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Effect of gypsum application on agro-energy performance of sugarcane varieties cultivated in a semi-arid environment

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Brazilian semi-arid soils can be dystrophic and often occur in areas with high agricultural potential. Gypsum application improves chemical and physical soil conditions, favoring root system development of plants and can improve sugarcane production for energy production, as a strategy for sustainable development, avoiding native vegetation destruction in semi-arid regions. This study aimed to analyze the impact of gypsum application on the agro-energy potential of three sugarcane varieties, through MS production, moisture, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, ash and gross calorific value (GCV). The experimental design consisted of 3 (varieties) x 2 (with and without gypsum) over two sugarcane growing periods in a completely randomized block design with four replications. The application of gypsum did not affect the tested agro-energy variables. GCV ranged around 17 MJ kg^{-1}, confirming the suitability of the varieties for bioenergy use in semi-arid regions, but there were no significant differences between sugarcane varieties.

Key words: Bioenergy, *Saccharum* spp, gross calorific value, oxisoils; soil amendments.

INTRODUCTION

The search for more efficient, sustainable and renewable energy production has led to global interest in energy from biomass (Katinas et al., 2007; Liu et al., 2013; Scarlat et al., 2013; Sajdak et al., 2014; Pérez et al., 2014). Fossil fuels are being replaced because they are finite sources and civilization needs to decrease greenhouse gases to reduce climate change impact (Sheng et al., 2005; Shuit et al., 2009; Shen et al., 2010).

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Brazil stands out as a major producer of renewable energy sources, mainly ethanol production from sugarcane, eucalyptus charcoal, electricity cogeneration from sugarcane bagasse, biomass in pulp and paper industry, waste from trees and second-generation ethanol (Goldemberg and Lucon, 2007). However, growth of economic activity is causing natural vegetation devastation and environmental degradation, as in the “Caatinga” biome, due to the use of extracted wood as an energy source for industries.

To minimize effects of this devastation, studies have been performed to improve the production of biomass for energy generation, to assure the survival and volume of exotic and native species (Barros et al., 2010) and increase volumetric efficiency and energy of eucalyptus clones (Gadelha et al., 2012). However, the material used has to have high biomass production capacity and suitable characteristics for power generation. Confirmation of the suitability of material for the production of biomass energy depends on the study of fiber, lignin and moisture content and calorific value (Vale et al., 2000), whose levels can vary within species, age, part of plant and/or interferences caused by cultivation practices (Decruyenaere et al., 2009).

Sugarcane stands out for its high dry matter production (Santos et al., 2012). However, its exploitation occurs mainly in more humid regions or in irrigated areas. The “Chapada do Araripe” area (Araripina, Pernambuco, Brazil), although in semi-arid region, is an exception, having deep soils with better water storage capacity and more suitable topography to grow sugarcane and other grasses to replace natural vegetation (Santos et al., 2012). However, the soils in this region are poor due to base leaching, high acidity and high aluminum saturation (Ribeiro-Silva et al., 2012). Limitations caused by subsoil acidity limit agricultural productivity, particularly root system growth, with direct effects on water and nutrient absorption (Miguel et al., 2010).

In the “Chapada do Araripe” area, the Araripe sedimentary basin stands out as the producer of most of Brazil’s gypsum, which has many industrial and agriculture applications (Rocha et al., 2008). Gypsum application adds calcium to soil, can reduce aluminum saturation in depth, and promotes root development so plants can access water and nutrients in deeper soil profiles (Ernani et al., 2001; Rocha et al., 2008; Carvalho et al., 2013). With improvement of root development, sugarcane can produce more biomass (Silva et al., 2011) and, consequently, improve its potential for power generation, because an increase in dry matter production leads to an increase in gross calorific value (Liu et al., 2013).

This study aimed to analyze the impact of gypsum application on agro-energy potential of three sugarcane varieties, through production of dry matter, neutral detergent fiber, acid detergent fiber, lignin and ash as well as moisture content and gross calorific value.

