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# Decreased potassium fertilization in sugarcane ratoons grown under straw in different soils

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## Abstract

The presence of straw from sugarcane (*Saccharum* ssp.) left on the soil surface after mechanical harvest has contributed to increase productivity of this crop and reduce potassium fertilization due to release of this nutrient and increased soil organic matter. Thus, the present study sought to evaluate the response of the second sugarcane ratoon cultivated under sugarcane straw resulting from harvest of the first ratoon, in function of potassium doses, in dystrophic Red Yellow Latosol (dRYL) and eutrophic Red Yellow Agirsol (eRYA). For this, two field experiments were conducted for the second sugarcane ratoon grown in the conservation system, where one experiment was developed in dRYL (variety SP81-3250) and the other in eRYA (variety RB855453). The treatments in both soil consisted of doses of 32.5, 65.0, 130.0 and 195.0 kg ha$^{-1}$ of $K_2O$ in the form of potassium chloride, and a control treatment, arranged in a randomized block design with five repetitions. Potassium fertilizer was applied alongside the row of ratoons, without incorporation. We evaluated the biometric variables (height, tiller number and diameter), potassium contents in the soil, leaf and straw, K accumulation in the straw, stalk and shoot, production of straw and stalks, and technological quality. Potassium doses resulted in a productivity increase of about 75 and 22 Mg ha$^{-1}$ in the dRYL and eRYA, respectively. The dose of 65 kg ha$^{-1}$ of $K_2O$, corresponding to 50% of the recommended dose for the conventional crop, promoted the acquisition of 88 and 95% of the maximum sugarcane crop yield in dRYL and eRYA, respectively. Potassium fertilization increases production and accumulation of this nutrient in sugarcane straw, potentially benefiting the upcoming crops.

**Keywords:** Mechanical harvest; potassium fertilization; potassium chloride; *Saccharum* spp; technological quality.
**Abbreviations:** DAB_days after budding of the second sugarcane ratoon, dRYL_Dystrophic Red Yellow Latosol, eRYA_Eutrophic Red Yellow Agirsol

## Introduction

In recent years important changes have occurred in the sugarcane production system in Brazil, evolving from pre-harvest burning of leaves to mechanized harvesting, meeting environmental legislation which has banned the use of sugarcane burning as well as economic aspects due to the lower cost of mechanical harvesting. In the Brazilian state of São Paulo, the largest and most advanced sugarcane producer in the country, mills and producers are preparing to adapt to the new Green Protocol of the sugar-alcohol sector signed in 2007 together with the government. This protocol calls for 100% harvest without burning in areas which may be mechanically harvested by 2014, and in areas which cannot currently be mechanically harvested by 2017. This new system of sugarcane conservation management has emerged as one of the most effective strategies to increase the sustainability of agricultural systems in tropical and subtropical regions. This system consists of mechanical sugarcane harvesting, so that green leaves, dry leaves and pointers are cut and left on the soil surface, forming a dead coverage referred to as straw. It is estimated that sugarcane residues left after mechanical harvesting varied from 10 Mg ha$^{-1}$year$^{-1}$ dry matter (Sampietro and Vattuone, 2006) to 45 Mg ha$^{-1}$ fresh matter (Asghar and Kanehiro, 1976). The presence of straw on the soil promotes many benefits to the sugarcane productive system, such as reducing water loss and increasing its infiltration into the soil, nutrient cycling and reduction of weeds, with consequent increased sugarcane productivity. Moreover, there is a growing demand to remove part of the straw in the field for bioenergy production and future production of 2$^{nd}$ generation ethanol. It is known that in straw potassium does not remain incorporated with the carbon chain, so that after harvest or senescence of the plants, this nutrient quickly returns to the soil in a readily available form for the crops (Hawkesford et al., 2011), acting as a significant potassium reservoir in conservation agricultural systems. In tropical soils, exchangeable potassium concentrations are normally considered low (below 1.5 $mmol_c$ dm$^{-3}$), and under these conditions sugarcane expressively responds to its application (Korndörfer and Oliveira, 2005). In a study conducted in India, Shukla et al. (2009) reported that K application in sugarcane promoted an increase in the number of shoots, nutrient uptake and production, where the dose of 66 kg ha$^{-1}$ $K_2O$ is responsible for greater crop production. Kumar et al. (2007) evaluated potassium in sugarcane ratoons in a clay loam soil and also observed that greater crop yield (88 Mg ha$^{-1}$) was obtained with the application of 40 kg ha$^{-1}$ $K_2O$. ElTilib et al. (2004), in studies with sugarcane ratoons in Sudan, also observed effects on productivity in function of the application of soil potassium, which reached 115 and 117 Mg ha$^{-1}$ of stalks using doses of 72 and 144 kg ha$^{-1}$ $K_2O$, respectively. Sugarcane is cultivated in various regions of the country in different types of soils, with distinct physicochemical properties, oftentimes outside the appropriate standards. However, in order to obtain better yields, the most appropriate soil type for the crop requirements should be selected. Soils with depth greater than one meter, with good water infiltration and retention capacity, pH near 6.5 and fertile are considered ideal for sugarcane cultivation. In Brazil, Latosols (Oxisols-USDA, 1999) and Agirsols (Ultisols - USDA, 1999) occupy large areas where sugarcane is cultivated, mainly because they result in high yields. However, these soils have very distinct characteristics, especially with regard to clay content, porosity, water storage and fertility. Therefore, considering that the high yields obtained in the sugarcane culture require large potassium fertilizer doses, the straw itself may provide considerable amounts of this nutrient to the soil. Moreover, because the conservation system may alter the soil chemistry and thus modify leaching of exchangeable bases in function of the increased cation exchange capacity of the soil, it is important to study the dynamics of K applied on the straw and the response of the sugarcane ratoons. Therefore, the hypothesis was suggested that straw left on the soil surface in the sugarcane culture can decrease application of the recommended potassium fertilizer dose in the conventional management system while maintaining the high expected productivity, due to the considerable and rapid release of this nutrient from the straw, improved CEC and soil structure, as well as other benefits. Thus, this study sought to evaluate the response of the second sugarcane ratoon cultivated beneath the straw, in function of the potassium doses in dystrophic Red Yellow Latosol and eutrophic Red Yellow Agirsol.

