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POTASSIUM NUTRITION IN RATOON SUGARCANE UNDER A CONSERVATION CROPPING SYSTEM

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ABSTRACT

Ratoon sugarcane response to potassium is dependent on the environmental conditions of the region. Cropping systems that do not burn crop biomass after harvest leave crop residues on the soil, affecting the soil-plant nutrient dynamics system and fertilizer requirements. The objective of this study was to evaluate the effect of potassium fertilization of first and second ratoon sugarcane crops on potassium contents in the soil, in the plant, and yield and quality of stalksin an Oxisol under a conservation cropping system. The following potassium rates were tested: 0, 27, 54, 108, and 162 kg K ha^{-1}, arranged in a randomized block design with five replicates. The application of potassium increased soil nutrient concentrations at six months, reaching 2.87 and 2.61 mmol$_c$ dm^{-3} with the highest rate in the first and second ratoons, respectively. The increase in available exchangeable-K content in the soil favored a greater plant uptake of this nutrient, reaching 12.1 and 10.0 g kg^{-1} in the first and second ratoons, respectively. The increase in potassium absorption by plants was reflected in the production of stems; the highest yields (87.0 and 132.9 t ha^{-1}) were obtained with the application of 162 kg K ha^{-1} in the first and second ratoons, respectively.

Key words. Plant nutrition, straw covering, Oxisol.

NUTRICIÓN POTÁSICA EN SOCA DE CAÑA DE AZÚCAR EN UN SISTEMA DE MANEJO CONSERVACIONISTA

RESUMEN

La respuesta en la aplicación de potasio en caña soca depende de las condiciones ambientales de la zona de cultivo. El sistema de cosecha de la caña de azúcar sin eliminación por la quema de paja deja residuos en el suelo que pueden alterar la dinámica de nutrientes en el sistema suelo-planta y la necesidad de fertilización. El objetivo del trabajo fue evaluar el efecto de la fertilización potásica en la primera y segunda soca de caña de azúcar sobre los niveles de potasio en el suelo y la planta, la producción y la calidad tecnológica de los tallos. bajo un sistema de manejo conservacionista sin quema de la paja. Los tratamientos consistieron en dosis de potasio: 0, 27, 54, 108 y 162 kg K ha^{-1} dispuestos en un diseño experimental de bloques al azar con cinco réplicas. Los trabajos se llevaron a cabo en el segundo ciclo de la caña de azúcar en un Hapludox típico de textura media. La aplicación de potasio en el suelo aumentó la concentración de K en el suelo a los seis meses, alcanzando 2,87 y 2,61 mmol$_c$ dm^{-3} con la mayor dosis en la primera y segunda soca, respectivamente. El aumento en el contenido disponible de K-intercambiable del suelo promovió el aumento de la absorción de este nutriente por las plantas, promediando 12,1 y 10,0 g kg^{-1} en la primera y segunda soca, respectivamente. El aumento en la absorción de potasio por la planta se vio reflejado en la producción de tallos, con una mayor producción (87,0 y 132,9 t ha^{-1}) con el uso de la dosis más alta de 162 kg K ha^{-1} en la primera y segunda soca de caña de azúcar, respectivamente.

Palabras clave. Nutrición de plantas, caña sin despaja a fuego, Latossol.

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INTRODUCTION

The major expansion of Brazilian sugar and ethanol markets and the incorporation of new cropping areas have driven studies on sugarcane production systems, particularly ratoon crops grown under conservation systems, *i.e.,* rational use of fertilizers and the use of alternative inputs and, especially, the maintenance of previous crop residual biomass on the soil. Mechanical harvesting leaves 10 to 20 tons of sugarcane residues (dry matter) ha^{-1} $year^{1}$ on the soil surface (Schultz *et al.,* 2010). This material enables recycling some nutrients such as potassium. An average of 56 kg ha^{-1} $year^{-1}$ of this element is added to the soil by sugarcane residues left on the soil surface (Oliveira *et al.,* 1999). The straw increases soil organic matter content (Mendonza *et al.,* 2000), improves its physical, chemical, and biological properties (Canellas *et al.,* 2003) and also, improves sugarcane yields (Ball-Coelho *et al.,* 1993).

Tropical soils are usually poor in exchangeable K contents (Benites *et al.,* 2010). Therefore, the potential modifications in the agroecosystem resulting from harvesting of non-previously burned sugarcane plants may require reformulations of fertilization management of ratoon crops, especially as to potassium, since this is the most demanded element by ratoon plants (Korndörfer & Oliveira, 2005).

In addition to that, low levels of potassium may shorten the plant cycle (Schultz *et al.,* 2010) besides being considered an essential element for ratoon crops yield recovery (Weber *et al.,* 2002). Notwithstanding its importance for sugarcane ratoon crops, research reports concerning this nutrient are restricted to plant stalk or ratoon crops in which the plants are burned before harvesting.

