Australian Journal of Crop Science AJCS
AJCS 10(1):69-75 (2016) ISSN:1835-2707

Nutrient partitioning and nutritional requirement in sugarcane

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Abstract

This study served a twofold purpose: first, to determine the content and quantify the partitioning of nitrogen (N), phosphorus (P) and potassium (K) in the stalks, leaves and tops of 11 sugarcane varieties cultivated under rainfed conditions; Secondly, to establish the requirements of N, P and K in kg Mg^{-1} of sugarcane produced by different varieties. The experiment was carried out in a field, in a soil classified as Argissolo Amarelo distrófico abrúptico. At the end of the first cycle, plant shoots were separated into stalk, leaves and tops. N, P and K contents were determined in each of these three compartments. Nutritional requirements were quantified based on the accumulation of nutrients in the shoots of the varieties and the production of stalks per hectare. For an average production of approximately 80 Mg ha^{-1} of sugarcane in the first cycle there may be a return to the soil of 135, 32 and 98 kg ha^{-1} of N, P and K, respectively. The highest accumulations of N, P and K were observed for two varieties; N and K for RB92579 and P for RB867515. Considering that in the first cycle the varieties were under rainfed conditions, the average requirements of N, P and K are 1.69, 0.40 and 1.21 kg Mg^{-1} of stalks, respectively. The varieties RB92579 and RB867515 were productive, but more demanding in N, P and K than the other varieties. This information may contribute to future studies on nutritional balance, nutrient cycling and nutrient replacement in sugarcane cultivation.

Keywords: *Saccharum* spp., nutrient content, nutritional efficiency, uptake, plant nutrition.
Abbreviations: SC_stalk compartment; LC_leaf compartment; TC_top compartment.

Introduction

Sugarcane (*Saccharum* spp.) is cultivated in Brazil, especially without irrigation, under rainfed conditions. This practice makes the cultivation vulnerable to water deficit periods during plant growth, which reduces production (Oliveira et al., 2011a). Thus, the average stem yield of 72 Mg ha^{-1} (CONAB, 2013) is below the genetic potential of the currently cultivated varieties, which is estimated to reach up to 300 Mg ha^{-1} (Albuquerque and Silva, 2008). Under this cultivation condition, the lower water availability compromises plant capacity uptake nutrients and modifies its nutritional requirement. Thus, the knowledge on sugarcane nutrition, under rainfed conditions, is essential to recommend more precise fertilizations (Coleti et al., 2006), reducing the cost of production of fertilizers and environmental contamination. Sugarcane is widely cultivated under rainfed conditions and in soils with various fertility levels. However, soil fertility is rarely considered as a criterion for the selection of the variety to be planted. This often occurs due to the lack of information on the specific nutritional requirement of each variety. Therefore, identifying the demand for nutrients like N, P and K under rainfed conditions, allows correctly recommending the varieties for conditions of either high or limited nutrient supply, in order to obtain maximum efficiency (Oliveira et al., 2010). In addition to the nutritional requirement, the amount of nutrients extracted from the soil and accumulated in sugarcane shoot compartments (stalks, leaves and tops) varies among varieties (Oliveira et al., 2011b). Nutrients accumulated in leaves and tops return to the soil either completely, through green cane harvest, or partially, through burnt cane, in which there is a significant N loss. However, in the stalks, the nutrients are essentially exported from the soil-plant system. Information on the partitioning of these amounts is important for the calculation of nutritional balance, nutrient cycling and nutrient replacement, serving as support for new methods and forms of fertilization that are more efficient, economically viable and with less waste (Coleti et al., 2006). Despite the importance of sugarcane in the Brazilian agribusiness, recent studies on nutrient partitioning and nutritional requirements, under rainfed conditions, are limited to two studies: one study focuses on using only one variety (Franco et al., 2007; Oliveira, 2011) while the other study examines varieties specific to the cultivation conditions of Southeast and Central-western Brazil (Tasso Júnior et al., 2007). Given this information, this study served a twofold purpose: first, to determine the content and quantify the partitioning of N, P and K in the stalks, leaves and tops of 11 sugarcane varieties cultivated under rainfed conditions; Secondly, to establish the requirements of N, P and K in kg Mg^{-1} of sugarcane produced by different varieties.