## Results

### *Potassium content in the soil*

Potassium fertilization doses had effects on the $K^+$ content of the dRYL (F= $39.34^{**}$) and eRYA (F= $35.23^{**}$) evaluated at 180 DAB (days after budding of the second sugarcane ratoon). The application of K also influenced the content of exchangeable potassium in the dRYL (F= $3.68^{**}$) and eRYA (F= $3.06^{*}$) evaluated at 360 DAB. The application of potassium in eRYA allowed for obtaining $K^+$ contents considered average (1.5-3.0 $mmol_c$ $dm^{-3}$) in the two evaluation periods. Application of the greater K dose in dRYL also resulted in an average $K^+$ content at 180 DAB. Concentrations of $K^+$ obtained with the other treatments were classified as low (Raij et. al., 1997) (Fig. 2 a, b). Despite intense extraction of K by sugarcane, levels of exchangeable potassium was not reduced during the crop cycle in the soils evaluated (Table 1) when the only source of potassium was the straw (control) (Fig. 2 a, b). The potassium doses provoked a linear increase in the content of exchangeable potassium in the eRYA evaluated at 180 DAB (Fig. 2 a) and in the concentration of $K^+$ in the dRYL and eRYA evaluated 360 DAB (Fig. 2 b), reaching values of 2.4, 1.3 and 2.5 $mmol_c$ $dm^{-3}$, respectively, with the application of higher potassium doses (Fig. 2 a, b). The application of potassium quadratically increased the exchangeable potassium content in dRYL assessed at 180 DAB, obtaining 195 kg $ha^{-1}$ of $K_2O$ from the application of 1.6 $mmol_c$ $dm^{-3}$ of $K^+$ (Fig. 2 a).

### *Plant growth*

The application of K in eRYA affected the height of sugarcane (F= $3.33^{*}$), however there was no influence of K application on stem diameter and number of tillers, which presented average values of 22.6 and 26.2 mm in diameter of the stem and 42 and 35 tillers, respectively, for dRYL and eRYA. Height of the sugarcane increased quadratically ($y= -0.0008439x^2 - 0.1871x +78.58$ $R^2=0.86$ $F=9.55^{**}$), reaching a maximum of 89 cm with the use of 111 kg $ha^{-1}$ of $K_2O$. However, with application of the dose of 65 kg $ha^{-1}$ of $K_2O$ it was possible to reach a height of 88.4 cm, which corresponds to a reduction of 46 kg $ha^{-1}$ of $K_2O$ compared to the dose that promoted greatest growth. The increase in potassium doses did not provoke an effect on sugarcane height in the dRYL, which had an average of 50.6 cm (F=$0.43^{ns}$). The application of greater K doses allowed that the RB855453 variety grown in eRYA (84 cm) reach a height of 48% greater than the variety SP81-3250 grown in dRYL (49 cm). Less growth was registered in sugarcane treated with the dose of 195 kg $ha^{-1}$ of $K_2O$ in eRYA compared to that cultivated with the dose of 65 kg $ha^{-1}$ of $K_2O$.

