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Growth, yield and nutrition of sugarcane ratoon as affected by potassium in a mechanized harvesting system

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Abstract

Sugarcane mechanical harvest deposes straw residue on the soil surface, increases soil organic matter and improves nutrients cycling, especially potassium (K). The objective of this work was to evaluate the effect of K fertilizer on vegetative growth, mineral nutrition, straw yield and technological quality; i.e., levels of total soluble solids, industry fiber (bagasse), apparent sucrose, juice purity, and reducing sugars in a ratoon sugarcane grown in Oxisol in a mechanized harvesting system. The experiment design was carried out in the 2009/10 cropping season in the state of São Paulo, Brazil, in the first regrowth of sugarcane after harvest using cultivar RB 86-7515. The experimental design was a randomized block with five replicates and five rates of K-fertilizer: 0 (control); 32.5; 65.0; 130.0 and 195.0 kg ha^{-1} of K_2O. Potassium levels in the soil and in the plant, stalk production and the technological quality were evaluated at harvest. The rate of 195 kg ha^{-1} of K_2O increased in 279, 78, 142 and 29% the K exchangeable content in the 0-20 and 20-40 cm layers at 180 and 360 DAS, respectively, increased soil potassium availability and promoted higher absorption of nutrients by plants, reaching 9.8 g kg^{-1} in leaves; i.e. 22.6% higher compared to the control treatment. The higher absorption of potassium was reflected on yield gain of 28.6% with 147.5 kg ha^{-1} of K_2O. Therefore, 130 kg ha^{-1} of K_2O is the most appropriate rate for the production of stalks of sugarcane grown in an Oxisol within the range evaluated. This rate kept potassium nutritional status very close to the adequate and promoted its accumulation in stalks at levels considered satisfactory to reach high yields in the first ratoon. Potassium fertilization had little effect in the technological quality.

Keywords: *Saccharum spp;* potassium nutrition; conservationist system; plant nutrition; potassium fertilization.
Abbreviations: K_potassium; DAS_days after sprouting; O.M._organic matter; CEC_cation exchange capacity; V_percentage of base saturation; SB_sum of bases; TRS_theoretical recoverable sugar; DM_dry matter.

Introduction

Energy consumption and global carbon emissions have increased worldwide, reinvigorating concerns about the polluting potential of fossil fuels (Martinelli and Filoso, 2008). Thus, energy demand is becoming a global concern and the production of alternative energy is a great challenge for researchers (Flores et al., 2013), as the continuing and rampant burning of oil, besides being finite, contributes to the greenhouse effect threatening the earth climate balance (Scarlat et al., 2011). Many countries are seeking energy alternatives to these fuels to reduce the dependence on oil and oil products (Monti et al., 2007), among them Brazil, where the production of ethanol from sugarcane receives primary attention, reaching 28 billion gallons in 2014 (Conab, 2014), taking sugarcane enormous socio-economic importance. This is very important because the energy to convert sugar into ethanol comes from milled sugarcane stalks (Baptista et al., 2014). Thus, as the burning of biomass only recycles CO_2 removed from the atmosphere by photosynthesis, everything indicates that in the end this will be one of the safest energy alternatives (Kalt and Kranzl, 2011). The expansion of sugarcane production in Brazil is strongly associated with high technology, such as mechanized harvest, since burning of straw left on the ground by traditional harvesting system is the causes of many environmental problems that led to changes enforced by new lows (Flores et al., 2014a). In Brazil and in the world, where rainfall is low and irregular in some regions, the incorporation of plant residues into the soil top layer increases soil organic matter (Mendonza et al., 2000), improves soil physical, chemical and biological characteristics (Canellas et al., 2003), extends crop longevity and boosts yields (Ball-Coelho et al., 1993). Still, increases water infiltration rate, prevents soil erosion (Flores et al., 2014b), and increases soil microbial activity. It is estimated that deposition of vegetable residues to the soil by mechanical cutting is in the range of 10 to 20 t ha^{-1} yr^{-1} of dry matter (Schultz et al., 2010), which promotes nutrients cycling, especially potassium (Hawkesford et al., 2012); around 56 kg ha^{-1} yr^{-1} of K (Oliveira et al., 1999). This is highly significant because tropical soils are naturally low in K exchangeable (below 1.5 mmol$_c$ dm^{-3}) (Benites et al., 2010), which contributes to shorten sugarcane crops longevity (Schultz et al., 2010). Potassium is the nutrient most extracted by sugarcane (Silva et al., 2007), especially by ratoon (Korndörfer and Oliveira, 2005) playing important metabolic functions such as tissue turgor regulation, enzyme activation, stomatal opening and closing and transport of carbohydrates, among others (Hawkesford et al., 2012); thus, potassium is essential to recover ratoon sugarcane yields (Weber et al., 2002). However, potassium is provided to ratoon via fertilizers in mineral form, especially potassium chloride or in organic form as vinasse in fertigation. This later form is applied in farms close to mills, where its use is economically viable (Korndörfer et al., 1999), while mineral fertilizers are used in areas far from the processing plant. Despite the importance of potassium for ratoon sugarcane, reports involving fertilization with this nutrient are few, especially in mechanized harvesting systems. Recent studies on potassium nutrition in ratoon sugarcane in mechanized harvesting systems reported high yield potential due to application of mineral K by potassium chloride (Flores et al., 2014a, b); however, further studies are necessary for results consistency and reliability. Therefore, the objective of this study was to evaluate the effect of K fertilizer on the vegetative growth, mineral nutrition, straw yield and technological quality of ratoon sugarcane grown in an Oxisol in a mechanized harvesting system.