Results and discussion

Content of nutrients in sugarcane

At the end of the first cycle, the content of nutrients in the plant shoots of the sugarcane varieties reflected the nutrition of these plants as a whole. Thus, the observed differences showed the capacity uptake, metabolism and redistribution of nutrients, which is inherent to each variety. According to this study, there are high contents of N for RB872552, P for RB943365 and K for RB867515 in the shoots of the sugarcane (Table 1). Therefore, these varieties may be recommended for more fertile soils and possibly respond better to N, P and K fertilization. The mean contents of N, P and K of the varieties on g kg^{-1} were higher in the top compartment (Table 1). This behavior may be explained by the higher metabolic and transpiratory activity in the younger leaves forming the tops, compared with the older leaves in the stalk (Lal, 1951). Thus, not only the upward flow in the xylem is maintained, but also the redistribution of the mobile nutrients in the plant, through the phloem, towards younger leaves (Maathuis, 2009).

In addition, the N content in the leaves was higher than in the other compartments. P contents in leaves and stalks were similar, while K was found in higher content in the stalks (Table 1). Rodrigues (1995) describes the importance of K in the conversion of intermediate sugars into sucrose and in the loading/unloading of sucrose in the phloem. Thus, the increase in sucrose concentration in the stalk after physiological maturation and its relation with K may explain the high K content in the stalk at the end of the crop cycle, since K is mobile inside plants (Maathuis, 2009) and may be transported from the source (leaves) to the drain (stalk).

Accumulation of nutrients in sugarcane

The mean accumulation of N, P and K in sugarcane shoots followed a decreasing order: N>K>P (Table 2). This result differs from the ones reported in field studies on nutrition that results from the cultivation of sugarcane in the first cycle developed in the state of São Paulo, in which K was the nutrient found in the highest concentration (Franco et al., 2007; Tasso Júnior et al., 2007; Oliveira, 2011). On the other hand, these same varieties when cultivated in the same soil, but under full irrigation, showed higher K accumulation in plant cane shoots, compared with N, on average (Oliveira et al., 2010). The mineralization of organic matter is a considerable source of N on the cultivation sugarcane in the first cycle (Azeredo et al., 1986; Trivelin et al, 1995; Gava et al., 2003; Franco et al., 2011). Additionally, some studies showed that the biological fixation of N is also an importance source of this nutrient (Boddey et al, 2003; Li-Ping et al., 2007; Herridge et al., 2008; Urquiaga et al., 2012). So, even in the beginning period of cultivation in which the availability of water was lower (Fig. 1), the N continued to be supplied differently of the K. The K nutrition of the sugarcane depended only of availability of K in the soil (Table 4). The variety RB867515 was the only one in which the accumulation of K exceeded N (Table 3). Recent research indicated that this variety did not respond satisfactorily to the biological fixation of N, because the number of microorganisms in this variety was low (Silva et al., 2012), or because inoculation of bacteria on the RB867515 did not promote biological fixation of N (Schultz et al., 2014). So, the variety RB867515 had reduced its additional source of N and reduced also the accumulation of N in the shoot of plants. This probably caused the most accumulation of K rather than N in this variety.

In environments with higher water availability, whether under irrigation (Oliveira et al., 2010) or a more uniform distribution of rains (Franco et al., 2007; Oliveira, 2011), K absorption may increase, without interfering with plant metabolism, because it does not constitute any organic compound. So, K may occur not only as a free ion in high concentrations in the cytosol, but may also accumulate in cell vacuoles (Shukla et al., 2009), which would cause K accumulation to exceed N accumulation. In this study, however, the lower water availability during the initial growth stage (Fig. 1) possibly reduced K absorption and, consequently, its accumulation in the shoots of the sugarcane varieties.

