

Potassium Nutrition in Sugarcane Ratoons Grown in Oxisols by a Conservationist System

¹Rilner Alves Flores, ²Renato De Mello Prado, ³Hilário Júnior Almeida,

²Márcio Alexandre Pancelli, ²Leandro Rosatto Moda and ³Carlos Leandro Rodrigues Dos Santos

¹Department of Soils, School of Agronomy, Federal University of Goiás, Goiania, Goiás, Brazil

²Department of Soils and Fertilizers, Universidade Estadual Paulista, Jaboticabal, Sao Paulo, Brazil

³Department of Soils, Federal University of Mato Grosso, Barra Do Garças, Mato Grosso, Brazil

Abstract: The presence of mulch on the soil surface after the mechanical harvesting of sugarcane (*Saccharum officinarum* L.) enhances the cycling of nutrients, especially K, which can decrease K-fertilizer recommendations for the crop. The aim of this study was to evaluate the effect of K-fertilizer addition in Oxisols, with initial concentrations 0.07 and 0.11 cmol_c K kg⁻¹, in the first ratoon sugarcane (no-till) in a conservationist system, i.e. rational use of fertilizers, use of alternative inputs and especially the maintenance of residues in soil that was previously burned to facilitate cutting. The following K doses were tested: 0, 32.5, 65, 130 and 195 kg K₂O ha⁻¹, arranged in a randomized complete block design with five replicates. The experiments were carried out on sugarcane ratoon in a Oxisol, texture clay (LV) and Oxisol, medium textura (LVA). Potassium content in the soil and in the plant, as well as the yield and the quality of stalks were evaluated. Soil K application increased K concentration in soil and plant and was reflected in the production of stalks, with higher production (87.5 and 87.0 t ha⁻¹) with the use of 99.6 and 161.9 kg K₂O ha⁻¹ in soils LV and LVA, respectively. However, it is expected that over time, the amount of K-fertilizer reduces due to the high nutrient cycling, particularly K, from the increase of the amount of straw on the soil surface after harvesting without burning.

Key words: Plant nutrition • Soil fertility • Residues covering • *Saccharum officinarum*

INTRODUCTION

One of the main cultures in Brazil, sugarcane harvested in the 2014/2015 season covered 9,130.1 million hectares with a productivity of 73.57 t ha⁻¹ [1]. The major expansion of Brazilian sugar and ethanol markets and the incorporation of new cropping areas have driven studies on the culture of sugarcane, particularly ratoon, grown in conservationist system, i.e., rational use of fertilizers and alternate inputs and, especially, the maintenance of plant residues on the soil from the previously crop. The straw increases the soil organic matter content [2], improves its physical, chemical and biological properties [3] and also, improves sugarcane yields [4].

Mechanical harvesting leaves 10 to 20 t ha⁻¹ of sugarcane residues (dry matter) per year on the soil surface [5]. This material enables recycling some nutrients

such as potassium. An average of 56 kg ha⁻¹ per year of this element is added to the soil by sugarcane straws left on the soil surface [6].

Tropical soils are usually poor in exchangeable K contents [7] and sugarcane ratoons respond very well to K-fertilizers [8] because K is the nutrient most extracted by ratoons [8, 9].

So, it is clear the importance of K for sugarcane ratoon, ie, the roots that remain in the field after cutting the crop. However, there are few studies in the literature about fertilization with this nutrient in ratoon under conservationist system [10, 11, 12]. Therefore, the cultivation of sugarcane in a conservation system increases residues amount on soil surface, improving the cycling of nutrients, especially K, making it possible to reduce the recommendation of this nutrient for the culture.

Therefore, the objective of this study was to evaluate the effects of K-fertilizer applied to sugarcane ratoon plants cultivated in two regions of the state of São Paulo in a conservationist system.