The objective of this study was to assess the effect of potassium on the soil chemical characteristics, on potassium buildup and on stalks production in the first and second sugarcane ratoons in an Oxisol under a conservation system.

MATERIAL AND METHODS

The first ratoon was installed in the first week of April 2010 with cutting performed in the last week of March 2011, and the second installed in the first week of July 2011 with cutting taking place in the last week of June 2012. Figure 1 shows the climatic data recorded throughout the period of study in the county of Assis-SP.

The experiment was carried out in the Lagoa Rica farm in the county of Assis, a private farm, (latitude 89° 59' 58'' S and longitude of 178° 59' 42'' W). The cultivar used was 'CTC 07', a high ratoon yielding cultivar, with median demand for soil natural fertilizers, resistant to rust. The soil is a typical dystrophic red-yellow latosol (Oxisol), of median texture (Embrapa, 2006).

Before installing the experiment, 15 soil subsamples were collected from each area to obtain a composite sample. Samples were drawn from 0-20 and 20-40cm- depth soil layers to perform chemical analyses to evaluate fertility levels. The analyses were conducted according to procedures described by Raij *et al.* (2001). Results were: pH: 5.5 and 4.8, OM: 12 and 10 g dm^{-3}, P: 56 and 41 mg dm^{-3}, K: 1.1 and 0.4 $mmol_c$ dm^{-3}, Ca: 25 and 16 $mmol_c$ dm^{-3}, Mg: 10 and 4 $mmol_c$ dm^{-3}, H+Al: 18 and 25 $mmol_c$ dm^{-3}, BS: 36 and 20 $mmol_c$ dm^{-3}, T: 54 and 45.4 $mmol_c$ dm^{-3}, V: 67 and 45%, respectively.

Samples were also collected from the crop residue layer covering the soil in both areas to assess the total amount of nutrients immobilized in that biomass. Samples were taken from three-1-m^2 randomly chosen areas and analyzed for nutrients following the procedures described by Bataglia *et al.* (1983). The dry matter weight recorded from the straw layer covering the first ratoon was 18.7 t ha^{-1}, and 19.3 t ha^{-1} the second. The results of the chemical analyses of the first and second ratoons were the following: N=5.4 and 9.7, P=1.9 and 0.7, K=4.1 and 0.7, Ca=3.2 and 4.7, Mg=1.1 and 1.8, S=5.2 and 1.1 g kg^{-1} and Cu=2.5 and 11, Fe=317 and 4113, Mn=40.5 and 133, Zn=6.5 and 28, B=5.7 and 14 mg kg^{-1}, respectively.

In both ratoons, treatments were arranged in a randomized complete block design with five treatments and five repetitions. The potassium fertilizer rate was based on values recommended for the state of Sao Paulo sugarcane cropping systems, bearing in mind yields between 80 and 100 t ha^{-1}, and that the recommended rate was 108 kg K ha^{-1}. Therefore, the potassium fertilizer rates used in the experiment were 0, 27, 54, 108, and 162 kg K ha^{-1}, corresponding to 0, 25, 50, 100, and 150% of the reference rate, that is, 108 kg K ha^{-1}. These rates were side-dressed in the rows, without incorporating, as suggested by Spironello *et al.* (1997). The other nutrients (phosphorus and nitrogen) were also applied according to Spironello *et al.* (1997). Thus, in both ratoons, 100 kg N ha^{-1} were applied.

In both experiments, each plot included five 10-m rows with 1.5 m –spacing between rows. Data was recorded from the three central rows.

In both experiments, soil samples were drawn from 10 randomly chosen points next to the three central rows of each plot at 0-20 cm depths, six months after the ratoon plants had begun sprouting. Soil exchangeable potassium was determined according to procedures suggested by Raij *et al.* (2001).

To determine the nutritional status of plants, leaf+1 (the first leaf from the top down showing the collard or sheath) samples were taken 8 months after plants had begun prouting. The center rib of each leaf was removed, according to instructions by Raij & Cantarella (1997). After sampling, leaves were washed, dried and ground. The chemical procedures to determine the nutrient levels in plants tissue followed the methodology proposed by Bataglia *et al.* (1983).

In both ratoons, twelve months after the ratoon plants had started to sprout, a harvest took place to determine the number of millable stalks and calculate the total production of stalks.Ten adjacent stalks were cut from the three central rows of each plot to determine the sugarcane technological quality (juice pol, sugarcane pol, total retrievable sugar, reducing sugars, fiber, brix, and purity) according to procedures described by Consecana (2006).