Moreover, the accumulation of N, P and K was different for each plant compartment. The highest contents occurred in the stalk, corresponding on average of 65.2, 71.9 and 72.4%, respectively, of the total amount accumulated and distributed in the shoots (Table 2). From these results, it can be inferred that a large portion of these nutrients is exported from the soil during cultivation of sugarcane first cycle, under rainfed conditions. These exported amounts, especially for N, are higher than the ones applied in conventional fertilizations, which range from 40 to 60 kg ha^{-1} of N (CFSEM, 1999; IPA, 2008; Raij et al., 2011), showing that the complement of N is probably supplied by the mineralization of organic matter (Azeredo et al., 1986; Trivelin et al, 1995; Gava et al., 2003; Franco et al., 2011) and biological fixation (Boddey et al, 2003; Li-Ping et al., 2007; Herridge et al., 2008; Urquiaga et al., 2012). The nutrients N, P and K uptake and accumulation of leaves return to the soil when the cane is harvested green, mainly N. When the cane is harvested burned the N is volatilized, as commonly occurs in Northeast Brazil. This information is important to the studies of nutrient cycling. For example, this research showed that for an average production of approximately 80 Mg ha^{-1} of sugarcane in the first cycle may return to the soil 135, 32 and 98 kg ha^{-1} of N, P and K, respectively (Table 2). Oliveira et al. (2011b) reported lower relative accumulation of N, P and K in the stalk compartment of sugarcane varieties cultivated under rainfed conditions when compared with irrigated plants. These authors found accumulations in varieties cultivated under rainfed conditions of 51, 58 and 57% for N, P and K, respectively, from the total extracted in the first cycle of the sugarcane. Oliveira (2011) working with nutrition demand in sugarcane under the edaphoclimatic conditions in the state of São Paulo, observed that the first cycle in the non-irrigated variety SP81-3250 exported 49, 55 and 66% of N, P and K, respectively. These two production environments provided higher water availability during the first cycle, in comparison with this study (Fig. 1), which promoted more plant growth and an increased productivity of stalks. This highlights the dilution effect with the increase in biomass production and decrease in the relative participation of the nutrients accumulated in sugarcane stalk. Considering the varieties RB92579 and RB867515, with high accumulations of N, P and K in the stalk associated with a high export of these nutrients, with values of 147 kg ha^{-1} of N for RB92579 (76.2%), 31 kg ha^{-1} of P for RB867515 (70.4%) and 146 kg ha^{-1} of K for RB92579 (83.4%) (Table 2), a review on the fertilization program of these varieties is suggested, since the exported amounts of N and K are higher than the ones added through the conventional fertilization recommended for sugarcane (CFSEM, 1999; IPA, 2008; Raij et al., 2011).

Table 1. Contents of nitrogen (N), phosphorus (P) and potassium (K) in plant shoots (PS) and in the compartments stalk (SC), leaf (LC) and top (TC) of different early-maturing and medium/late-maturing sugarcane varieties.

Variety	N				P				K			
	SC	LC	TC	PS	SC	LC	TC	PS	SC	LC	TC	PS
	(g kg^{-1})											
	Early-maturing varieties											
SP79-1011	3,39fC	10,76aB	15,42dA	9,86c	1,06fC	1,48bB	2,82dA	1,78f	3,67cB	3,46dC	10,23dA	5,79e
RB813804	4,50dC	6,91cB	13,56fA	8,32g	1,53bB	0,97dC	3,41aA	1,97c	3,51cB	2,34fC	8,54fA	4,80h
RB863129	4,57dC	6,56dB	14,62eA	8,59f	1,27eC	1,48bB	1,77fA	1,51h	3,58cC	3,81cB	5,33gA	4,24g
RB872552	6,70bC	8,25bB	16,83bA	10,59a	1,33dC	1,56bB	2,56eA	1,82e	3,31cC	3,88cB	9,56eA	5,62f
RB943365	4,20eC	5,97eB	16,18cA	8,78e	0,96gC	2,10aB	3,38aA	2,15[a]	1,56fC	4,77aB	11,59bA	5,97c
	Medium/late-maturing varieties											
RB72454	5,54cC	6,69dB	16,52cA	9,58d	1,23eB	1,04dC	3,35aA	1,88d	3,45cB	3,33eB	8,35fA	5,05g
RB763710	4,15eC	7,10cB	18,19aA	9,81c	1,25eB	1,33cB	2,60eA	1,73g	3,67cB	3,14eC	10,77cA	5,86d
SP78-4764	4,23eC	5,57eB	14,35eA	8,05h	1,18eB	1,00dC	3,06cA	1,75g	3,04dC	3,56dB	11,36bA	5,99d
SP81-3250	4,27eC	5,82eB	15,62dA	8,57f	1,47cB	0,95dC	3,21bA	1,88d	2,75eB	1,72gC	9,45eA	4,64i
RB867515	4,73dC	7,21cB	17,17bA	9,70d	1,62aB	1,34cC	3,18bA	2,05b	6,63bB	4,43bC	12,39aA	7,82a
RB92579	7,81aC	6,91cB	15,49dA	10,07b	1,42cB	1,25cC	2,84dA	1,84e	7,78aB	3,29eC	11,31bA	7,46b
Média	4,92C	7,07B	15,81A	-	1,30B	1,32B	2,93A	-	3,91B	3,43C	9,91A	-
$F_{Variety}$	256.191,00*				178.443,00*				890.854,00*			
$F_{Compartment}$	49.097,32*				30.004,38*				37.105,01*			
$F_{Variety*Compartment}$	75.901,00*				89.101,00*				209.455,00*			
C.V. (%)	2,24				2,76				2,58			