MATERIALS AND METHODS

Two field experiments were conducted with sugarcane ratoon plants in two regions of the State of São Paulo during the crop year of 2010/2011. These regions were different with respect to soil and climate and also to the amount of straw left over the soil surface after harvest. The first experiment was set during the first week of April 2010 and the second during the third week of that same period. The climatic data recorded during both experiments in Jaboticabal and Assis, which are municipalities of the state of São Paulo, Brazil, are shown in Figure 1.

The first experiment was carried out in the Santo Antonio farm in the county of Jaboticabal, a private farm, (latitude 21° 11' 52" S and longitude of 48° 13' 52" W). The cultivar used was 'CTC 05' cultivated in a Oxisol, texture clay (LV) [13]. The second experiment was carried out in the Lagora Rica farm in the county of Assis, a private farm, (latitude 89° 59' 58" S and longitude 178° 59' 42" W). The cultivar used was 'CTC 07', cultivated in a Oxisol, median texture (LVA) [13]. Both cultivars have a high yielding, with median demand of soil natural fertilizers and are resistant to rust.

Before starting the experiment, 15 soil subsamples were taken from each area in order to obtain the composite sample. These samples were taken at depths from 0 to 20 cm. These samples were used for the chemical analysis of the soil types to evaluate their fertility levels. These chemical analyses were conducted according to procedures described in Raij *et al.* [14]. The results of chemical analysis of soil in Jaboticabal and Assis were: pH CaCl₂ 5.0 and 5.5; OM (organic matter): 24 and 12 g kg⁻¹; P_{Ion exchange resin}: 15 and 56 mg kg⁻¹; K: 0.7 and 1.1 mmol_c dm⁻³; Ca: 30 and 25 mmol_c dm⁻³; Mg: 16 and 10 mmol_c dm⁻³; H + Al: 38 and 18 mmol_c dm⁻³; SB (sum of bases): 47 and 36 mmol_c dm⁻³; CEC (cation exchange capacity): 85 and 54 mmol_c dm⁻³; and V (base saturation): 55 and 67%, respectively.

At the same time, crop residues were taken from the soil surface in both areas to evaluate total amounts of nutrients immobilized in residual biomass. The samples were taken from three randomly chosen 1 m² areas and the nutrient chemical evaluation was based on procedures described in Bataglia *et al.* [15]. The dry matter of the residues covering the first experiment (LV) was 13.9 t ha⁻¹

whereas in the second experiment (LVA) was 18.7 t ha⁻¹. The residues chemical analyses of the LV and LVA showed the following respective results: N: 3.5 and 5.4; P: 0.5 and 1.9; K: 1.2 and 4.1; Ca: 3.1 and 3.2; Mg: 0.7 and 1.1; S: 1.6 and 5.2 g kg⁻¹; Cu: 3.0 and 2.5; Fe: 346.0 and 317.0; Mn: 85.0 and 40.5; Zn: 5.0 and 6.5; and B: 7.9 and 5.7 mg kg⁻¹.

In both experiments the treatments were arranged in the field according to a randomized complete block design with five treatments and five repetitions. The referential K fertilizer dose (130 kg K₂O ha⁻¹) was based on values recommended for the State of São Paulo, having in mind a yield between 80 and 100 t ha⁻¹. So, K fertilizer doses were: 0, 32.5, 65, 130 and 195 kg K₂O ha⁻¹, which corresponded to 0, 25, 50, 100 and 150% of the referential dose, that is, 130 kg K₂O ha⁻¹. These doses were applied manually side dressed to the sugarcane rows, without incorporation, according to indications by Spironello *et al.* [16]. Two other nutrients (P and N) were applied also according to indications by Spironello *et al.* [16], so that the first experiment (LV) received a rate of 30 kg P₂O₅ ha⁻¹ and 100 kg N ha⁻¹ applied in both experiments.

In both experiments, each plot was composed of five 10 m long rows with a spacing of 1.5 m between rows. The experimental data were collected only from the three central lines of each plot.

Soil samples were collected 6-mo after ratoon plants started to sprout in both experiments. These samples were taken from 10 randomly chosen points next to the three central rows of each plot at depths between 0-20 and 20-40 cm. The exchangeable K in the soil was determined according to procedure reported by Raij *et al.* [14].