In both ratoons, the potassium accumulated in the aerial plant part, twelve months after plants had started to sprout, was determined in leaves and stalks separately. After weighing the fresh biomass, 400 g of each fraction were dried in an oven at 65 °C until constant weight was reached. Following that, the potassium content of the plant tissue was determined according to procedures described by Bataglia *et al.* (1983). In addition, the straw covering the soil at harvest was evaluated as total dry mass, potassium content and accumulated potassium.

Data was submitted to the analysis of variance and to an F test. The polynomial regression analysis of all data was performed using the statistical program AgroEstat (Barbosa & Maldonado, 2012).

RESULTS AND DISCUSSION

The rates of potassium fertilizer increased the exchangeable potassium contents at depths between 0 and 20 cm as observed in soil samples taken in both ratoons six months after the ratoon plants started sprouting. Exchangeable potassium levels in the first and second ratoons reached values of 2.87 and 2.61 $mmol_c$ dm^{-3}, respectively, when the highest rate of potassium fertilizer (162 kg K ha^{-1}) was used, as shown in Figure 2a.

These results were expected since nutrient rates applied and nutrients losses by lixiviation were small due to low precipitation in the region in the first months of evaluation, both in the first and second ratoons (Fig. 1). Similar results were reported by several investigators (Mendonza *et al.*, 2000; Sampaio *et al.,* 1991; Silva, 2010; Flores *et al.,* 2012; Pancelli, 2011), which reported that the application of potassium resulted in linear increments of potassium in the soil. According to Coelho & Verlengia (1973), approximately 50% of the total K absorbed during the vegetative phase of the plant is absorbed when the plants are between 5 and 9 months of age with a strong influence by the amount of rainfall (Fig. 1) and the soil conditions.

The application of potassium fertilizer had a significant effect on the soil K content at depths between 20 and 40 cm, with a quadratic adjustment in the first ratoon, and a linear adjustment in the second one, reaching 1.41 and 1.74 $mmol_c$ dm^{-3} with the application of 108.7 and 162 kg K ha^{-1}, respectively (Figure 2b). The increment in K levels in the sub-superficial soil layers resulting from the application of K rates in the soil may have been the consequence o a high percolation of this element in the soil profile as influenced by the sandy texture and low CEC (54 and 45.4 $mmol_c$ dm^{-3}). Even with low precipitation in the first six months of evaluation of the first ratoon (Figure 1), the amount of rainfall was sufficient for percolating K in the soil, since according to Mielniczuk (1982), soil CEC varies with soil organic matter content, with the amount and type of clays, and soil pH is the main component determining the higher or lower exchangeable K/solution K ratios, that is: for the same amount of total K, the higher the CEC, the lower the K in the soil solution. This will reduce K losses by lixiviation and lower unnecessary absorption of K by the plants while it will promotea higher storage capacity of K in the soil. Werle *et al.* (2008) state that increasing the levels of K in the soil favors lixiviation even in argillic soils with high CEC values.

Potassium fertilizer affected the K content in the leaf +1 in both ratoons, linearly increasing the K content, reaching 12.1 and 10.0 g $kg^{-1}$with the rate of 162 kg K $ha^{-1}$for the first and second ratoon, respectively (Figure 3). Similar results were reported by Espironello *et al.* (1986) which observed increments in K in leaf +3 and by Silva (2010) and Pancelli (2011) in leaf +1.

Potassium fertilization in the first and second ratoons did not affect nutrient levels other than K. In the first ratoon, nutrient levels found in leaves for N, P, Ca, Mg, S, B, Cu, Fe, Mn, and Zn were 17.6, 1.9, 3.7, 1.6, 2.6 g kg^{-1}, 7, 5, 110, 31 and 20 mg kg^{-1}, respectively (Table 1). According to Raij (2011), the values found for N, B, Cu, and Zn are low – the adequate levels of these nutrients being between 18 – 25 g kg^{-1}, 10 – 30 mg kg^{-1}, 6 – 16 mg kg^{-1}, and 25 – 100 mg kg^{-1} respectively, whereas the values found for the other nutrients were considered adequate.

In the second ratoon, the average contents of nutrients in the leaves for N, P, Ca, Mg, S, B, Cu, Fe, Mn, and Zn were of 19.1, 2.2, 2.1, 1.3, 1.2 g kg^{-1}, 13, 9, 50, 26 and 37 mg kg^{-1}, respectively (Table 1). The plant tissue S values were considered low according to Raij (2011), who determined