F – F calculated by F-test; C.V. – coefficient of variation; *significant (p>0,05); Means followed by the same lowercase letters in the column do not differ by the Scott-Knott (p>0,05).

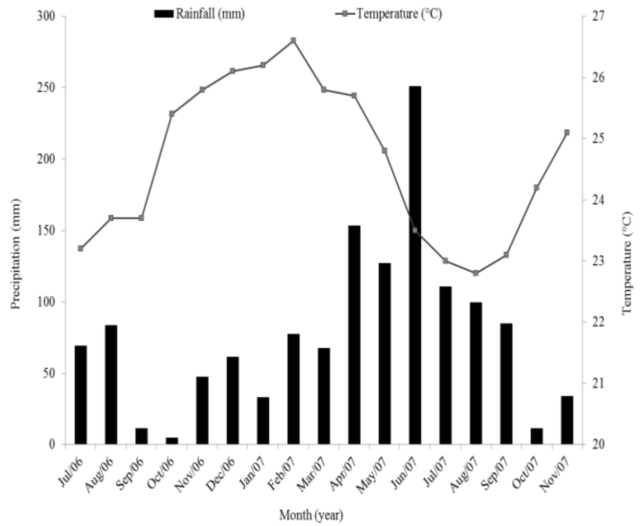

Fig 1. Mean rainfalls and temperatures at the Sugarcane Experimental Station of Carpina-PE during the experiment.

Table 2. Accumulation of nitrogen (N), phosphorus (P) and potassium (K) in plant shoots (Total) and in the compartments stalk (SC), leaf (LC) and top (TC) of different early-maturing and medium/late-maturing sugarcane varieties.

Variety	N				P				K			
	SC	LC	TC	Total	SC	LC	TC	Total	SC	LC	TC	Total
	----------				($kg\ ha^{-1}$)				----------			
	Early-maturing varieties											
SP79-1011	49eA	13bB	18bB	80e	15Da	2bB	3bB	20f	53dA	4bB	12bB	69d
RB813804	84dA	18aB	16bB	118d	28bA	3bB	4bB	35b	66cA	6bB	10bB	82c
RB863129	83dA	19aB	20bB	122d	23cA	4bB	2bB	29d	65cA	11bB	7bB	83c
RB872552	119bA	19aB	28bB	166b	24cA	4bB	4bB	32c	59cA	9bB	16bB	84c
RB943365	73dA	23aC	42aB	138c	17dA	8aB	9aB	34c	27eA	18aB	30aA	75d
	Medium/late-maturing varieties											
RB72454	81dA	15bB	22bB	118d	18dA	2bB	5bB	25e	50dA	7bB	11bB	68d
RB763710	73dA	18aB	29bB	120d	22cA	3bB	4bB	29d	65cA	8bB	17bB	90c
SP78-4764	93cA	24aB	35aB	152b	26bA	4bB	7aB	37b	67cA	15aC	27aB	109b
SP81-3250	78dA	22aB	23bB	123d	27bA	4bB	5bB	36b	50dA	7bB	14bB	71d
RB867515	91cA	28aC	41aB	160b	31aA	5bB	8aB	44A	128bA	18aB	29aB	175a
RB92579	147aA	22aB	24bB	193a	27bA	4bB	4bB	35b	146aA	11bB	18bB	175a
Mean	88A	20C	27B	135	23A	4B	5B	32	71A	10C	17B	98
$F_{Variety}$	42,680.00*				32,375.00*				103,563.00*			
$F_{Compartment}$	1,495.12*				1,740.38*				1,318.72*			
$F_{Variety*Compartment}$	11,439.00*				8,720.00*				29,109.00*			
C.V. (%)	13.83				13.78				15.75			

F – F calculated by F-test; C.V. – coefficient of variation; *significant (p>0,05); Means followed by the same lowercase letters in the column do not differ by the Scott-Knott (p>0,05).