To determine plants' nutritional status, in both experiments, samples leaf +1 (the first leaf from the top down showing the collar (sheath) totally visible) were used, 8-mo after plants had started to sprout (December 2010). The central nervure of each leaf was removed, according to procedure reported by Raij and Cantarella [17]. After being collected, leaves were decontaminated, dried and ground. Chemical methods for determining levels of nutrients in plant tissues were reported by Bataglia *et al.* [15].

In both experiments, 12-mo after ratoon plants had started to sprout, a harvest was conducted to determine the number of millable stalks and the total production of stalks. From the three central rows of each plot, 10 adjacent stalks were picked to determine the sugarcane technological quality [pol (sucrose) per cent in juice, pol (sucrose) per cent in sugarcane, theoretically recoverable sugar (TRS), reducing sugars (RS), fiber, °brix and purity] according to procedures described by Consecana [18].

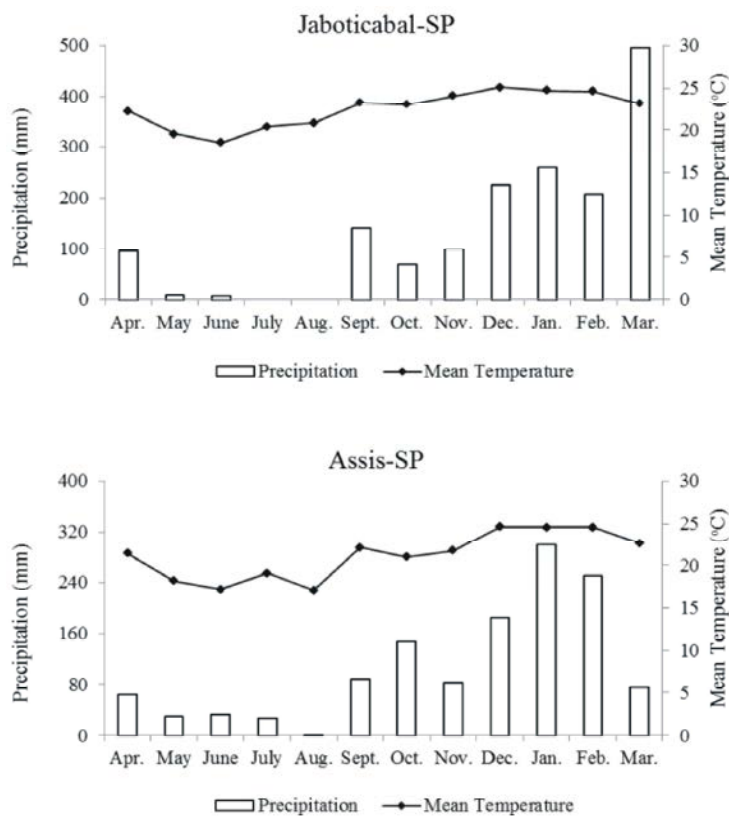


Fig. 1: Pluviometric indexes related to the period during which the experiments were carried out in Jaboticabal-SP (LV area) and in Assis - SP (LVA area)

In both experiments, were evaluated K accumulated aerial part, stalks and leaves, at harvest. After weighing fresh material, 400 g of each fraction were dried at 65°C in an oven until constant weight. Potassium content of plant tissue was determined according to Bataglia *et al.* [15]. In addition to that, residues covering soil surface, at harvest, was evaluated in terms of total dray matter, K content and accumulated K.

Data was submitted to the analysis of variance and to F test. The polynomial regression analysis of all data was performed using the statistical program AgroEstat [19].

RESULTS AND DISCUSSION

The rates of K-fertilizer increased the exchangeable potassium contents at depths between 0 and 20 cm as observed in soil samples taken in both experiments, 6-mo after the ratoon plants started sprouting. Exchangeable potassium levels in the LV and LVA areas reached values, respectively, of 1.0 and 2.9 mmol_c dm⁻³, respectively when the highest rate of K-fertilizer (195 kg K₂O ha⁻¹) was used, as shown in Fig. 2a.