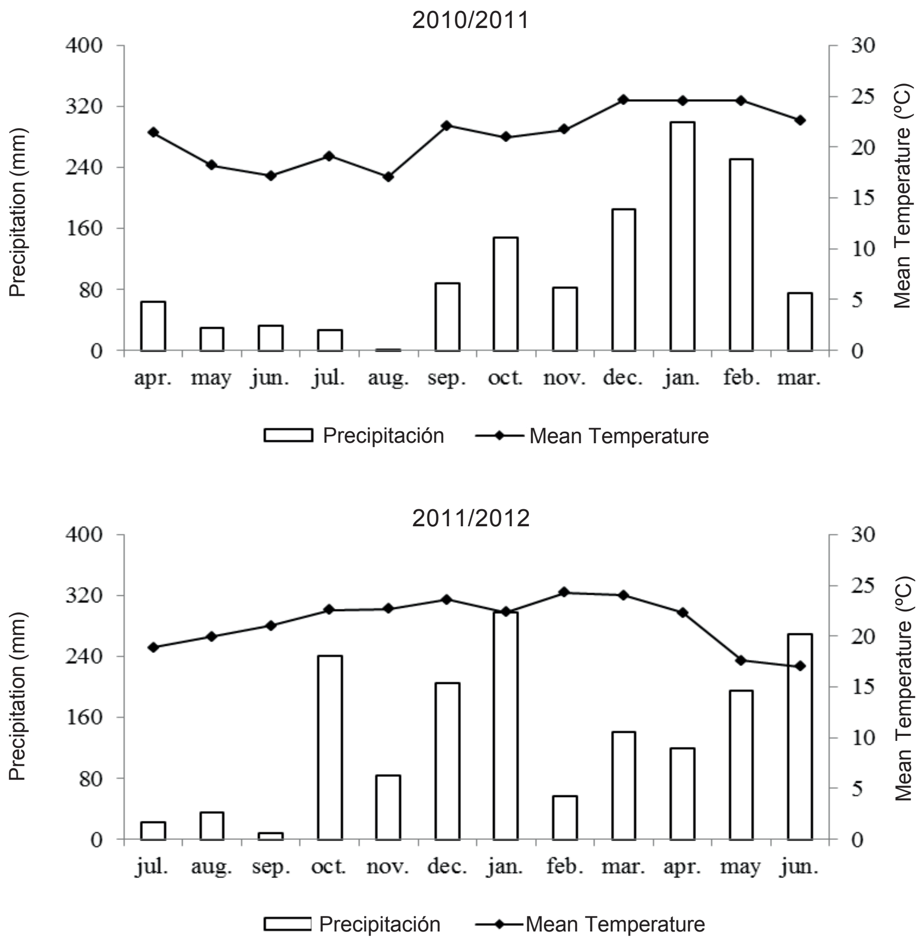

Figure 1. Pluviometric indexes related to the first and second ratoon sugarcane cropping periods in Assis - SP.
Figura 1. Índices precipitaciones para el período de la realización de estudios con la primera y segunda soca de caña de azúcar en la región de Asís, respectivamente.

adequate levels of S ranging between 1.5-3.0 g. According to Raij (2011), the values found for K in the first ratoon were adequate – between 10-16 g kg^{-1}. However, for the second ratoon, values of K in the leaf +1 were considered low, less than 10 g kg^{-1}, except in the plots where the highest rate of potassium was applied, presenting values of K of 9.3 g kg^{-1} (Figure 3). It is also noteworthy the fact that high yielding crops may show a nutrient dissolution effect, meaning that in more developed plants, the nutrient concentrations seem to be lower than in less developed plants (Jarrel & Beverly, 1981).

The buildup of K in plant tissue, 12 months after the sugarcane ratoon plants had started to sprout was, in both ratoons, significantly affected by the rates of potassium fertilizer (Figure 4). K level in the stalk (Figure 4a), in the leaves (Figure 4b), and in the aerial plant biomass (Figure 4c) increased linearly with the K rates applied to both ratoons. The highest values of K for first and second ratoons were 84.3 and 156.1 kg ha^{-1} in the stalk; 154.3 and 130.4 kg ha^{-1} in the leaves and 238.6 and 286.5 kg ha^{-1} in aerial plant biomass, when applying the 162 kg K ha^{-1} rate. Silva (2010) and Espironello *et al.* (1986) verified that the application of K increased the buildup of this nutrient in both leaves and stalks. Espironello *et al.* (1986) also reported significant positive correlations between K levels in the leaves and sugar cane yield.

Potassium fertilization had no significant effect on the K concentration in the straw post, harvest in both ratoons. In the first and second ratoons, the amounts of K present in the straw were 16.2 and 8.0 kg ha^{-1} (Table 2).