Table 3. Stalk yield and requirements of nitrogen (N), phosphorus (P) and potassium (K) for different early-maturing and medium/late-maturing sugarcane varieties.

Variety	Stalk yield ($Mg\ ha^{-1}$)	N	P	K
		----------	($kg\ Mg^{-1}$ Stalk)	----------
Early-maturing varieties				
SP79-1011	71.29c	1.13e	0.29e	0.98e
RB813804	79.95b	1.47d	0.44b	1.02d
RB863129	87.87a	1.38d	0.34d	0.94e
RB872552	76.73b	2.17a	0.41b	1.10c
RB943365	80.69b	1.70c	0.41b	0.93e
Medium/late-maturing varieties				
RB72454	68.07c	1.74c	0.37c	1.02d
RB763710	79.21b	1.52d	0.37c	1.14c
SP78-4764	76.24b	1.99b	0.49a	1.44b
SP81-3250	83.17a	1.49d	0.42b	0.85e
RB867515	87.62a	1.83c	0.50a	1.99a
RB92579	90.10a	2.14a	0.39c	1.94a
Mean	80.09	1.69	0.40	1.21
$F_{Variety}$	5,159*	40,267*	36,290*	123,620*
C.V. (%)	7.59	6.12	5.23	5.96

F – F calculated by F-test; C.V. – coefficient of variation; *significant (p>0,05); Means followed by the same lowercase letters in the column do not differ by the Scott-Knott (p>0,05).

Table 4. Soil chemical and physical characterization.

Chemical attributes										
Layer	pH H_2O	$P_{Mehlich-1}$ ($mg\ dm^{-3}$)	(H+Al)	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	CEC	V	m
(m)	H_2O	($mg\ dm^{-3}$)	----------		($cmol_c dm^{-3}$)		----------		--- (%)	---
0.0 – 0.2	5.4	8	6.4	0.2	1.6	1.2	0.07	9.33	31.4	6.3
0.2 – 0.4	5.2	7	6.8	0.5	1.0	0.5	0.05	8.50	20.0	22.7
0.4 – 0.6	5.0	6	6.8	0.7	0.75	0.5	0.03	8.20	17.0	26.1

Physical attributes					
Layer (m)	Bulk density ($Mg\ m^{-3}$)	Sand	Silt	Clay	Textural class
		----------	($g\ kg^{-1}$)	----------	
0.0 – 0.2	1.44	769.4	61.4	169.2	Sandy loam
0.2 – 0.4	1.36	689.4	46.4	264.2	Sandy clay loam
0.4 – 0.6	1.39	661.0	54.8	284.2	Sandy clay loam

CEC – Cation Exchange Capacity (Ca^{2+}, Mg^{2+}, K^+, Al^{3+}, H); V – base saturation; m – aluminum saturation.

Therefore, based on the export of nutrients by these varieties and on the recommended fertilization for the first cycle according to IPA (2008), a fertilization deficit of about 127 kg ha^{-1} of N and 104 kg ha^{-1} of K, for instance, is noted. Also, considering that the contribution of biological fixation of N to the first cycle is about 40 kg ha^{-1} for Brazilian edaphoclimatic conditions (Urquiaga et al., 2012), there would still be a N deficit of 87 kg ha^{-1}. As for K, there will be a reduction in this deficiency in areas under fertigation with vinasse (byproduct of the sugar industry), because of the additional K supply.