It was also observed that the application of K-fertilizer had no significant effect on the soil K content at depths between 20 and 40 cm in the LV area, however, there were increases significant in the LVA area, reaching 1.41 mmol_c dm⁻³ with the rate 131 kg K₂O ha⁻¹ (Fig. 2b). Similar results were reported by[2],[11],[12],[20] and [21], which reported that the application of potassium resulted in linear increments of potassium in the soil.

The values of K level found in the soil in the LV area are considered low values. This is thought to be in part due to the uptake of K by the sugarcane plants since this is the most consumed element by plants of that species and the soil samples were taken 6-mo after the ratoon plants had started to sprout.

However, the increment in K levels in the sub superficial soil layers resulting from the application of K rates in the soil of texture medium (LVA) may have been the consequence of large percolation of this element in the soil profile as influenced by a sandy texture and low CEC (54 mmol_c dm⁻³). Even with low precipitation in the first 6-mo of evaluation of the second experiment (LVA)

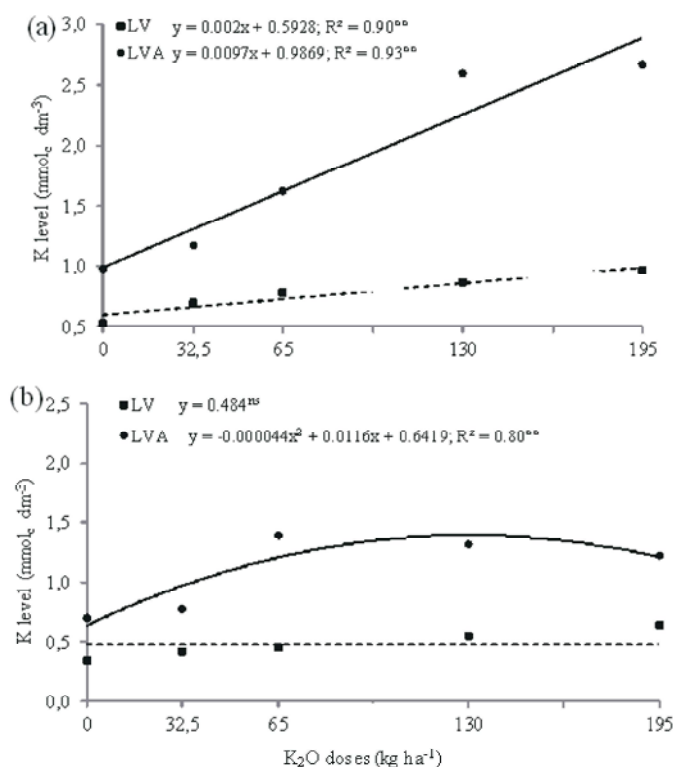


Fig. 2: Effect of K-fertilizer rate on the exchangeable level of K in the soil at depths between 0 and 20 cm (a) and between 20 and 40 cm (b) 6-mo after the ratoon sugarcane plants had started to sprout. LV: Oxisol, texture clay. LVA: Oxisol, median texture. ^{ns} - not significant. [∞] - significant ($P \leq 0.01$)

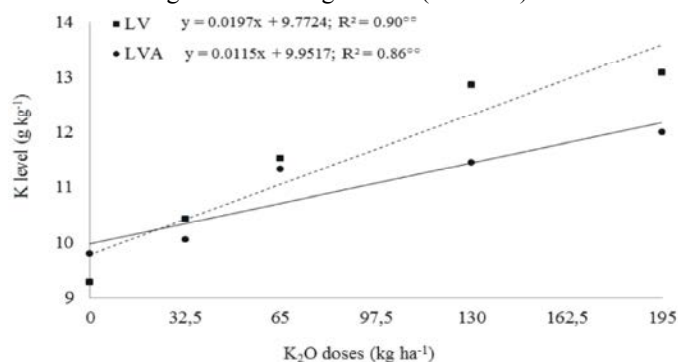


Fig. 3: Effects of K-fertilizer rate on the leaf +1 K content 8-mo after the ratoon sugarcane plants had started to sprout. LV: Oxisol, texture clay. LVA: Oxisol, median texture. [∞] significant ($P \leq 0.01$)