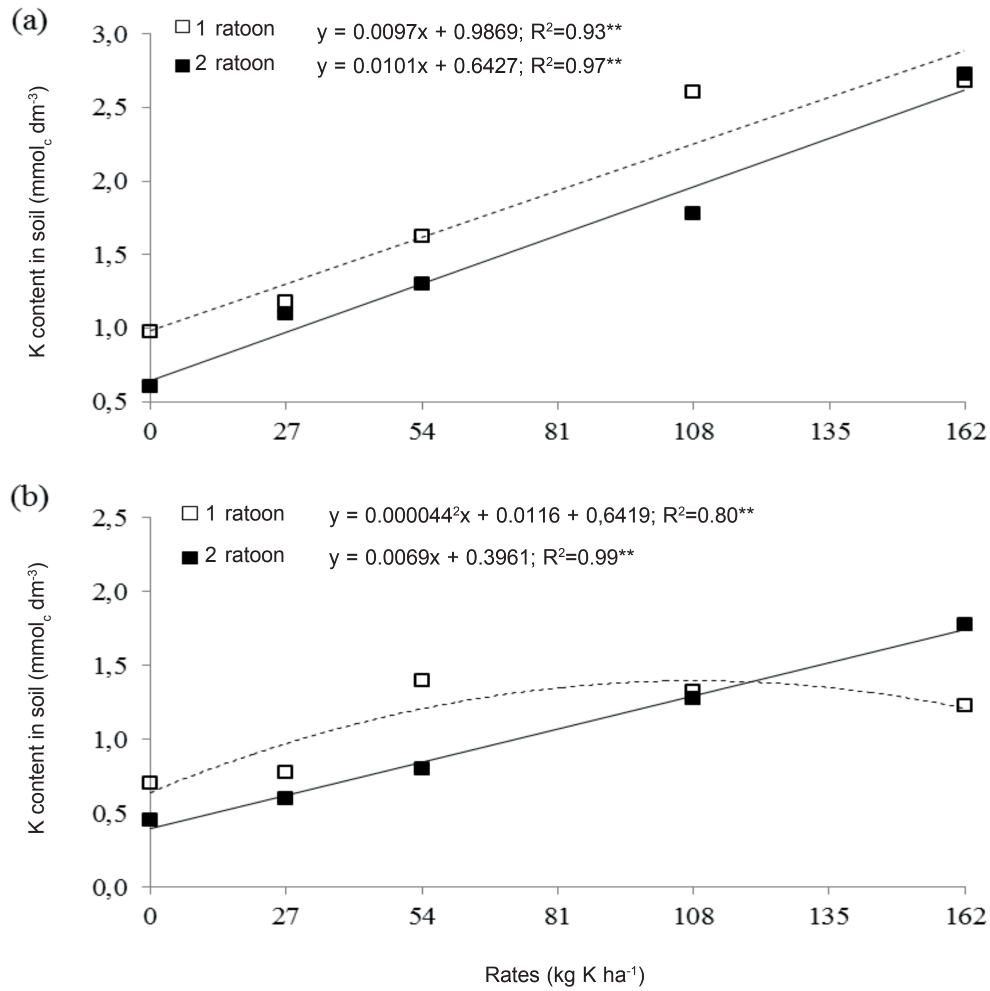

Figure 2. Effect of potassium fertilizer rate on the exchangeable K levels in soil at depths between 0 and 20 cm (a) and between 20 and 40 cm (b) 6 months after the budding on the first and second ratoon sugarcane. ** significant at the 1% level of probability.

Figura 2. Efecto de la dosis del contenido de potasio de potasio intercambiable en el suelo en la capa de 0-20 cm (a) y 20 a 40 cm (B) de profundidad a los 6 meses después de la gemación de la primera y segunda caña de retoño azúcar. ** - Significativo al 1% de probabilidad.

Potassium fertilization produced increases in stalk yield in the first ratoon and second ratoon, reaching 87.0 and 132.9 t ha ^{1} with the use of 162 kg K ha^{-1}, respectively (Figure 5).

The maximum stalk yield (87.0 and 132.9 t ha^{-1}) obtained in both ratoons was associated with the highest K concentration in the leaf +1; that is, 12.2 and 10.0 g kg ^{1} brought about by the fertilizer rate of 162 kg K ha^{-1} (Figure 3), respectively. Raij (2011) considers the values found for K concentration in leaf +1 in the both ratoons adequate; that is, between 10 and 16 g kg^{-1}. Silva (2010) and Pancelli (2011) also reported that the highest yields (119.5 and 127 t ha^{-1}) of sugarcane ratoon crops were associated with increasing levels of K in leaf +1 (50.9 and 9.3 g kg^{-1}) resulting from rates of 162 and 122 kg K ha^{-1}, respectively.

The application of K brought about linear effects on all studied variables (K level in leaf +1, buildup of K in the stalks, leaves and aerial part, and stalks yield. These findings could be explained by the low soil CEC, since according to Mielniczuk (1982), soil CEC is the most important factor determining higher or lower K losses resulting from lixiviation and lower unnecessary absorption of K by the plants and larger capacity of storing K in the soil.