Results and Discussion

Soil potassium content and initial plant growth

The potassium rates applied showed significant effects in the soil K exchangeable content in both depth layers (0-20 and 20-40 cm) at 180 and 360 DAS (Fig 1). The polynomial regression analysis showed similar performance for both layers (0-20 and 20-40 cm), with linear increases in the soil K exchangeable levels, reaching 1.30 mmol$_c$ dm^{-3} (Fig 1A), 0.67 mmol$_c$ dm^{-3} (Fig 1B) at 180 DAS, 1.46 mmol$_c$ dm^{-3} (Fig 1C) and 0.62 mmol$_c$ dm^{-3} (Fig 1D) at 360 DAS, respectively at the highest K fertilizer rate. Therefore, there was an increase of approximately 279, 78, 142 and 29% in the K exchangeable content in the 0-20 and 20-40 cm layers at DAS 180 and 360, respectively, at the K fertilizer highest rate. Fertilization did not affect the first ratoon initial growth (Table 1). Thus, growth variables showed average values of 2.2 m for plant height, 17 tillers per linear meter and 28 mm for tiller diameter at 120 DAS. Increase observed in the K exchangeable content at both depths were due to the effect of K fertilization, and possibly to the intense release of this nutrient from the straw. It is known that potassium remains almost entirely in ionic form within the plant tissue (Hawkesford et al., 2012); thus, potassium can easily leave the cell after the disruption of the plasma membrane, helping to supply this nutrient to the soil. Another explanation is that the low potassium percolation may have occurred due to the soil clayey texture and to the high soil cation exchange capacity (CEC), 99.1 mmol$_c$ dm^{-3} (Table 2). Soil CEC, which varies depending on the organic matter content, type and amount of clay and soil pH is the main component that determines the higher or lower ratio K exchangeable/K solution, as reported by Mielnickzuk (1982). I.e. there will be less potassium in the soil solution in high CEC soils for the same amount of total K, reflecting in reduced losses by leaching, less K unnecessary removal by the crop and higher K storage capacity. This explains the increase in the K exchangeable content in the soil top layer with K fertilizer applications, because the soil already had high CEC, and there was the contribution of organic matter increase and K saturation in the colloid exchange complex. Because the release of organic acids by straw affects the cation leaching order, allowing the accumulation of K exchangeable in the top layers, mainly due to increased leaching of divalent and/or trivalent cations (Ziglio et al., 1999). However, according to Werle et al. (2008), raises in soil K exchangeable levels can also favor leaching, even in clayey soils with high CEC; which explain the observed increment of this element, even in fewer amount, in relation to the top layer in the 20-40 cm depth layer. Another factor that may be associated with this increment in the influence of rainfall in the region in the months preceding the first evaluation, as shown in Fig 2, i.e. with 1,200 mm in the first 180 days after sprouting (DAS). K exchangeable levels in the soil corroborates results obtained by Flores et al. (2012 and 2014b), which also observed effects in potassium contents after K fertilizers application in an Oxisol. In another study by the same authors in 2012, the highest contents of K exchangeable in the soil reported were 1.8 and 1.2 mmol$_c$ dm^{-3} in the 0-20 and 20-40 cm layers at 180 DAS, respectively, also with 195 kg ha^{-1} of K_2O. These authors attributed this findings to the increase in K exchangeable from one crop season to the next due to the mineralization of vegetal residues (straw) left on the soil surface after mechanically harvesting the first ratoon, which added K to the soil through the application of this nutrient via fertilizer and by the soil organic matter mineralization process. It is important to point out that even with increases in the soil K exchangeable from K fertilization and organic matter mineralization in the first ratoon, K exchangeable levels in the soil were considered low (<1,5 mmol$_c$ dm^{-3}) by Raij and Cantarella (1997). The explanation for these low contents might be associated witch high rainfall in the region from August to January (Fig 2), which may have lowered the levels of this nutrient by leaching. It is believed that the absence of any effect on the growth variables in the first ratoon were due to the low levels of available K exchangeable in the soil, once even with the highest rates applied these levels remained below the critical level for the crop as suggested by Raij and Cantarella (1997). The reduced availability of potassium in the soil may be related to low rainfall in the early months of evaluation (Fig 2). According to Berding et al. (2005) hydric soil conditions in the rhizosphere region are very important for the emergence and growth of sugarcane tillers, because most of the potassium is transported to the roots surface via diffusion; a process highly dependent on the soil water content (Oliveira et al., 2004). Another relevant factor related to the lower nutrient extraction rate by the crop until the fifth month after regrowth is that the period of higher nutrient absorption occurs in the period of higher vegetative growth, between the fifth and the ninth months after regrowth, according to Coelho and Verlengia (1973). Tiller number and diameter data corroborate those obtained by Flores et al. (2012), which found no effect of K fertilizer in ratoon sugarcane grown in traditional cropping systems; they reported mean values of 29 for tiller per meter and 29 mm for tiller diameter. Similarly, in studies conducted in India in soils with sandy texture (13.3% and pH 7.4 in water), Shukla et al. (2009) did not observe any increase in tiller growth, tiller diameter and plant height with 66 kg ha-1 of K fertilizer applied to the soil, which had average values of 196.9 cm in height and 22.5 mm in tiller diameter. Similar results were obtained in the present study. However, in another study with ratoon sugarcane in a sandy soil (15.4% clay, pH 7.82 in water) in India, Singh et al. (2010) reported significant increases of 8.25 and 19.35% in tiller diameter and plant height, respectively, using 80 kg ha^{-1} of K_2O. Other studies conducted in Pakistan in sugarcane first cut also reported significant increases of 21.6 and 15% in plant height and tiller diameter at the rate of 200 kg ha^{-1} of K_2O (Akhtar and Akhtar, 2002). The increase in potassium content of cultivar RB 86-7515 grown in an Oxisol, probably occurred due to higher potassium supply via fertilizer, with subsequent increase of this nutrient in the root absorption region, enabling the crop to keep its nutritional potassium status near the range considered adequate, according to Raij and Cantarella (1997) (10-16 g kg^{-1}). However, since the

Table 1. Analysis of variance of ratoon sugarcane initial growth variables variebles cultivar RB 867515 with different levels of potassium. Pitangueiras, SP, Brazil, 2010.

