decreasing the transpiration surface and consequently the metabolic expense of maintaining tissues (Smit & Singels 2006, Inman-Bamber et al. 2008).

The RB92579 variety showed the greatest decline in the number of tillers (38 %) and RB011941 the lowest one (30 %) between the two assessments (Table 3). According to Costa et al. (2011), this reduction in tillering occurs due to the increased competition for water, light and nutrients, leading to the death of the youngest, weakest and worst positioned tillers.

Leaf area did not differ between varieties at 116 DAP. Costa et al. (2011) found similar results in assessments made at the same phenological phase, with a leaf area of 300 cm² and 400 cm² per plant, in four varieties of sugarcane. Analysis conducted in the maturation phase (395 DAP) showed that the RB991536 variety exhibited a greater leaf area, if compared to the varieties RB92579 and RB011941 (Table 3). Since the leaf is the main plant organ that absorbs photons and drives the photosynthetic

Table 2. Analysis of variance of height, diameter, number of leaves, number of shoots and leaf area of sugarcane, at 116 and 395 days after planting (DAP).

	Height		Diameter		Nº of leaves		Nº of shoots		Leaf area	
	116 DAP	395 DAP	116 DAP	395 DAP	116 DAP	395 DAP	116 DAP	395 DAP	116 DAP	395 DAP
Variety (A)	ns	*	ns	ns	*	ns	ns	ns	ns	*
Gypsum (B)	ns	ns	ns	ns	ns	ns	ns	*	ns	*
Interaction (A x B)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mean	61.2	275.1	2.11	2.98	6.15	4.50	19.36	13.0	353.3	460.4
CV (%)	17.2	10.2	13.10	10.80	10.40	19.60	11.20	8.8	17.8	18.6

ns: not significant; * significant at 5 % by the F-test.

Table 3. Plant height, stalk diameter, number of leaves, number of shoots and leaf area of three varieties of sugarcane, at 116 and 395 days after planting (DAP).

Variety	Phenological phase	Height	Diameter	Nº of leaves	Nº of shoots	Leaf area
		cm				cm²
RB011941	116 DAP	60.00 a*	2.20 a	6.55 a	18.63 a	344.49 a
RB92579		62.20 a	2.15 a	5.90 b	20.14 a	355.75 a
RB991536		61.40 a	2.00 a	6.00 b	18.98 a	359.75 a
RB011941	395 DAP	275.24 ab	2.90 a	4.70 a	13.03 a	424.45 b
RB92579		290.25 a	2.95 a	4.60 a	12.44 a	439.23 b
RB991536		260.00 b	3.10 a	4.20 a	12.90 a	517.55 a

* Means within the same phenological phase followed by different letters in the column are different at 5 % by the Tukey test.

process, the greater the area, the greater the radiation interception (Costa et al. 2011).

The morphological characteristics of sugarcane (plant height, stalk diameter, number of leaves, number of shoots and leaf area) assessed in the two phenological phases were not influenced by the gypsum doses applied (Table 2). However, gypsum influenced the leaf area and number of shoots at 395 DAP (Figure 2), with a decline of 4.94 cm^2 in leaf area per plant and an increase of 0.08 canes per meter for each metric ton of gypsum applied (Figure 2). This decline in leaf area is due to the larger number of shoots, causing greater competition for water, light and nutrients among plants (Costa et al. 2011), thereby reducing proportionally the leaf area. Similar results were obtained by Oliveira et al. (2007), who found a decline in leaf area as a function of the increased number of shoots, in three varieties of sugarcane in northeast Paraná State.

The gypsum doses resulted in a better distribution of the sugarcane root system at deeper layers. Gypsum resulted in sugarcane plants displaying more root uniformity along the soil profile (Figure 3). Korndörfer et al. (1989) assessed the growth and distribution of the sugarcane root system in a Red-Yellow Latosol and observed that 90 % of the root system distribution was concentrated in the 0-30 cm deep layer. Sampaio & Salcedo (1987) found that 75 % of the sugarcane root mass was located in the first 20 cm below the soil surface, in Northeastern Brazil. In Hawaii, Lee (1926) reported that 65 % of sugarcane roots were found up to 20 cm below the surface. The root distribution along the soil profile observed in the present study with gypsum application was better (Figure 3), if compared to the results obtained by Korndörfer et al. (1989), Sampaio & Salcedo (1987) and Lee (1926), who did not apply gypsum.