Table 1. Effect of potassium fertilization in the macro and micronutrient contents in "leaf +1" at eight months after the first and second sugarcane ratoons started to spriout in the county of Assis-SP.

Tabla 1. Efecto de la fertilización con potasio en el contenido de macro y micronutrientes en la "Hoja 1" a los ocho meses después del brote de la primera y segunda soca de caña de azúcar, municipio de Assis-SP.

First Ratoon											
Rates	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
kg K ha^{-1}	g kg^{-1}						mg kg^{-1}				
0	17.1	1.8	9.8	3.6	1.6	2.5	7	4	109	30	19
27	17.7	1.9	10.0	3.7	1.6	2.5	7	5	110	32	19
54	17.7	1.9	11.3	3.7	1.6	2.7	7	5	110	31	20
108	17.8	1.9	11.5	3.7	1.7	2.7	7	5	111	31	20
162	17.9	1.9	12.0	3.7	1.6	2.7	7	5	111	31	20
F Test	0.7^{ns}	1.3^{ns}	10.1**	0.1^{ns}	0.3^{ns}	1.4^{ns}	0.2^{ns}	0.1^{ns}	0.1^{ns}	0.1^{ns}	0.79^{ns}
C.V. (%)	4.2	5.0	5.4	7.4	10.8	7.3	9.6	13.7	7.9	16.7	5.5
Second Ratoon											
Rate	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
kg K ha^{-1}	g kg^{-1}						mg kg^{-1}				
0	19.5	2.2	7.9	2.1	1.2	1.4	13	9	50	26	36
27	18.2	2.4	8.3	2.1	1.3	1.2	13	9	50	27	37
54	18.9	2.2	8.9	2.1	1.2	1.1	12	9	50	26	37
108	18.9	2.1	9.4	1.9	1.2	1.0	13	9	50	26	37
162	20.1	2.1	9.9	2.1	1.2	1.2	13	9	50	24	37
F Test	0.5^{ns}	0.7^{ns}	9.9**	0.1^{ns}	0.7^{ns}	1.1^{ns}	0.01^{ns}	0.4^{ns}	0.01^{ns}	0.4^{ns}	0.5^{ns}
C.V. (%)	10.4	14.4	5.7	20.8	10.9	18.8	25.6	13.2	5.3	12.1	4.5

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

** y ^{ns} – significativo al 1% y no significativo en la probabilidad de 5%, respectivamente, mediante la prueba F.

Table 2. Content and buildup of potassium in the straws remaining on the soil surface due to the application of potassium in the soil at twelve months after the first and second sugarcane ratoons started to sprout in the county of Assis-SP.

Tabla 2. Contenido y acumulación de potasio en la paja que queda en la superficie del suelo dependiendo de la aplicación de potasio en el suelo a los doce meses después del brote de la primera y segunda soca de caña de azúcar, municipio de Assis-SP.

Rates	Buildup of K in Straw	
	First Ratoon	Second Ratoon
kg K ha^{-1}		
0	15.9	7.8
27	16.6	8.0
54	16.2	8.1
108	16.2	8.1
162	16.3	8.2
F Test	0.05^{ns}	0.045^{ns}
C.V. (%)	13.8	9.5

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

^{ns} – no significativo al 5% de probabilidad mediante la prueba F.

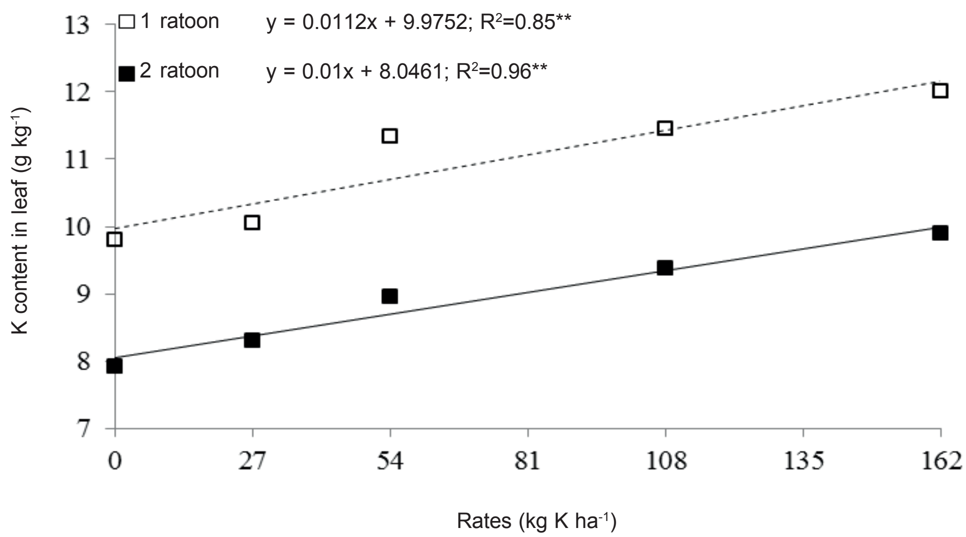

Figure 3. Effects of potassium fertilizer rate on the leaf + 1 K content 8 months after the budding on the first and second ratoon sugarcane. ** significant at the 1% level of probability.