Potassium rate (K_2O)	Plant height	Number of tillers m^{-1}	Tiller diameter
kg ha^{-1}	m		mm
0	2.2	17	28
32.5	2.2	17	28
65.0	2.2	16	28
130.0	2.2	17	28
195.0	2.3	18	28
F test	0.18^{ns}	0.60^{ns}	0.33^{ns}
C.V. (%)	5.0	10.7	3.3

^{ns} – not significant at the 5% level of probability by the F test.

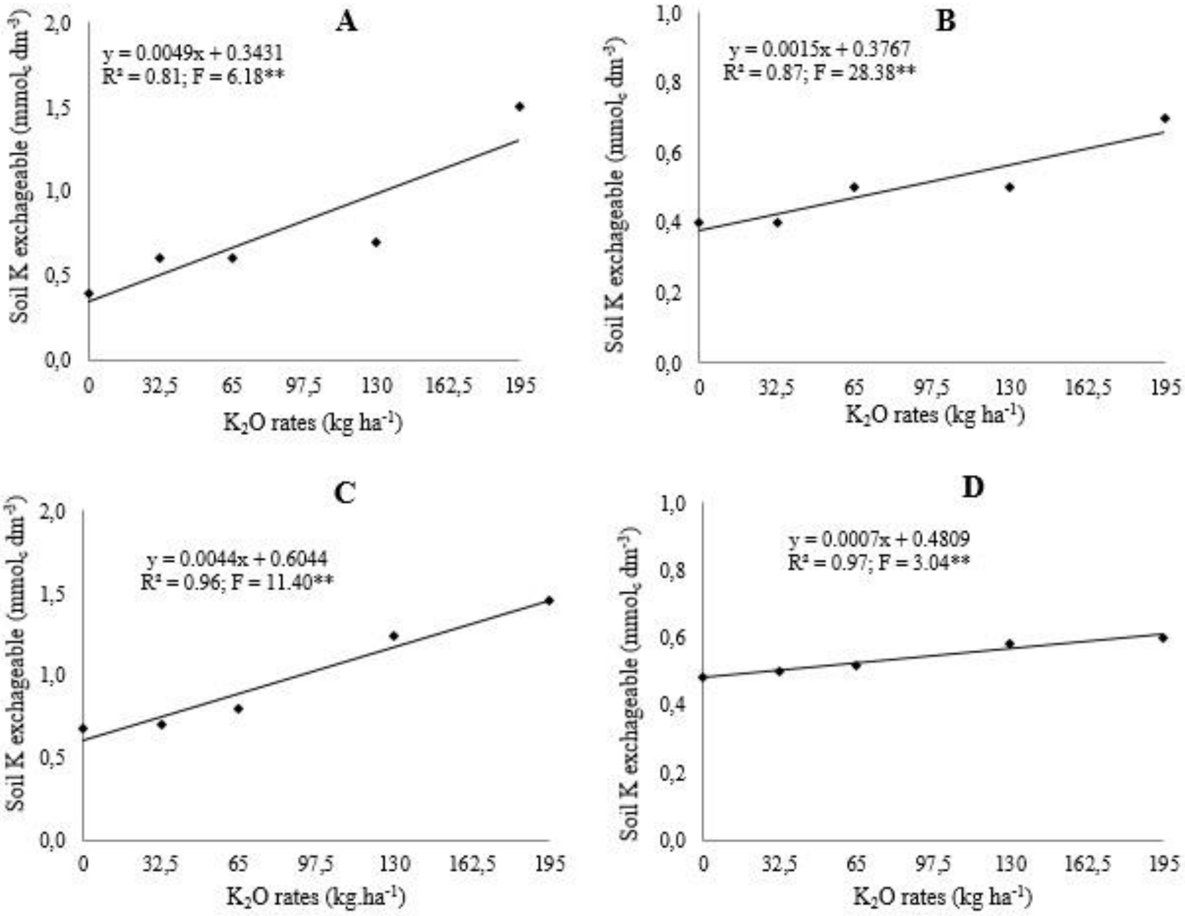

Fig 1. Effect of potassium applications on the soil K exchangeable content in the 0-20 (A) and 20-40 cm (B) layers at 180 DAS and at 360 DAS in the 0-20 (C) and 20- 40 cm (D) layers in the first ratoon sugarcane.
** - Significant at the 1% level of probability by the F test.

increment in K exchangeable in the soil was not significant, because in both treatments the contents of this nutrient in the soil were below the critical level for the crop (<1.5 $mmol_c$ dm^{-3}), there was no inhibitory potassium competition with other divalent cations such as calcium and magnesium (Hawkersford et al., 2012). According to Rossetto et al. (2004) high amounts of K fertilizer could promote leaching of Mg^{+2} and Ca^{+2} into the deeper soil layers, leaving them outside the roots absorption region due to the imbalance in the ratio of these nutrients; thereby reducing its leaves contents.