(Fig. 1), the amount of rainfall was sufficient for percolating K in the soil, since according to Mielniczuk [22], the soil CEC which varies with the soil organic matter content, with the amount and type of clay and soil pH is the main component determining the higher or lower relation exchangeable K/solution K, that is: for the same amount of total K, the lower the K in the soil solution with a high CEC. This will reduce K losses by lixiviation and lower unnecessary absorption of K by the plants and higher capacity of K storage in the soil. Werle *et al.* [23]

stated that increasing the levels of K in the soil favors lixiviation even in argillaceous soils with high CEC values.

K-fertilizer affected K content in the leaf +1 in both experiments, promoting its increment with linear adjustments in K content, reaching 13.6 and 12.2 g kg⁻¹ with the of rate 195 kg K₂O ha⁻¹, respectively (Fig. 3). Similar results were reported by Espironello *et al.* [24] which observed increments in K in leaf +3 and by Silva [11] and Pancelli [12] in leaf +1.

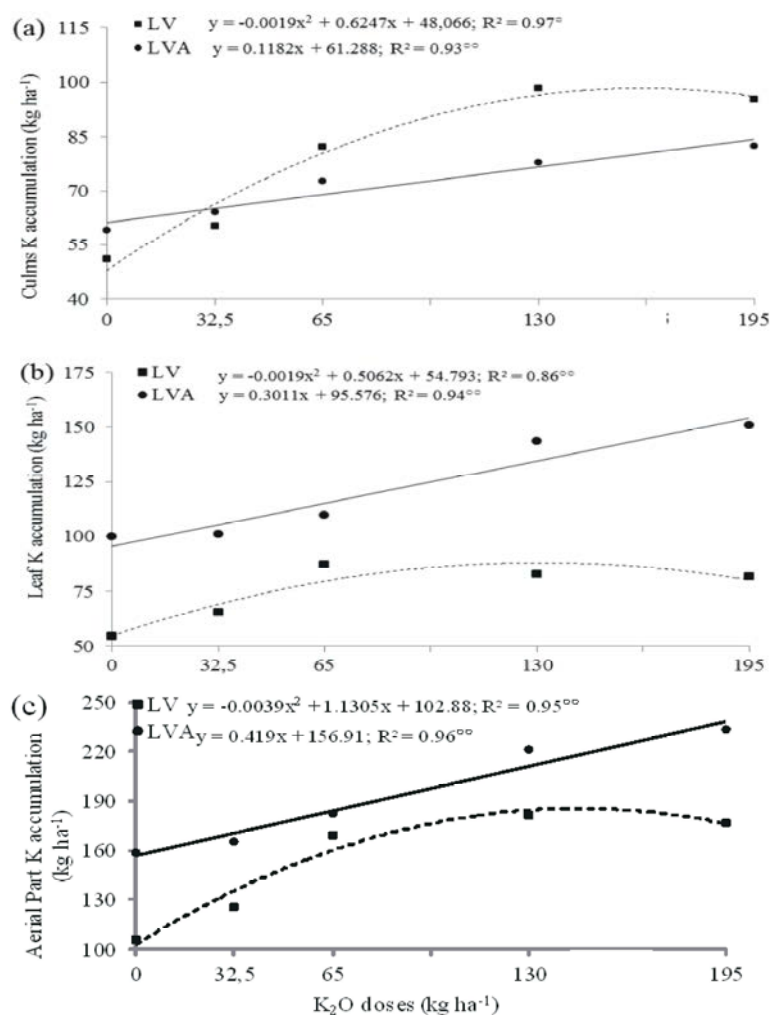


Fig. 4: Effect of K-fertilizer rate on the accumulation of K in the stalks (a), in the leaf (b) and in the plant aerial part (c) 12-mo after the ratoon sugarcane plants had started to sprout. LV: Oxisol, texture clay. LVA: Oxisol, median texture. °, °° significant ($P \leq 0.01$ and 0.05)