Figura 3. Efecto de la dosis del contenido de potasio de la hoja de K 8 meses después de la gemación de la primera y segunda soca de caña de azúcar. ** - Significativo al 1% de probabilidad.

In the literature, there are different reports concerning the adequate K rate to reach maximum yield of sugarcane ratoon crops. The rate leading to the highest stalk yields was 66.4 kg K ha^{-1} in a Vertisol in Mexico (Garcías *et al.,* 2000), 119.5 kg K ha^{-1} in three soils (Dinder, Hagu, and Nars) in Sudan (El-tilib *et al.,* 2004), 54.8 kg K ha^{-1} in sandy soils in India (Shukla *et al.,* 2009), 54.8 kg K ha^{-1} in a argillic soil also in India (Kumar *et al.,* 2007), and 78 to 137 kg K ha^{-1} in a yellow latosol (Oxisol) in Brazil (Uchôa *et al.,* 2009).

Potassium fertilization did not affect other quality parameters; in the first ratoon, mean values were: 77.3, 10.6, 12.5, 0.8, 12.0%, 16.2%, 108.3 kg t^{-1} and 8,8 t ha^{-1} for Purity, Sugarcane Pol, Juice Pol, Reducing Sugar, Fiber, Brix, and ATR, Theoretically Recoverable Sugar, respectively. However, only in the second ratoon, there was a significant increase in Reducing Sugar (y=0.0005x+ 0.5445; R^2=0.99*), and in Theoretically Recoverable Sugar (t ha^{-1}) (y=0.054x+9.2924; R^2=0.92**). Potassium fertilization did not affect other quality parameters, in the second ratoon, with mean values of 19.7, 17.6, 88.9, 12.1, 14.8% and 147.85 (kg ha^{-1}) of Brix, Juice Pol, Purity, Fiber, Sugarcane Pol, Theoretically Recoverable Sugar (kg ha^{-1}), respectively.

Several research studies also show the absence of significant effects of K fertilization on sugarcane technological characteristics (Uchôa *et al.,* 2009; Caione *et al.,* 2011; Garcías *et al.,* 2000; Silva, 2010). On the other hand, several research studies indicate significant effects of K fertilization on the technological characteristics of sugarcane (Orlando Filho *et al.*, 1993; Silva, 2010).

CONCLUSIONS

The application of K fertilizer to the soil increased this element content both in the soil and in the plant, and had an effect on stalk yield in both ratoons, improving the quality of the crop and increasing the theoretical recoverable sugar (t ha^{-1}) only in the second ratoon sugarcane crop.

After two years of evaluation, reductions in the fertilization rates for ratoon sugarcane crops are not advisable since maximum yields were reached with rates close to those recommended by the literature.