Plant nutritional status

The high precipitation that occurred from the fourth month of evaluation on (Fig 2) increased soil potassium availability favoring higher nutrient uptake, especially potassium, evidenced in Table 3. Where a linear increase in the K leaf content can be observed due to increases in the K fertilizer rates applied to the soil, which amounted to 9.81 g kg^{-1} at the highest rate (195 kg kg^{-1} of K_2O), or an increase of 22.6% in the K leaf content, compared to the initial amount found in the soil (7.7 g kg^{-1}) (Fig 3). In all treatments, K leaf levels were below the sufficiency range (10 to 16 g kg^{-1}) for the crop (Raij and Cantarella, 1997). Potassium applications did not affected others nutrients content significantly, which showed average levels of N = 17; P = 1.5; K = 9; Ca = 3.9; Mg = 1.4; S = 1.5 g kg^{-1} and B = 7; Cu = 5; Fe = 65; = 63 Mn and Zn = 16 mg kg^{-1}. It is important to point out that the variation of nutrients in the treatments was in relation to the K fertilizer rates and that the other nutrients were applied to the soil in equal amounts, following recommendations by

Table 2. Soil chemical attributes in the surface (0-20 cm) and subsurface (20-40 cm layers), five days after sugarcane plant cutting (2008/09) at Pitangueiras, SP, Brazil.

Depth (cm)	pH	OM	P	K	Ca	Mg	H+Al	SB[a]	T[b]	V[c]
	$CaCl_2$	g dm^{-3}	mg dm^{-3}	------------------------mmol$_c$ dm^{-3}--------------------						%
0-20	5.0	32	20	1.1	39	17	42	57.1	99.1	58
20-40	4.9	26	22	0.6	40	13	42	53.6	95.6	56

[a] Sum of bases; [b] Cation exchange capacityat at pH 7.0; [c] Percentage of base saturation.

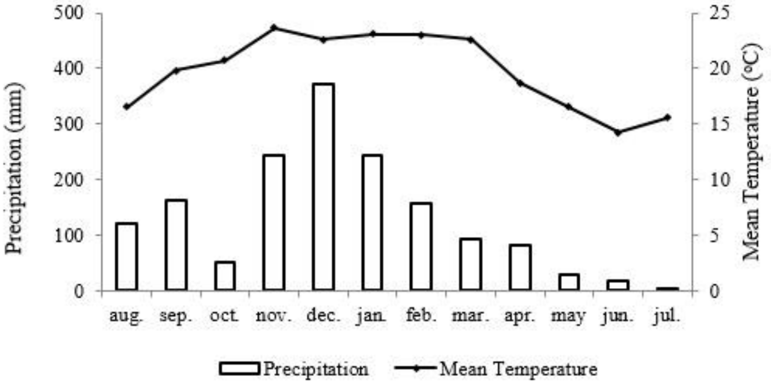

Fig 2. Precipitation and temperature during the experimental period at Pitangueiras, SP, Brazil.

Table 3. Analysis of variance of macro and micronutrients in the leaf +1 in ratoon sugarcane cultivar RB 867515 with different levels of potassium at Pitangueiras, SP, Brazil, 2010.

Potassium rate (K_2O)	N	P	K	Ca	Mg	S
kg ha^{-1}		———————— g kg^{-1} ————————				
0	17	1.5	8	4.2	1.4	1.5
32.5	17	1.6	8	3.9	1.3	1.4
65	18	1.6	8	3.7	1.3	1.5
130	17	1.5	9	3.6	1.4	1.5
195	17	1.5	10	4.3	1.5	1.5
F test	1.53^{ns}	0.58^{ns}	12.48**	2.65^{ns}	1.20^{ns}	0.49^{ns}
C.V. (%)	5.6	4.9	9.9	9.6	10.8	5.0

Potassium rate (K_2O)	B	Cu	Fe	Mn	Zn
kg ha^{-1}		———————— mg kg^{-1} ————————			
0	7	5	66	60	16
32.5	7	6	64	64	17
65	7	5	62	66	17
130	6	5	66	60	16
195	7	5	66	67	16
F test	1.25^{ns}	1.43^{ns}	0.22^{ns}	0.65^{ns}	1.74^{ns}
C.V. (%)	10.9	11.4	11.5	16.1	19.55

** and ^{ns} – significant at the 1% level and not significant at the 5% level of probability, respectively, by F test.

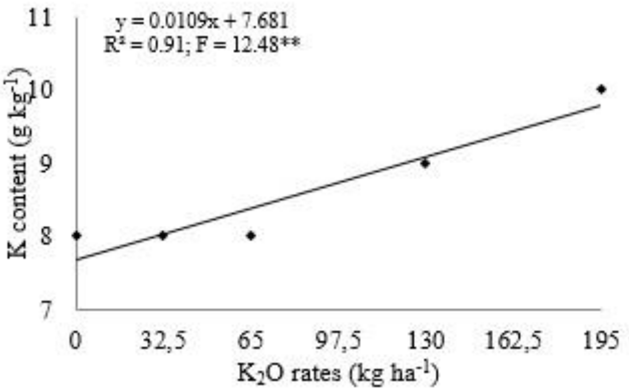

Fig 3. K content in the leaf +1, at 240 DAS, as a function of K_2O rates applied to an Oxisol, Pitangueiras, SP, Brazil, 2010.
** - significant at the 1% level of probability by the F test.