### *Nutritional state of the sugarcane*

The application of K influenced the content of this nutrient in the leaves of sugarcane cultivated in dRYL (F= $40.8^{**}$). There was no effect of potassium doses on the levels of other nutrients in the sugarcane leaves. Foliar potassium levels ranged from 10.4 to 12.8 g $kg^{-1}$ in the variety SP81-3250 grown in dRYL and 11.9 to 13.6 g $kg^{-1}$ in the variety RB855453 cultivated in eRYA (Table 2). In all treatments and soils evaluated, K contents were within the range deemed appropriate (10-16 g $kg^{-1}$ of K) for the cultivation of sugarcane (Raij et al., 1997). Potassium doses applied in the dRYL increased foliar K content in sugarcane (Fig. 3), reaching a maximum level of 12.9 g $kg^{-1}$ of K with application of the dose of 170 kg $ha^{-1}$ of $K_2O$. However, it is interesting to note that in this case the dose of 65 kg $ha^{-1}$ of $K_2O$ in dRYL resulted in 11.9 g $kg^{-1}$ of K in the leaf dry mass (Table 2). This content is within the adequate range, and permits for reducing the utilization of potassium fertilizer by 105 kg $ha^{-1}$ when compared to the dose that resulted in the maximum foliar K content. There was no effect of the treatments on foliar potassium in eRYA, which presented an average of 12.5 g $kg^{-1}$ of K. Foliar contents of Ca and Mg decreased with the application of potassium levels in dRYL (Fig. 4 a, b). There was no effect of K doses on the foliar contents of Ca and Mg in eRYA, however, with increasing rates of K applied the foliar concentrations of these two nutrients showed a 14% reduction in the content of Ca and 21% reduction in Mg content (Fig. 4 a, b), possibly indicating an antagonistic effect of $K^+$ on both $Ca^{2+}$ and $Mg^{2+}$. Foliar contents of Ca obtained in eRYA were superior to those achieved by sugarcane grown in dRYL (Fig. 4 a). However, even with the decrease in levels of these two nutrients, they were within the range considered adequate for the sugarcane ratoon (Malavolta et al., 1997; Raij et al., 1997). Only the mean levels of macronutrients N (17.3 - dRYL and 17.3 - eRYA), P (1.4 - eRYA) and S (1.4 - eRYA) in g $kg^{-1}$ and Cu (2.4 - dRYL and 3.3 - eRYA) in mg $kg^{-1}$ presented values very close to the lower limit of the adequacy range

**Table 1.** Chemical and particle size attributes of dystrophic Red Yellow Latosol and eutrophic Red Yellow Agirsol in the topsoil five days after harvesting the first ratoon

| Depth (m) | pH | O.M. | P | K | Ca | Mg | H+Al | SB[a] | T[b] | V[c] |
|---|---|---|---|---|---|---|---|---|---|---|
| | $CaCl_2$ | g $dm^{-3}$ | mg $dm^{-3}$ | ------------------------mmolc $dm^{-3}$-------------------- | | | | | | % |
| dRYL - 0.0-0.20 | 4.8 | 15 | 6 | 0.7 | 22 | 7 | 34 | 30 | 63 | 47 |
| eRYA - 0.0-0.20 | 4.8 | 17 | 5 | 0.8 | 22 | 8 | 34 | 31 | 65 | 48 |
| | Granulometry | | | | | | | | | |
| | Clay | | Silt | | Fine Sand | | | Coarse Sand | | |
| | ----------------------------------------- g $kg^{-1}$---------------------------------------- | | | | | | | | | |
| dRYL - 0.0-0.20 | 170 | | 41 | | 563 | | | 226 | | |
| eRYA - 0.0-0.20 | 164 | | 41 | | 452 | | | 343 | | |