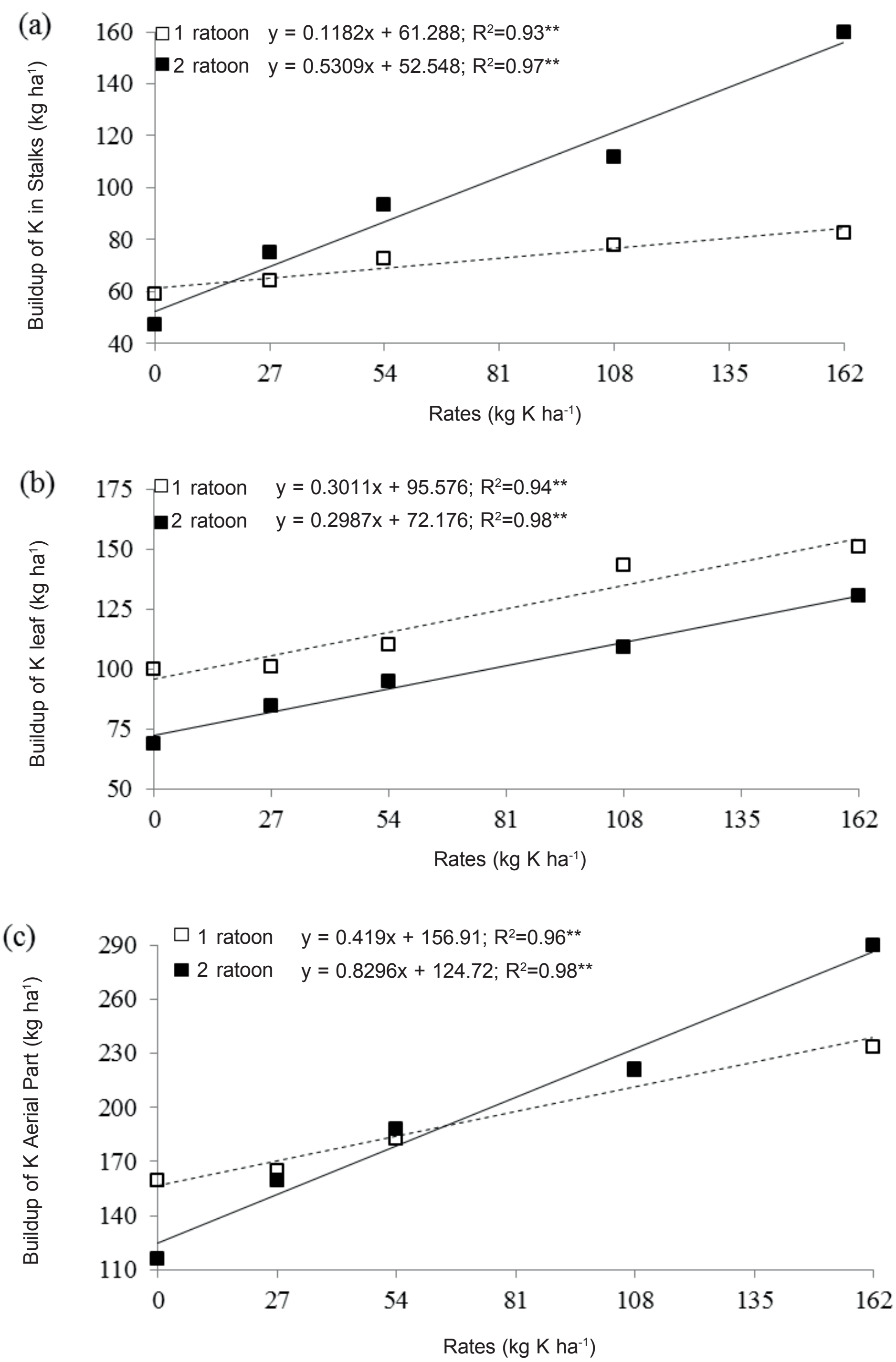

Figure 4. Effect of potassium fertilizer rate on the buildup of K in the stalks (a), in the leaf (b), and in the plant aerial biomass (c) 12 months after the budding on the first and second ratoon sugarcane. ** significant at the 1% level of probability.

Figura 4. Efecto de la dosis de fertilizante de potasio en la acumulación de K en los tallos (a) de la hoja (b), y en la parte aérea de la planta (c) 12 meses después de la brotación en la primera y segunda caña soca. ** - Significativo al nivel de 1% de probabilidad.

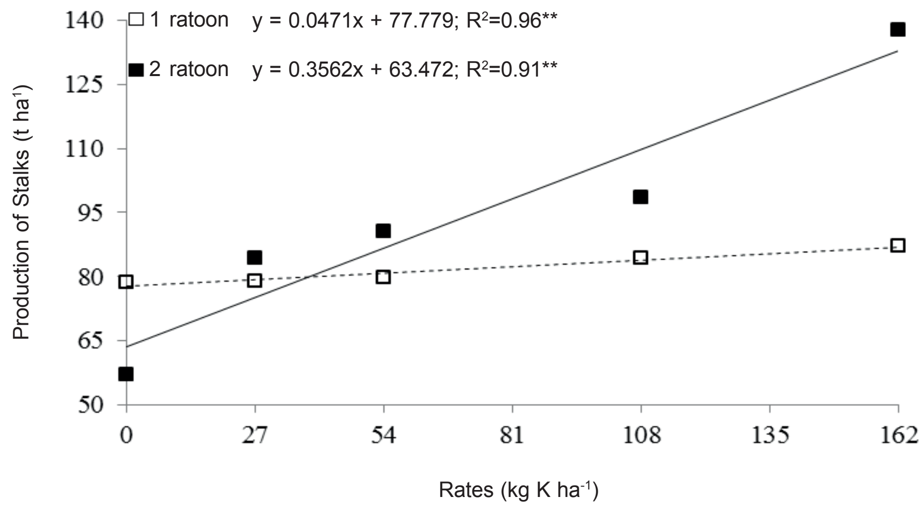

Figure 5. Effects of potassium fertilizer rate on stalks production 12 months after the budding on the first and second ratoon sugarcane crops. ** significant at the 1% level of probability.

Figura 5. Efectos de la dosis de fertilizante potásico sobre la producción de caña 12 meses después de la brotación en la primera y segunda caña soca. ** Significativo al nivel de 1% de probabilidad.

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