Table 1. Chemical and physical characteristics of Oxisol.

Soil Attributes	Depth (m)	
	0.0 – 0.2	**0.2 – 0.4**
pH [(1)]	4.85	4.54
Ca^{2+} ($cmol_c$ dm^{-3}) [(2)]	0.95	0.30
Mg^{2+} ($cmol_c$ dm^{-3}) [(2)]	0.68	0.38
K^+ ($cmol_c$ dm^{-3}) [(4)]	0.14	0.09
Na^+ ($cmol_c$ dm^{-3}) [(5)]	0.23	0.24
P (mg dm^{-3}) [(6)]	4.00	1.00
Al^{3+} ($cmol_c$ dm^{-3}) [(7)]	0.37	0.70
(H + Al) ($cmol_c$ dm^{-3}) [(8)]	3.74	3.27
TOC (g kg^{-1}) [(9)]	8.1	5.2
S-SO_4^{-2} (mg dm^{-3}) [(10)]	1.83	0.69
Argila (g kg^{-1}) [(11)]	136.38	133.97
Ds (kg dm^{-3}) [(12)]	1.43	1.41
K_0 (mm h^{-1}) [(13)]	65.24	92.83

[1]Water (1:2.5); [2.3.7]KCl 1 mol L-1; [4.5.6]Mehlich-1; [8]$Ca(OAc)_2$ 0.5 mol L^{-1} pH 7; [9]Total organic carbon - $K_2Cr_2O_7$ 0.167 mol $^{L-1}$; [10]Alvarez et al. (2001); [12]Soil density – Ruiz (2004); [13]Saturated hydraulic conductivity – Embrapa (1997).

MATERIALS AND METHODS

Environmental particulars

The experiment was carried out under field conditions during February 2010 to April 2012, in Araripina (latitude: 07° 27'37 "S, longitude: 40° 24'36"W; altitude: 831 m) Pernambuco, Brazil. The predominant vegetation is classified as hyperxerophilic “Caatinga” with deciduous forest stretches. Climate is 'Bshw' type in the Köppen classification (Peel et al., 2007). The soil used was classified as an Oxisol (Table 1).

Plant material and experimental characteristics

Three varieties of sugarcane (RB867515, RB92579 and RB962962) were grown with (495 kg ha^{-1}) and without (0 kg ha^{-1}) gypsum ($CaSO_4$ $2H_2O$), applied within the furrows on the depth of 0.3m. Calculation was based on lime requirement for 0.2 to 0.4 m depth according to exchangeable aluminum neutralization, considering the high percentage of aluminum saturation in this layer, with values greater than 30% (Alvarez et al., 1999). The experiment used a completely randomized block design with four replications in 3 x 2 factorial split plots. The experimental plot consisted of 7 rows with 6 m length and 1 m spacing, totaling 42 m^2. The area used was 6 m^2 in the center of each plot. RB867515, RB92579 and RB962962 varieties were selected because they are considered to have high fiber content, and RB962962 is recommended for areas with scarce water (RIDESA, 2010).

Along with soil analysis, correction and fertilization was performed, with application of 550 kg ha^{-1} of dolomitic limestone, incorporated with a disc harrow in the layer from 0.0 to 0.2 m (IPA, 2008), along with 300 kg ha^{-1} of ammonium sulfate, 286 kg ha^{-1} of triple superphosphate and 150 kg ha^{-1} of potassium chloride. The triple superphosphate was applied at planting, while ammonium sulfate and potassium chloride were split (1/3 at planting and 2/3 seventy days afterwards) . Planting was done eight days after gypsum application (IPA, 2008).

The experiment covered two growing seasons (14 months after planting and 12 months after the first harvest). In the second growing period, fertilization was not performed. Rainfall in the first and second seasons was 899.7 mm and 412.9 mm, respectively. Samples were obtained of 10 whole plants (stem + leaves + tips) in each plot. The number of tillers in each area was counted and then weighed for fresh matter (mg ha^{-1}). After that, the samples were crushed and 1 kg was removed to dry at 65°C until constant weight.