Spironello et al. (1997). Also, the lowest increase in K exchangeable in the soil was not raised with the fertilizer rates applied because the levels of the nutrient did not exceed the critical level indicated for the crop (<1.5 mmol$_c$ dm^{-3}), reducing the effect of the inhibiting competition of this nutrient with other divalent cations, such as calcium and magnesium (Hawkersford et al., 2012). Which explains the lack of effect in this nutrient contents by applying K fertilizer to the soil. Added to this the fact that increased K fertilizer rates could favor Mg^{+2} and Ca^{+2} leaching into the deeper layers of the soil, leaving them outside the roots absorption region due to the imbalance in the relationship between these nutrients (Rossetto et al., 2004), helping to reduce their leaf content in the crop. Only the average levels of macronutrients N (17) g kg^{-1}, K (9) g kg^{-1} and Cu (5) mg kg^{-1} presented similar values compared to the lower limit of the sufficiency range considered adequate (N 18-25; K 10-16 g kg^{-1} and Cu 6-15 mg kg^{-1}) (Raij and Cantarella, 1997). However, B content (7 mg kg^{-1}) was below the range considered adequate by the same authors (10-30 mg kg^{-1}). Levels of other nutrients in the soil were within those considered appropriate for the crop (Table 3). Still, it is pertinent to point out that nutritional deficiency symptoms were not observed in the first ratoon. Results by Flores et al. (2014a, b) corroborate those obtained in the present study, once these authors also observed significant increases in the foliar levels of potassium at 240 DAS in a ratoon sugarcane cropped in conservationist systems. Whereas Flores et al. (2014a) obtained 13.6 and 9.1 g kg^{-1} in the first and second ratoons, and Flores et al. (2014b) obtained 11.8 and 9.7 g kg^{-1} in the first and second ratoons, respectively. Differences among levels of nutrients found in this study and in the literature are possibly related to environmental conditions and cultivars with different yields, i.e., areas of high yield potential can dilute the nutrients in the tissues. The dilution effect decreases the concentration of nutrients in the plant tissue with plant growth (Jarrell and Beverly, 1981). This fact was evidenced in a study by Flores et al. (2014b) where the yield of stalks from the first ratoon reached 77 t ha^{-1} at the rate of 195 kg ha^{-1} of K_2O and the stalk K content reached 13.6 g kg^{-1} at 240 DAS while the second ratoon yielded 92 t ha^{-1} at the rate of 195 kg ha^{-1} of K_2O and the stalk potassium content reached 9.1 g kg^{-1} at 240 DAS. Similarly, in another study by Flores et al. (2014a) the production of stalks reached 87 t ha^{-1} at the rate of 195 kg ha^{-1} of K_2O in the first ratoon and the K content reached 111.8 g kg^{-1}, at 240 DAS, while the second ratoon yielded 132.9 t ha^{-1} at the rate of 195 kg ha^{-1} of K_2O and the stalk potassium content reached 9.7 g kg^{-1} at 240 DAS.

K accumulation in leaves stalks and canopy

The application of K fertilizer to the soil affected this nutrient pileup in stalks (Fig 4A), leaves (Fig 4B) and canopy (Fig 4C) in the first ratoon at 360 DAS.

However, it is important to point out that there was a significant linear adjustment, wherein the accumulation of potassium reached 142 kg ha^{-1} in stalks, 112 kg ha^{-1} in leaves and 254 kg ha^{-1} at the highest rate of K fertilizer applied, with increases of 111, 95 and 103% in stalks, leaves and canopy, respectively. It is also important to point out that for potassium accumulation determinations in the plant the content of potassium at 360 DAS was 4-6 and 2-3 g kg^{-1} in leaves and stalks, respectively. Increases in leaves, stalks and canopy were due to the high yield of stalks obtained in the first ratoon. Potassium, for not having a structural function (Marschner, 1995), but present in plants in ionic form and having its translocation from roots to reserve organs favored, plays an important role in sugarcane production, especially in ratoon. Thus, potassium is of major importance to increase sugarcane stalk yield and plays important roles in several physiological and metabolic processes such as photosynthesis, osmoregulation, translocation of nutrients, nitrogen uptake, and synthesis of protein and starch (Hawkesford et al., 2012). Also, increases in potassium accumulation in leaves and stalks may be linked to the crop ability to absorb large amounts of nutrients, especially when provided in excess (luxury consumption) since potassium is the nutrient most extracted by sugarcane (Silva et al., 2007), especially in ratoon (Korndörfer and Oliveira, 2005).

The export of potassium in ratoon sugarcane to achieve yields between 60 and 120 t ha^{-1} is 1.10 kg t^{-1} according to Raij and Cantarella (1997). Therefore, in this study there was an export of 0.98 kg t^{-1}, considering the maximum yield of 127.2 t ha^{-1} achieved at the rate of 147.5 kg ha^{-1} of K_2O, i.e., an export similar to that recommended by the literature. Flores et al. (2014a, b) obtained similar results for potassium accumulation in leaves, stalks and canopy. Results obtained by Flores et al. (2014b) showed significant increases in potassium accumulation with K fertilizer supply, being 106.8 and 156.6% for storage in stalks, 61.3 and 114.6% for accumulation in leaves and 79.6 and 128.3% for accumulation in the canopy, in the first and second ratoons, respectively. However, results obtained by Flores et al. (2014a) showed significant increases in this nutrient accumulation: 37.6, 196.9% for storage in stalks, 61.4, 80.7% for the accumulation in leaves and 52.7, and 129.3% for the accumulation in the canopy in the first and second ratoons, respectively.