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

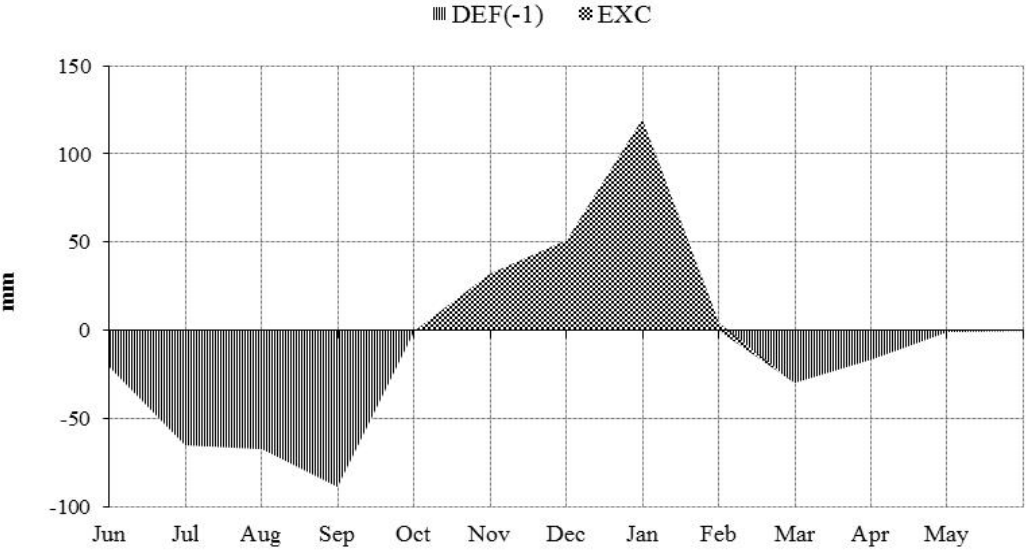

**Fig 1.** Representation of the water balance (Thornthwaite and Mather, 1955) of both soils evaluated in the city of Taiúva, SP - Brazil, from June 2011 to May 2012. DEF: Deficit; EXC: Surplus (CAD = 120 mm).

(Malavolta et al., 1997; Raij et al., 1997). Levels of the other nutrients in the leaves were considered within the levels considered adequate for cultivation of sugarcane (Table 2).

### *Accumulation of potassium in the straw, stalks and shoots*

There was an effect of K doses on accumulation of this nutrient in sugarcane straw grown in eRYA (F= $27.09^{**}$) and in the shoots in dRYL (F= $13.31^{**}$) and eRYA (F= $22.12^{**}$). Potassium application quadratically increased K accumulation in the straw of sugarcane in eRYA and in the stalk in dRYL and eRYA, reaching maximum accumulations of 157; 209 and 149 kg $ha^{-1}$ of K for the doses of 195, 124 and 121 kg $ha^{-1}$ of $K_2O$, respectively (Fig. 5 a, b). However, the doses of K did not influence the accumulation of this nutrient in the straw in dRYL, with an average of 209 kg $ha^{-1}$ of K. Potassium accumulation in the straw of sugarcane grown in dRYL was higher than that obtained in eRYA for all treatments. The dose of 130 kg $ha^{-1}$ of $K_2O$ in dRYL resulted in 223 kg greater potassium accumulation than the same dose in eRYA (Fig. 5 a). The increase in K accumulation in sugarcane shoots fit to a linear equation in the eRYA ($y = 0.68465x + 143.580$; $R^2 = 0.85$; $F = 75.05^{**}$) with averages ranging from 120 to 283 kg $ha^{-1}$ of K between the control treatment and the dose of 195 kg $ha^{-1}$ $K_2O$, and quadratically in the dRYL ($y = -0.01604x^2 + 4.244x + 188.44$; $R^2 = 0.95$; $F = 8.62^{**}$), where the greatest accumulation of K (469.3 kg $ha^{-1}$ of K) was achieved with the dose of 132 kg $ha^{-1}$ $K_2O$.

### *Production of stalks and straw*

Application of the treatments affected the production of stalks of sugarcane grown in dRYL (F= $48.75^{**}$). The K doses quadratically increased production of stalks of sugarcane in both soils (Fig. 6), reaching maximum stalk productions of 113 and 106 Mg $ha^{-1}$ with the doses of 117 and 123 kg $ha^{-1}$ of $K_2O$, respectively, for dRYL and eRYA. However, it is important to emphasize that application of the dose of 65 kg $ha^{-1}$ of $K_2O$ promoted 88 and 95% of the maximum production in dRYL and eRYA, respectively, with a reduction of more than 55 kg $ha^{-1}$ of potassium fertilizer.