Measurement of variables

The variables analyzed were: moisture, production of dry matter, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin and ash and gross calorific value (GCV). Dry matter production and moisture were obtained after drying samples. NDF, ADF and lignin determinations were according to Silva and Queiroz (2002).

Insoluble ash was determined in lignin samples after lignin determination. Weighed samples were placed in dried and weighed porcelain crucibles, which were in turn placed inside a muffle furnace at 500°C for 3 h. Ash quantification was performed at room temperature by weight difference before and after combustion (Rech, 2010; Silva and Queiroz, 2002). GCV was determined according to the NBR 8633/84 standard from the Brazilian Association of Technical Standards (ABNT). The determination was performed with 0.5 g of dried and ground sample, placed in a porcelain crucible in a combustion chamber (IKA calorimeter, model C2000). Reading was in MJ kg^{-1} of released energy by each variety.

Statistical analysis

Statistical analyses, including analysis of variance (ANOVA), were performed using the SISVAR 3.01 software (Ferreira, 2011). Based on the significance of the F-test, the Tukey test was applied for a comparison of the means at $P < 0.05$ significance level.

RESULTS AND DISCUSSION

Moisture and dry matter production

Gypsum application did not affect the moisture and dry matter production of sugarcane varieties for the two harvests (Table 2). However, there was more moisture in RB962962 variety than in others during the second harvest (Table 2). This difference is probably due to genetic factors, morphological characteristics that can influence conversion of solar radiation into dry matter and/or water availability and temperature conditions (Bonnett et al., 2006).

Rainfall during the second growing season was lower than in the first. RB962962 has better ability to maintain water content in tissue, with is recommended for drought areas (RIDESA, 2010). However, biomass energy efficiency is related negatively with moisture (Furtado et al., 2012; Sajdak et al., 2014).

The need for evaporation of extra water present in biomass will consume part of total energy released upon combustion and reduce plant material calorific value, with consequent reduction in agro-energy performance (Quirino et al., 2005).

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin

Gypsum application did not affect the content of NDF, ADF and lignin for the two harvests (Table 3). The only differences between varieties were: NDF content in RB92579 was greater than in RB962962 in the second harvest; ADF content in RB867515 was greater than in RB92579 in the first harvest; and FDA content was lower for RB92579 in the second harvest. Lignin content remained the same among varieties (Table 3).

Similar results were described by Oliveira et al. (2012), when analyzing NDF, ADF and lignin contents in four sugarcane varieties (RB72454, RB867515, RB855536 and IAC86-2480). The values were not statistically different and average levels were similar to this experiment. ADF is basically made up of lignocellulosic material, where the pulp accounts for the largest fraction (Santos et al., 2012). The ADF concentrations quantified were above the 52% threshold suggested by Samson et al. (2005) for material used as an energy source. However, lignin contents were below the 10% indicated by McKendry al. (2002). Despite having high production and adequate fiber levels (RIDESA, 2010), the three varieties tested are mainly recommended for sugar production, as opposed to fibrous varieties from Cuba.

Lignin is the component richest in carbon, making sugarcane stems the best part for energy production (Samson et al., 2005; Moore et al, 2013). However, during field experimentation after full stem growth, water stress acted to reduce the lignin content of the three varieties.

Ash content and gross calorific value (GCV)

Ash and GCV were not changed by gypsum application in the two harvests (Table 4). Ash contents also did not vary between varieties, but GCV changed in both growth periods. In the first, RB92579 showed greater GCV than RB962962, while in the second, the GCV of RB962962 was greater than RB867515 (Table 4).

According to Flowers et al. (2012), the average ash content found in stems and leaves of elephant grass genotypes developed for energy purposes are between 6.9 and 5.8% in stems and 9.84 and 9.84% in leaves. The values in the three sugarcane varieties were between 2.01 and 2.49% (Table 4). However, low ash content is a positive feature for use of sugarcane biomass for energy purposes. The most important parameter to characterize a material's combustion is GCV, and this is inversely proportional to ash content (Liu et al., 2013) and moisture (Furtado et al., 2012; Sajdak et al., 2014).