Yield

K fertilization increased stalk production in the first ratoon, promoting an increment of 127.2 t ha^{-1} at the rate of 147.5 kg ha^{-1} of K_2O with quadratic adjustment (Fig 5); i.e., an increase of 28.6% in stalk production, compared to the control treatment. The effect of K fertilizer rates on the yield could be due to the low K exchangeable level in the soil top layer before the experiment installation. These potassium amounts below the critical level for the crop are limiting to increase ratoon sugarcane yields, because the critical level to achieve 90% of maximum yield is 1.5 mmol$_c$ dm^{-3} (Raij and Cantarella, 1997). In addition, according to Orlando Filho et al. (1993) the involvement of potassium in the soil sorption complex is critical to provide high yields in ratoon sugarcane. In this study, in the absence of K fertilization these authors rated the involvement of this nutrient in the sorption complex low because the saturation of the element in the CEC was 1.1%.

The performance of the first ratoon stalk production was due to significant increases with quadratic adjustments supported by various reports. Rossetto et al. (2004) evaluated the effect of liming and potassium fertilization in the yield of ratoon sugarcane and observed significant increases with linear adjustments in six out of seven experiments, using the largest K fertilizer rate (200 kg ha^{-1} of K_2O). Yet, Otto et al. (2010) evaluated ratoon sugarcane yields by applying the total amount of K fertilizer at the same time and in split applications. The same authors found increases in yield with quadratic adjustments, corroborating those obtained in the present study, in both forms of application, which reached 162.4 and 160.9 t ha^{-1} with 130 and 150 kg ha^{-1} of K_2O, respectively. Shukla et al. (2009) found the rate of 66 kg ha^{-1} of K_2O responsible for the increase of 74 t ha^{-1} in the produ-

Table 4. Effect of potassium on broth technological quality at 360 DAS in the first ratoon.

Potassium rate (K_2O)	Purity	PC	Pol	AR	Fiber	Brix	ATR
kg ha^{-1}	-----------------------	--% sugarcane --	---------------------				kg t^{-1}
0	91	17	20	0.4	12	22	168
32.5	91	17	20	0.5	12	22	165
65	91	17	20	0.5	12	22	167
130	89	16	19	0.5	11	21	160
195	91	17	20	0.5	12	22	168
F test	2.02^{ns}	2.61^{ns}	2.84^{ns}	2.48^{ns}	1.66^{ns}	2.68^{ns}	5.13*
C.V. (%)	1.3	3.1	3.4	7.3	1.1	2.6	2.8

^{ns} – not significant at the 5% level of probability by F test. * - significant at the 5% level of probability by the F test.

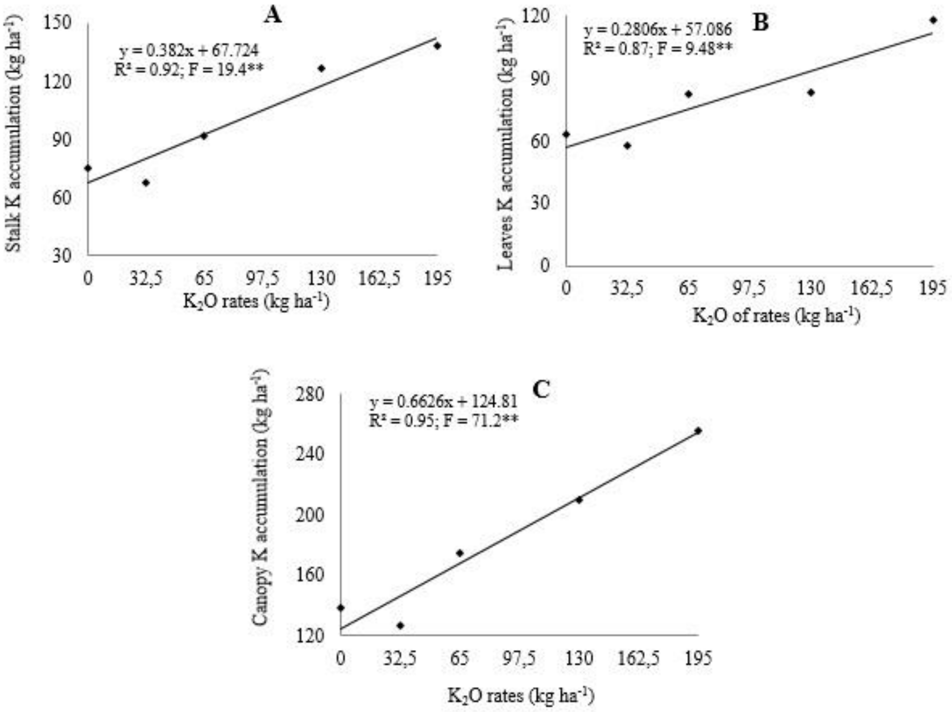

Fig 4. K accumulation in the stalk (A), leaves (B) and canopy (C) at 360 DAS as a function of K_2O rates applied in an Oxisol. Pitangueiras, SP, Brazil, 2010. ** - significant at the 1% level of probability by the F test.

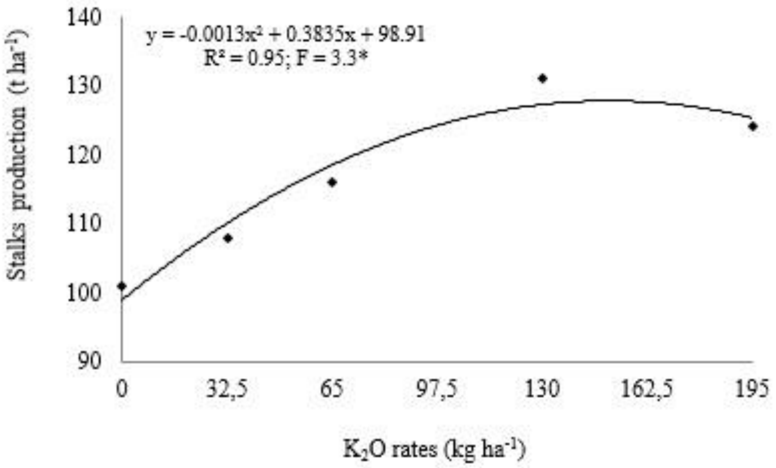

Fig 5. Stalks production at 360 DAS as a function of K_2O rates applied in an Oxisol, Pitangueiras, SP, Brazil, 2010.
* - significant at the 5% level of probability by the F test.