For the other analyzed nutrients, there were no significant changes because of the potassium fertilization in the first and second experiments. In the first experiment (LV), the levels of the nutrients found in the leaves for N, P, Ca, Mg, S, B, Cu, Fe, Mn and Zn were 14.3, 1.7, 3.5, 1.8 and 2.1 g kg⁻¹ and 8.5, 108, 68 and 14 mg kg⁻¹, respectively. According to Raij [25], 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 experiment, it was observed that the average contents of nutrients in the leaves for N, P, Ca, Mg, S, B, Cu, Fe, Mn and Zn were of 17.6, 1.9, 3.7, 1.6 and 2.6 g kg⁻¹ and of 7, 5, 110, 31 and 20 mg kg⁻¹, respectively.

According to Raij [25], the values found for N, B, Cu and Zn are considered low, whereas the values found for the other nutrients are adequate. According to Raij [25], the values found for K in both experiments are adequate. However, in the LV and LVA areas, in the plots where no K-fertilizer had been applied (the control treatments), the values of K level found were 9.3 and 9.8 g kg⁻¹, respectively.

It is also noteworthy the fact that highly yielding crops, may show nutrients dilution effect, that is: in more developed plants, the nutrients concentration seem to be lower than in less developed plants [26].

The buildup of K in the plant tissue, 12-mo after the sugarcane ratoon plants had started to sprout was, in both experiments, significantly affected by the rates of K-fertilizer applied (Fig. 4). In first experiment (LV), there

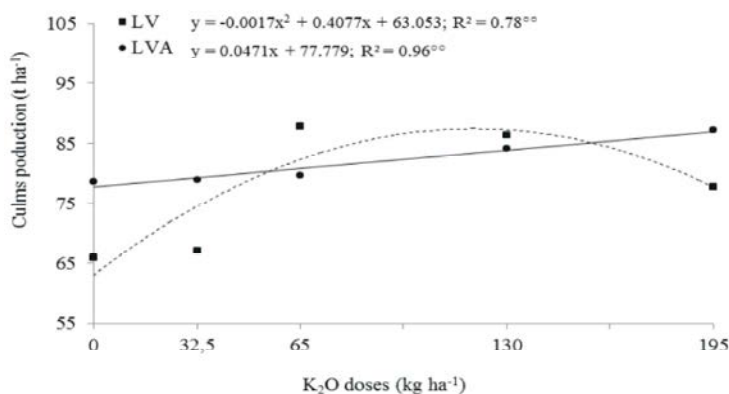


Fig. 5: Effects of K-fertilizer rate on stalks production 12-mo after the ratoon sugarcane plants had started to sprout. LV: Oxisol, texture clay. LVA: Oxisol, median texture. °° significant ($P \leq 0.01$)

was an increased quadratically in the buildup of K with the rates application of K-fertilizer, where the highest value of K in the stalk (99.4 kg ha^{-1}) was caused by the rate of $164 \text{ kg K}_2\text{O ha}^{-1}$ (Fig. 4a); in the leaves (88.5 kg ha^{-1}) by the K rate of $110 \text{ kg K}_2\text{O ha}^{-1}$ (Fig. 4b) and in the plant aerial part (184.8 kg ha^{-1}) by the K rate of $127 \text{ kg K}_2\text{O ha}^{-1}$ (Fig. 4c). In second experiment (LVA), there was an increased linear the buildup in the of K, where the highest value of K in the stalk was 84.3 kg ha^{-1} (Fig. 4a), in the leaves of 154.3 kg ha^{-1} (Fig. 4b) and in the plant aerial part of 238.6 kg ha^{-1} (Fig. 4c) were obtained using rate of $195 \text{ kg K}_2\text{O ha}^{-1}$ in the soil.