Combustion conditions, variety, nutrition, soil and climatic conditions and grinding efficiency for sugarcane can influence ash concentration and other characteristics

Table 2. Moisture and shoot dry matter production (SDM) of three varieties of sugarcane in the presence and absence of gypsum in first and second harvests.

Factor	Moisture		Average	SDM		Averege
	With Gypsum	No Gipsum		With Gypsum	No Gipsum	
Varieties			*1º harvest*			
RB867515	78.04	72.79	75.42a	15.76	16.72	16.24a
RB92579	72.73	71.03	71.88a	20.92	21.75	21.34a
RB962962	74.87	73.17	74.02a	24.78	29.33	27.06a
Average	75.21A	72.33A		20.49A	22.60A	
		F			*F*	
Varieties		0.98 ns			4.05 ns	
Gypsum		1.93 ns			1.51 ns	
*Varieties*Gypsum*		0.32 ns			0.50 ns	
C.V. Portion (%)		6.88			35.30	
Subplot C.V. (%)		6.90			9.57	
Varieties			*2º harvest*			
RB867515	69.31	70.75	70.03b	12.51	8.31	10.41a
RB92579	66.68	67.39	67.03b	6.97	5.95	6.46a
RB962962	76.21	75.67	75.94a	10.79	9.25	10.02a
Average	70.73A	71.27A		10.09A	7.84A	
		F			F	
Varieties		36.04 *			3.56 ns	
Gypsum		0.48 ns			4.33 ns	
*Varieties*Gypsum*		0.56 ns			0.83 ns	
C.V. Portion (%)		3.01			36.41	
Subplot C.V. (%)		2.66			29.56	

Means followed by the same lowercase letter in each sub-column and capital letters in the same row for each plant harvest are not significant at 5% probability according to the Tukey test. *Significant; NSNot significant.

(Turn, 2003). According to Liu et al. (2013), differences in ash content can occur due to mineral composition of plant material and this change GCV. Results for GCV in sugarcane stems noted in previous studies were 18.87 MJ kg^{-1} found by Ripoli et al. (1991) and ranged from 14 to 22 MJ kg^{-1} as described by Quirino et al. (2005) for species appropriate for energy production. In addition, the values found in this study are very close to those found in studies of other species used for energy purposes (Queno et al., 2011; Flores et al., 2012).

Calorific value is the most important parameter for biomass production and hence for energy purposes (Liu et al., 2013), but it needs to be combined with high DM production. The varieties tested did not differ in SDM production (Table 2) and in response to gypsum application, although this application affected cation percolation and improved the root environment (Ernani et al., 2001; Carvalho et al., 2013). Gypsum application also did not affect sugarcane productivity. However, there was a change in GCV between varieties (Table 4), showing that other studies should be conducted to select adequate varieties for use as biomass for energy production, because combustion, variety, nutrition conditions, soil, climate and grinding may have influenced the varieties' response.

Conclusion

The three varieties tested are viable for bioenergy use in semi-arid conditions, due to NDF, ADF, lignin and GCV values found. Appropriate GCV values, around 17 MJ kg^{-1}, and high fiber content, mean these varieties can be used for energy production in semi-arid environment instead of natural vegetation. However, gypsum application was not an effective practice and did not contribute to improvement of the evaluated parameters, probably due to low rainfall recorded in the trial period.

Table 3. Neutral detergent fiber (NDF). acid detergent fiber (ADF) and lignin of three varieties of sugarcane in the presence and absence of gypsum in first and second harvests.