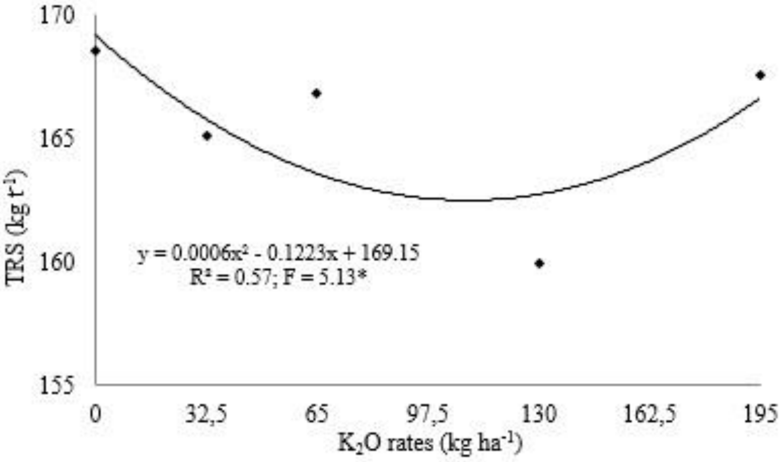

Fig 6. TRS as a function of K_2O rates applied in an Oxisol. Pitangueiras, SP, Brazil, 2010. * - significant at the 5% level of probability by the F test.

ction of ratoon sugarcane, while Kumar et al. (2007) obtained higher yields (88 t ha^{-1}) using 40 kg ha^{-1} of K_2O in a similar study with ratoon sugarcane grown in a clayey loam soil. The high stalks yield obtained in this mechanized cutting system experiment (127.2 t ha^{-1}), was achieved with 147.5 kg ha^{-1} of K_2O, without reducing the rate of fertilizer recommended by the literature in conventional farming systems (130 kg ha^{-1} of K_2O), i.e. with previous straw removal by fire before cutting. However, the achieved yield was 30 t ha-1 higher in the average, compared to the expected yield at the recommended rate for conventional sugarcane cropping, corroborating the favorable effect of the straw left on the soil after the mechanical harvest and the effect of potassium in nutrition and yield of ratoon sugarcane cropped in a conservationist system.

Technological quality

Potassium affected TRS (F = 5.13*) and juice content at 360 DAS (Table 4). There was a small and significant reduction in the juice content of TRS with potassium fertilization, with quadratic adjustment. This decrease was only 3.7% compared to the initial content, reaching 162.9 kg t^{-1} with 101.9 kg ha^{-1} of K_2O (Fig 6). However, there was no effect of potassium application for the other variables, which showed average levels of 90.6; 17; 20; 0.5; 12 and 22% for PC, Pol, Ar, Fiber and Brix contents, respectively. Therefore, the technological variables average results are consistent with those found by Ripoli and Ripoli (2009). Several study reports show the lack of effect on the technological quality of sugarcane straws as a function of K fertilizer applications (Uchôa et al., 2009), but, conversely, other studies support the positive effect of this nutrient supply (Otto et al., 2010). In the literature, there are indications that factors such as climate, cultivar and soil management affect the amount of accumulated sugar in sugarcane stalks, making it difficult to evaluate the fertilizer effect on this parameter (Pereira et al., 1995). Therefore, the effects of potassium on quality are contradictory because genetics, soil and climate conditions are distinct among the experiments. In general, the increase in the supply of potassium to the soil is more important to stalk production than to the technological quality of ratoon sugarcane, fact also reported by Feltrin et al. (2010).

Materials and Methods

Location and climate

The experiment was carried out in the county of Pitangueiras, state of São Paulo, Brazil from August 2009 to July 2010 in an area provided by Pitangueiras Sugar and Alcohol mill with the following coordinates: latitude 178°59'42" E, longitude 89°59'58" S, at 513 m altitude. According to Köppen, the climate is Aw tropical rainy with dry winters and the coldest months averaging temperatures above 18°C. The driest month has less than 60 mm rainfall and the rainy season delays for the fall. Weather data is shown in Fig 2.

Soil classification and chemical properties

The soil was classified as Oxisol, (USDA, 2006), with low natural potassium content (less than 1.5 $mmol_c$ dm^{-3}). Before treatments application to the first ratoon, 15 soil subsamples were collected in the control plots at 0-20 and 20-40 cm depths and the composite sample used for soil fertility assessment (Raij et al., 2001) (Table 1). In the same period, the straw biomass (vegetal covering left on the ground after the mechanical harvest) was quantified from samples collected in four spots randomly chosen in one square meter area. Subsequently, samples were analyzed to determine the levels of macronutrients (Bataglia et al., 1983). The straw from the top layer produced 11.3 t ha^{-1} of dry matter with 17% moisture. The chemical analysis results were N = 3.9; P = 0.1; K = 0.4; Ca = 1.9; Mg = 0.2; and S = 0.1 g kg^{-1}.