Potassium fertilization had no significant effect on this nutrient concentration on straw covering the soil surface at harvest in both experiments. In the first and second experiments the amounts of K present in the straw were 42.5 and 16.2 kg ha^{-1} , respectively.

Potassium fertilization increased stalk production in both experiments, promoting increases in stalk yield in the first (LV) and second (LVA) experiment, reaching 87.5 and 87.0 t ha^{-1} with the use of rate of 120 and $195 \text{ kg K}_2\text{O ha}^{-1}$, respectively (Fig. 5).

The maximum stalk yield in the LVA area was associated with the highest K concentration in the leaf +1 (12.2 g kg^{-1} ; Fig. 3) was brought about by the fertilizer rate of $195 \text{ kg K}_2\text{O ha}^{-1}$. In the LV area the highest yield (87.5 t ha^{-1}) was reached when the K content in leaf +1 was 11.3 g kg^{-1} (Fig. 3). Raji [25] considered the values found for K concentration in leaf +1 in the both experiments, adequate; that is, between 10 and 16 g kg^{-1} . Silva [11] and Pancelli [12] 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 195 and $147 \text{ kg K}_2\text{O ha}^{-1}$, respectively.

In the LVA area, 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), this being an indication that the application of K in soils of median texture may lead to more losses of this element, mainly by lixiviation [7]. However, according to Mielniczuk [22], the 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.

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 stalks yield was $80 \text{ kg K}_2\text{O ha}^{-1}$ in a Vertisol in Mexico [27], $144 \text{ kg K}_2\text{O ha}^{-1}$ in three soils (Dinder, Hagu and Nars) in Sudan [28], $66 \text{ kg K}_2\text{O ha}^{-1}$ of in sandy soils in India [29], $66 \text{ kg K}_2\text{O ha}^{-1}$ in an argillaceous soil also in India [30], 94 to $165 \text{ kg K}_2\text{O ha}^{-1}$ in a yellow latosol (Oxisol) in Brazil [31].

The application of K-fertilizer, in the first experiment (LV), promoted an increase only in some quality parameters restricted, such as °Brix ($y=0.0001x^2+0.016x+15.412$, $R^2=0.66^*$) and Theoretically Recoverable Sugar (TRS) (kg t^{-1}) ($y=-0.0008x^2+0.1562x+114.49$, $R^2=0.74^{**}$) and (TRS) (t ha^{-1}) ($y=-0.0004x^2+0.0717x+7.139$, $R^2=0.86^{**}$). However, the application of K-fertilizer in soil did not affect other quality parameters with mean values of: 85.7 , 11.6 , 13 , 0.6 and 9.8% for Purity, Sugarcane Pol, Juice Pol, Reducing sugars and Fiber, respectively.

However, the application of K-fertilizer in soil in the second experiment (LVA) resulted in mean values of: 77.3 , 10.6 , 12.5 , 0.8 , 12% , 16.2% , 108.3 kg t^{-1} and 8.8 t ha^{-1} of Purity, Sugarcane Pol, Juice Pol, reducing sugar, Fiber, °Brix and Theoretically Recoverable Sugar.

The values found in this experiment for fiber, purity and cane pol are a little lower than the ones indicated by Segato *et al.* [32] as the adequate ones, i.e., 12.5%, 85% and 14% to characterize a sugarcane crop as mature and ready to be harvested.

Several research works also show the absence of significant effects of potassium fertilization on sugarcane technological characteristics [11, 27, 31, 33]. On the other hand, several research works indicated significant effects of potassium fertilization on the technological characteristics of sugarcane [11, 34].

CONCLUSIONS

The application of K-fertilizer on sugarcane ratoon production under conservationist system increases the soil K content promoting an increase in its availability, reflecting in higher stalk yield at the two evaluated experiments. However, only in the LV area (Oxisol, texture clay) there is an increase technological quality in ratoon.

In the first year of study, independently of soil type and sugarcane variety, it is not possible to suggest reductions in the fertilization rates for ratoon sugarcane crops, once maximum yields were reached with rates close to those recommended by the literature.

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