Factor	NDF		Average	ADF		Average	Lignin		Average
	With Gypsum	No Gipsum		With Gypsum	No Gipsum		With Gypsum	No Gipsum	
	....				%				....
Varieties					1º Harvest				
RB867515	67.21	66.01	66.61[ab]	58.24	58.30	58.27[a]	4.02	3.88	3.95[a]
RB92579	70.95	69.81	70.38[a]	56.08	56.12	56.10[b]	3.48	3.39	3.44[a]
RB962962	65.53	64.60	65.07[b]	57.76[a]	57.92	57.84[ab]	4.87	4.13	4.50[a]
Average	67.90[A]	66.81[A]		57.36[A]	57.45[A]		4.12[A]	3.80[A]	
		F			F			F	
Varieties		5.41*			7.96 *			3.87 [ns]	
Gypsum		0.37 [ns]			0.05 [ns]			1.07 [ns]	
*Varieties*Gypsum*		0.002 [ns]			0.008 [ns]			0.45 [ns]	
C.V. Portion (%)		4.94			2.01			19.43	
Su plot C.V. (%)		6.54			1.77			19.40	
Varieties					2º H[a]rvest				
RB867515	75.75	68.38	72.07[a]	55.32	54.09	54.71[a]	3.17	1.96	2.57[a]
RB92579	76.40	76.92	76.66[a]	52.65	53.51	53.08[b]	3.01	3.45	3.23[a]
RB962962	72.41	72.56	72.49[a]	54.55	55.17	54.86[a]	3.01	3.79	3.40[a]
Average	74.85[A]	72.62[A]		54.17[A]	54.26[A]		3.06[A]	3.07[A]	
		F			F			F	
Varieties		3.65 [ns]			15.77 *			0.97 [ns]	
Gypsum		2.12 [ns]			0.03 [ns]			0.00 [ns]	
*Varieties*Gypsum*		2.81 [ns]			1.98 [ns]			0.98 [ns]	
C.V. Portion (%)		5.10			1.30			41.31	
Subplot C.V. (%)		5.09			2.12			49.51	

Means followed by the same lowercase letter in each sub-column and capital letters in the same row for each harvest are not significant at 5% probability according to the Tukey test. *Significant; [NS] Not significant.

Table 4. Ash and gross calorific value (GCV) of three varieties of sugarcane in the presence and absence of gypsum in first and second harvests

Factor	Ash		Average	GVC		Average
	With Gypsum	No Gipsum		With Gypsum	No Gipsum	
	dag kg^{-1}			MJ kg^{-1}		
Varieties			*1º harvest*			
RB867515	2.01	2.46	2.24[a]	17.75	17.13	17.44[ab]
RB92579	2.37	2.18	2.28[a]	17.37	18.41	17.89[a]
RB962962	2.30	2.17	2.24[a]	16.99	16.89	16.94[b]
Average	2.23[A]	2.27[A]		17.37[A]	17.48[A]	
		F			*F*	
Varieties		1.00[ns]			9.58 *	
Gypsum		0.91 [ns]			0.11 [ns]	
*Varieties*Gypsum*		0.60 [ns]			2.38 [ns]	

Table 4. Contd.

C.V. Portion (%)		50.49			2.48	
Subplot C.V. (%)		31.16			4.43	
Varieties				*2º harvest*		
RB867515	2.41	2.45	2.45^{a}	17.43	17.08	17.26^{b}
RB92579	2.29	2.29	2.31^{a}	17.35	17.52	17.44^{ab}
RB962962	2.28	2.38	2.33^{a}	18.46	17.37	17.92^{a}
Average	2.36	2.36		17.75^{A}	17.32^{A}	
		F			F	
Varieties		0.79^{ns}			7.36 *	
Gypsum		0.99^{ns}			4.12^{ns}	
*Varieties*Gypsum*		0.29^{ns}			3.12^{ns}	
C.V. Portion (%)		7.81			2.30	
Subplot C.V. (%)		12.24			2.49	

Means followed by the same lowercase letter in each sub-column and capital letters in the same row for each harvest are not significant at 5% probability according to the Tukey test. * Significant; ns Not significant.

Conflict of Interests

The authors have not declared any conflict of interests.

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