Nutritional requirement in sugarcane

The average stalk yield of the first cycle ranged from 68 to 90 ton ha^{-1} (Table 3). The varieties RB92579, RB867515, SP81-3250 and RB863129 showed the highest stalk yields, with a mean value of 87.1 Mg ha^{-1}. The lowest yields were observed for RB72454 and SP79-1011, with a mean value of 69.6 Mg ha^{-1}. For the other varieties, this value was 78.5 Mg ha^{-1}. Besides the highest stalk yield, RB92579 showed higher demands for N and K, and RB867515 for P and K (Table 3). This characteristic, associated with the higher nutrient accumulation in the shoots of the plant cane (Table 2), shows the high nutritional requirement of these varieties. Thus, they are recommended for production in areas with more fertile soils, combined with higher doses of nutrients. SP79-1011 and RB72454 showed low demands for N, P and K and, consistently, also showed the lowest stalk yields (Table 3). Thus, they should be replaced by more efficient varieties.
Among the most productive varieties, RB863129 had the lowest demands for N, P and K, RB92579 for P, SP81-3250 for N and K and RB867515 for N, which showed higher efficiency to convert the absorbed nutrients into biomass. On the other hand, RB872552 and SP78-4764 were less efficient, because they showed high demands for N and P, respectively, and low stalk yield (Table 3). Comparing the nutritional requirements of the sugarcane varieties, under rainfed conditions or full irrigation in the same crop year, rainfed plants showed higher demand for N and P, and lower for K (Oliveira et al., 2010). Under rainfed conditions, the lower water availability at the soil surface increases the production of total root biomass, as showed Farias et al. (2008), because it stimulates deeper root growth in soil layers (Laclau and Laclau, 2009), which may increment the inflow of N and P to supply the higher nutritional and energetic demands of the root growth. Thus, shoot biomass production is reduced and the contents of absorbed nutrients remain high in plant tissues, due to the increase in concentration. In the irrigated cultivation, the constant water availability during cultivation sugarcane first cycle growth promotes lower root growth (Laclau and Laclau, 2009) and higher shoot biomass production (Oliveira et al., 2011a), which increases leaf transpiration rate and the demand for K in order to maintain osmotic and water balances in the plant. Since K is preferentially absorbed through specific ionic channels, its inflow is facilitated and the process is faster and without energy consumption (Maathuis, 2009). The excess of K accumulates in the cytosol and, in higher amounts, in cell vacuoles, increasing the contents in stalk and leaf tissues.

Materials and Methods

Plant materials

The vegetable material used in the experiment included five sugarcane varieties of early maturation (SP79-1011, RB813804, RB863129, RB872552 and RB943365) and six of medium/late maturation (RB72454, RB763710, SP78-4764, SP81-3250, RB867515 and RB92579). The varieties, when planted in December/January, with a life cycle of 12, 14 or 16 months are classified as early, medium/late, and late maturation, respectively (Simões Neto and Melo, 2005).

Location and characteristics of the cultivation area

The experiment was carried out in a field, in the Zona da Mata of the Pernambuco state, from July 2006 to November 2007. The geographic coordinates of the experimental area are 7º51'133''S and 35º14'102''W. According to Köppen classification, the predominant climate of the region is Ams, tropical monsoon, rainy with dry summer and average annual rainfall of approximately 2,200 mm (Koffler et al., 1986). The annual rainfall is characterized by averages ranging from 1,000 to 2,000 mm. During the experiment, the accumulated rainfall was equal to 1,141.4 mm and the average temperatures were above 23 ºC (Fig. 1). The soil in the experimental area was classified as Argissolo Amarelo distrófico abrúptico (EMBRAPA, 2013). Chemical and physical characterizations were performed in the layers of 0.0-0.2, 0.2-0.4 and 0.4-0.6 m (Table 4). For the chemical characterization, the following parameters were determined: pH (H_2O), Ca^{2+}, Mg^{2+}, K^+, Al^{3+}, (H+Al) and P. Ca^{2+}, Mg^{2+} and Al^{3+} were extracted using 1.0 mol L^{-1} KCl and determined through atomic absorption spectrophotometry. P and K were extracted using Mehlich-1 and determined through colorimetry and flame photometry, respectively. (H+Al) was extracted using 0.5 mol L^{-1} calcium acetate and determined through titration. For physical characterization, soil bulk density and granulometry, which allowed identifying the textural class, were determined. All soil chemical and physical analyses followed the protocols established by EMBRAPA (2009).