Root distribution in the deepest soil layer (40-60 cm) increased from 12 % to 23 %, when 5 Mg ha^{-1} of gypsum were applied. The increase in root density was around 1.10 g dm^{-3} of soil at the most efficient technical dose of 12.5 Mg ha^{-1} of gypsum (Figure 4). In studies applying gypsum and limestone to sugarcane, Rocha et al. (2008) concluded that applying gypsum from Araripe resulted in a larger percentage of roots in subsurface layers, corroborating the findings of the present study. This increase in roots at the deepest layers likely occurred due to the high

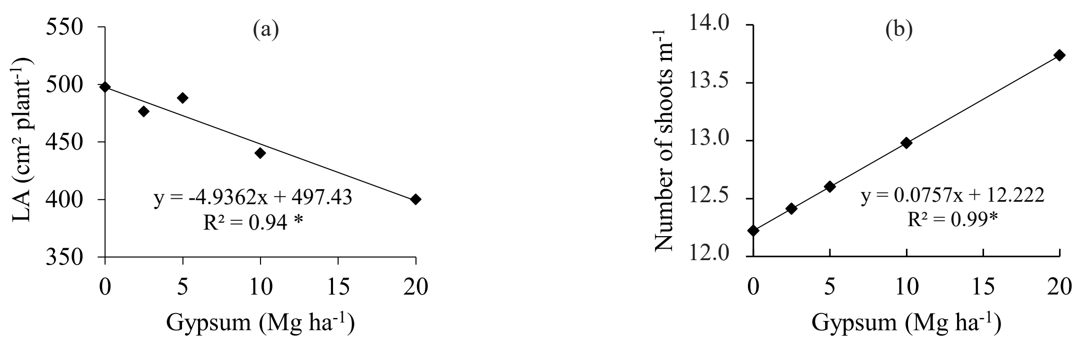

Figure 2. Leaf area (LA) per plant (a) and number of shoots per meter (b) of sugarcane, at 395 days after planting, as a function of five gypsum doses.

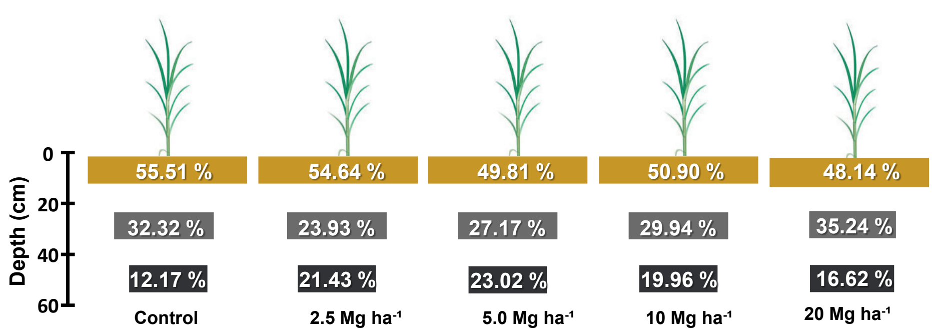

Figure 3. Distribution of roots at three depths (0-20 cm, 20-40 cm and 40-60 cm), as a function of gypsum doses.

calcium content and decline in aluminum, primarily in subsurface layers. A better soil conditioning, at deeper layers, allows a greater root system uniformity along the profile. The rise in calcium levels and decrease in aluminum also affect the physical condition of the soil, primarily reducing clay dispersion, increasing porosity and consequently the penetration capacity of roots (Morelli et al. 1992). A number of studies have shown the efficiency of gypsum in raising the calcium content at depth (Caires et al. 1999). Rocha et al. (2008) compared the sugarcane root system, when gypsum and limestone were applied separately or together, observing an increase in calcium levels at depth in treatments involving gypsum, especially when applied alone.