Experimental design

The experimental design was a randomized block with five treatments and five replicates. Each plot consisted of five 10 m rows spaced by 1.5 m, totaling 75 m^2 and the three central rows used as sampling area leaving two meters in each side as border.Treatments consisted of five rates of potassium using 130 kg ha^{-1} of K_2O as recommended for the State of São Paulo as reference for an expected production of stalks between 80 and 100 t ha^{-1} (Spironello et al., 1997). The rates of 0 (control); 32.5; 65; 130 and 195 kg ha^{-1} of K_2O corresponded to 0%, 25%, 50%, 100% and 150% of the reference rate (130 kg ha^{-1} of K_2O), respectively.

Plant traits and plant materials

In the 2008/09 previous cropping season, before the implementation of the experiment, the first phase of soil tillage for growing sugarcane in a conventional cropping system was performed by plowing, harrowing and 30 cm deep furrowing, followed by base fertilization recommended by Spironello et al. (1997). Stalk production in this season reached 103 t ha^{-1} and the mechanized harvest performed in August 2009. Thus, evaluations carried out for the first ratoon were in a conservationist management system (no-till); i.e., balanced fertilization, use of alternative inputs and deposition of sugarcane residues on the ground without previous removal of straw by fire to facilitate cutting.

The cultivar tested was RB 86-7515 characterized by having fast growth, high yield, and drought tolerant with good ratoon sprouting (even in mechanized harvesting systems); it also has high sucrose content and is resistant to most diseases (rust, scald and mosaic) besides being little demanding.

Potassium chloride (60% K_2O) was used as potassium source, side dressed without incorporating, as suggested by Spironello et al. (1997). The source of nitrogen was urea (100 kg ha^{-1}), as suggested by the same authors and phosphorus was not applied. Weed control was not necessary because the straw left on the soil surface prevented weed growth.

Plant growth and potassium content in the soil

Growth evaluations were performed at 120 DAS, recording the number of tillers in 1.5 m row at three sites at random in each plot. At the same time, evaluations of stalk diameter (up to the first internode) were performed using a digital caliper and plant height evaluated measuring the distance from the ground to the fully visible atrium of the first leaf from top to bottom (leaf +1, i.e., the first leaf with a fully developed and visible sheath) in ten plants per plot. Soil samples were collected at 180 and 360 DAS in the row side (fertilization range) from 0 to 20 and 20 to 40 cm depths in 10 random spots in three sampling rows in each plot and soil exchangeable potassium contents determinations performed following methodology described by Raij et al. (2001).

Analysis of stalks nutritional status

To assess the nutritional status of the plants in full development at 240 DAS, the middle third of 15 leaves +1 were collected discarding the middle rib (Raij et al., 2001), decontamination, dried at 65°C until constant mass was attained and ground in a Willey mill type. Macro and micronutrients in plant tissue determinations followed the methods described by Bataglia et al. (1983).

Stalk production and technological quality evaluation

Plants were harvested at 360 DAS in a three-square meter sampling area in two random spots in each plot, and stalks separated from straws and weighed to calculate the average yield per hectare. In addition, ten contiguous stalks were collected from the center rows in each plot to evaluate the technological quality (total soluble solids - °Brix, industrial fiber; apparent sucrose - %juice Pol; juice purity; cane Pol% - PC and reducing sugars - AR) following methodology described by Consecana (2006).

TRS - Theoretical recoverable sugar was obtained from the equation:

TRS (kg of sugar per ton of stalk milled) = (10 x 0.905 x 1.0526 x PC%) + (10 x 0.905 x AR%).

Where, the value of 0.905 corresponds to 9.5% losses from the industrial process, excluding fermentation and distillation, and the 1.0526 value corresponds to the stoichiometric conversion factor of sucrose in reducing sugars (Consecana, 2006).

Potassium accumulation in leaves, stalks and canopy

Dry matter accumulation in leaves and stalks was recorded at harvest. One 400 g subsample was collected from each sample in each plot, dried at 65° C for 72 hours and ground in a Willey mill. Afterward the potassium content in stalks and leaves was determined following methods described by Bataglia et al. (1983). Potassium accumulation in leaves, stalks and canopy (leaves + stalks) was calculated by the following formulas:

$\text{Ac } K_{(leaf)} = \text{Ac } DM_{(leaf)}\ (\text{kg ha}^{-1}) \times \text{content of } K_{(leaf)}\ (\text{kg kg}^{-1})$

$\text{Ac } K_{(stalk)} = \text{Ac } DM_{(stalk)}\ (\text{kg ha}^{-1}) \times \text{content of } K_{(stalk)}\ (\text{kg kg}^{-1})$

Wherein Ac refers to accumulation and DM to dry matter content. Potassium accumulation in the canopy was calculated adding up potassium contents in leaves and stalks

Statistical analysis

Results were subjected to the analysis of variance by the F-test. When significant by this test, linear and quadratic polynomial regressions were conducted taking into account highest coefficients of determination (R^2) using the software AgroEstat (Barbosa and Maldonato Júnior, 2012).

Conclusions

The application of potassium into the soil promoted increases in K exchangeable levels in 279 and 78% in the surface layer (0-20 cm) and in sub-surface (20-40 cm) layers, respectively, in the first 180 days after sugarcane ratoon sprouting. The increased availability of potassium in the soil with the application of potassium chloride increased the absorption of this element by the plants, reflecting in stalk yield gains. The rate of 130 kg ha^{-1} of K_2O is the most appropriate for the production of stalks of sugarcane grown in an Oxisol within the range evaluated. This rate kept the potassium nutritional status very close to the adequate in the first ratoon, enabling the accumulation of potassium in the stalks at satisfactory levels to achieve high yields. The supply of potassium to the soil had little effect on the technological quality.

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