Sugarcane planting

Before initiating the experiment, the soil was disk-harrowed, in order to destroy crop residues, and limestone was incorporated in the entire area to the depth of 0.2 m. The amount of limestone applied, 465 kg ha^{-1}, was calculated based on the neutralization of the exchangeable Al or the increase of exchangeable contents of (Ca + Mg), considering 3.0 $cmol_c$ dm^{-3} as the critical level of (Ca + Mg) (IPA, 2008). Fertilization was performed based on the soil chemical analysis (Table 4) and on the recommendation for the state of Pernambuco (IPA, 2008). The fertilizers were applied immediately after opening the planting furrows, as urea (N: 30 kg ha^{-1}), triple superphosphate (P_2O_5: 120 kg ha^{-1}) and potassium chloride (K_2O: 70 kg ha^{-1}).
Then, five sugarcane varieties were planted in the area and cultivated under rainfed conditions. Three-bud sets were distributed in the planting furrows, in order to obtain 18 buds m^{-1}, and were completely covered with soil. Topdressing fertilization was performed 90 days after planting, 0.10 m away from the sugarcane rows, by applying 50 kg ha^{-1} of N as ammonium sulfate and 50 kg ha^{-1} of K_2O as potassium chloride.

Contents of N, P and K

At the end of the vegetative growth cycle of the sugarcane (510 days after planting), the shoots of eight plants were randomly collected in the experimental area of each plot. Plants were separated into compartments: stalks, leaves and tops. The sugarcane top was composed of the stalk tip and the +1 leaf (first visible dewlap). Fresh and dry leaves starting from the +1 leaf down were considered as the leaves (leaf + sheath). After removing tops and leaves, the rest was considered as the stalk (Oliveira et al., 2010).

The stalks, leaves and tops of the sampled plants were weighed at the field, in order to determine the total fresh weight. Then, these parts were ground into forage material and subsamples were collected for wet weight determination. The subsamples were dried in a forced-air oven at 65 ºC at a constant mass, in order to obtain the dry weight, and then they were ground. Using the ground plant material, 0.5 g were weighed in order to determine the content of N, which was extracted through sulfuric digestion and determined by distillation. For P and K, 0.1 g were used; P was determined through colorimetry and K through flame photometry (EMBRAPA, 2009).

Accumulation of N, P and K

The accumulation of N, P and K in tops, leaves and stalks of the sugarcane varieties was calculated by multiplying the dry weight of each compartment by the nutrient content in each respective compartment. In order to calculate the total extracted amount of nutrients, the sum of the accumulated amounts in each compartment was considered. The amount of nutrients accumulated in the compartment stalks was considered as the amount exported of nutrients, i.e., the part that was effectively removed from the soil (Oliveira et al, 2010).

Stalk yield and nutritional requirements

Stalk yield (Mg ha^{-1}) was estimated by weighing the stalks from the experimental area of each plot at the field using a dynamometer and the stalks from the plants sampled for the partitioning analysis. The nutritional requirement was calculated by dividing the total nutrient uptake in the shoots by the stalk yield observed for each variety.

Experimental design, treatments and statistical analysis

The experiment was set in a randomized block design, with 11 treatments and four replicates. Each plot was composed of five 10-m-long planting furrows, 1.10 m apart. The experimental area of each plot was composed of the three central furrows, which were 8 m long, since 1 m on each side was disregarded in order to avoid the border effect.

The treatments consisted of 11 sugarcane varieties, five of early maturation (SP79-1011, RB813804, RB863129, RB872552 and RB943365) and six of medium/late maturation (RB72454, RB763710, SP78-4764, SP81-3250, RB867515 and RB92579), cultivated under rainfed conditions. The data were evaluated by the factorial method and subjected to analysis of variance, using the F test at 5% of probability. When significant, the content and the accumulation of nutrients between the compartments and the varieties, as well as the production and the nutritional requirement of the varieties, were compared by the Scott-Knott test at 5% of probability.

Conclusions

The higher N demand under rainfed conditions suggests that nitrogen fertilization in the cultivation of sugarcane in the first cycle for the currently used varieties should be reviewed and may be considered as a limiting factor for the increase in sugarcane yield in Northeast Brazil. In addition, since the varieties RB92579 and RB867515 were very productive, uptake and exported high amounts of N, P and K, however, suggest that they are used in environments suitable to their high nutritional requirements.

Acknowledgments

The authors would like to thank the National Council for Scientific and Technological Development (CNPq), for granting the scholarships, and the scholars and volunteers, for their help in conducting the experiment and collecting the data. Additionally, we would also like to thank Angela Arenivar Graduate Teaching Assistant at Texas A&M University for her English language corrections.

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