Stalk and sugar yield were not influenced by gypsum (Table 4). This may have occurred due to the high vigor of the first cane cycle, given the use of seed reservoir by the seedling. Moreover, the lack of response may be explained by the high chemical quality of the 0-40 cm soil layer (Table 1), which contains most of the roots. Because the first 40 cm was corrected at the time of planting, the soil exhibited a low Al^{+3} content and high Ca^{+2} levels (Table 1), thereby limiting the corrective action of gypsum in neutralizing the toxic effects of aluminum (Sousa et al. 1995, Oliveira et al. 2007). Also, chemical analyses show that the soil contains high levels of Ca and S.

Furthermore, since the varieties used in the present study are considered drought-resistant and the rainfall levels were high (Figure 1), plants did not face drought stress, diminishing the beneficial effect of the gypsum.

The effect of applying gypsum will likely be evident in subsequent cycles, given that base removal due to harvest, application of nitrogen fertilizers, organic acid exudation by the root system and decomposition of crop remnants may acidify the soil, reduce the calcium content and increase calcium levels along the soil profile. As such, the gypsum applied at planting will be an important conditioner to attenuate the effects of soil acidification.

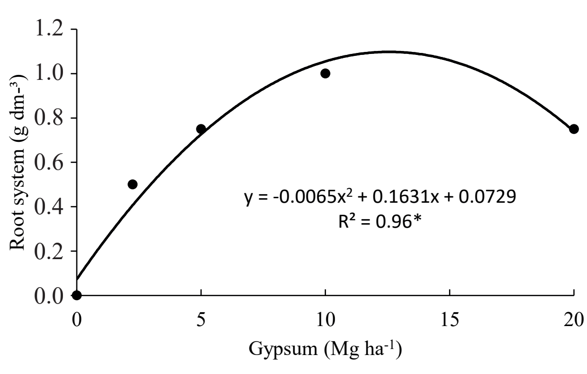

Figure 4. Sugarcane root system density in the soil (40-60 cm layer), as a function of gypsum doses.

The stalks yield differed among the varieties (Table 4). RB92579 had a yield 11.3 % higher than the average for the other two varieties. The average yield of the three sugarcane varieties (147.21 Mg ha^{-1}) was higher than the national average (76.9 Mg ha^{-1}) and that of the Alagoas State (50.0 Mg ha^{-1}) (Conab 2016). This high yield is primarily due to the mean accumulated rainfall during the study period (Figure 1).

Given that the maximum water availability does not coincide with maximum light saturation, net photosynthetic rates are negatively affected, resulting in a lower yield in Alagoas, when compared to other regions, such as the Center-South (Oliveira et al. 2007). Nevertheless, the yield achieved in this experiment is considered high for the Alagoas State (Oliveira et al. 2007) and higher than that found in other countries. For example, in studies conducted with eight varieties of sugarcane under irrigated environments, in south Texas, Silva et al. (2007) observed an average yield of 135.2 Mg ha^{-1}.

RB92579 was the variety that contained the highest level of sugar in the cane (Table 5). Considering that sugar yield is directly influenced by stalk yield, RB92579 should be the preferred variety in the region.

Table 4. Mean squares for the analysis of variance of cane yield.

	Mean square
Variety (A)	3,069.90*
Gypsum (B)	145.02^{ns}
Interaction (A x B)	76.07^{ns}
Mean	147.21
CV (%)	5.62

ns: not significant; *: significant at 5 % by the F-test.

Table 5. Stalk and sugar yield of three sugarcane varieties.

Variety	Stalk yield	Sugar yield
	Mg ha^{-1}	
RB011941	150.09 b*	21.65 b
RB92579	157.90 a	24.10 a
RB991536	133.63 c	23.00 ab

* Means followed by different letters in the same column differ at 5 % by the Tukey test.

CONCLUSIONS

1. Gypsum do not influence shoot growth during the vegetative growth phase. However, in the maturation phase, the number of shoots is higher and the leaf area is lower with the gypsum application;
2. Sugarcane yield is not affected by gypsum, but it improves the distribution of the root system along the soil profile. Thus, high doses of gypsum would not be viable in years with abundant rainfall, or in soils with low acidity.

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