Productivity increase was on the order of 75 and 22 Mg $ha^{-1}$ between the control treatment and the dose that resulted in the greatest estimated productivity in the dRYL and eRYA, respectively. The foliar K content that was associated with greatest production in dRYL was 12.7 g $kg^{-1}$, considered adequate as indicated by Raij et al. (1997). It was also verified that the dose of 195 kg $ha^{-1}$ of $K_2O$ caused a decrease in stalk yield compared with the dose of 65 kg $ha^{-1}$ of $K_2O$ in dRYL (Fig. 6); however, although there was a statistical difference, this reduction was only 24% of the maximum yield. Straw production presented variations among the treatments in dRYL (F=$3.39^{*}$) and eRYA (F= $3.39^{*}$). The

**Table 2.** Average results of nutrient contents in the leaf +1 at 240 DAB for the second sugarcane ratoon in function of potassium dose application in dRYL and eRYA.

| Doses | N | | P | | K | | Ca | | Mg | | S | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | dRYL | eRYA | dRYL | eRYA | dRYL | eRYA | dRYL | eRYA | dRYL | eRYA | dRYL | eRYA |
| kg ha$^{-1}$ | ------------------------------ g kg$^{-1}$ ------------------------------ | | | | | | | | | | | |
| 0 | 16.6a | 17.4a | 2.2a | 2.1a | 10.4c | 11.9a | 2.9ab | 3.7a | 1.4a | 1.4a | 1.5a | 1.3a |
| 32.5 | 17.4a | 17.0a | 2.2a | 2.1a | 11.4b | 11.7a | 3.4a | 3.4a | 1.4a | 1.3a | 1.6a | 1.4a |
| 65.0 | 17.4a | 17.1a | 2.2a | 2.1a | 11.9b | 12.5a | 2.9ab | 3.2a | 1.4a | 1.2a | 1.5a | 1.4a |
| 130.0 | 17.6a | 17.7a | 2.3a | 2.1a | 12.8a | 13.6a | 2.7ab | 3.5a | 1.2a | 1.3a | 1.6a | 1.3a |
| 195.0 | 17.4a | 17.4a | 1.8a | 2.1a | 12.8a | 12.8a | 2.6b | 3.2a | 1.2a | 1.1a | 1.6a | 1.3a |
| F-test | 0.2 | 0.3 | 1.0 | 0.2 | 40.8$^{**}$ | 1.0 | 2.9 | 0.9 | 1.8 | 1.0 | 2.4 | 0.1 |
| CV%$^{a}$ | 12.8 | 6.19 | 19.1 | 4.1 | 2.9 | 13.0 | 14.7 | 14.7 | 12.1 | 17.5 | 5.3 | 10.7 |

| Doses | Cu | | Zn | | Fe | | Mn | |
|---|---|---|---|---|---|---|---|---|
| | dRYL | eRYA | dRYL | eRYA | dRYL | eRYA | dRYL | eRYA |
| kg ha$^{-1}$ | ------------------------------ mg kg$^{-1}$ ------------------------------ | | | | | | | |
| 0 | 3a | 4a | 19a | 21a | 68.0a | 74.0a | 67.8a | 45a |
| 32.5 | 3a | 3a | 19a | 17a | 74.2a | 71.8a | 68.0a | 38a |
| 65.0 | 3a | 2a | 21a | 20a | 72.6a | 72.8a | 64.6a | 48a |
| 130.0 | 2a | 4a | 22a | 22a | 70.4a | 71.0a | 66.0a | 51a |
| 195.0 | 2a | 4a | 17a | 17a | 72.0a | 73.8a | 60.4a | 42a |
| F-test | 1.5 | 1.9 | 1.5 | 0.4 | 0.4 | 0.2 | 1.3 | 2.7 |
| CV%$^{a}$ | 31.4 | 41.3 | 18.2 | 42.9 | 11.8 | 8.8 | 9.4 | 14.0 |

Means followed by the same letter in the column are not statistically different according to the Tukey test at 5% probability. $^{a}$Coefficient of variation, **significant at the probability level of 1% (**P<0.01) by the F-test

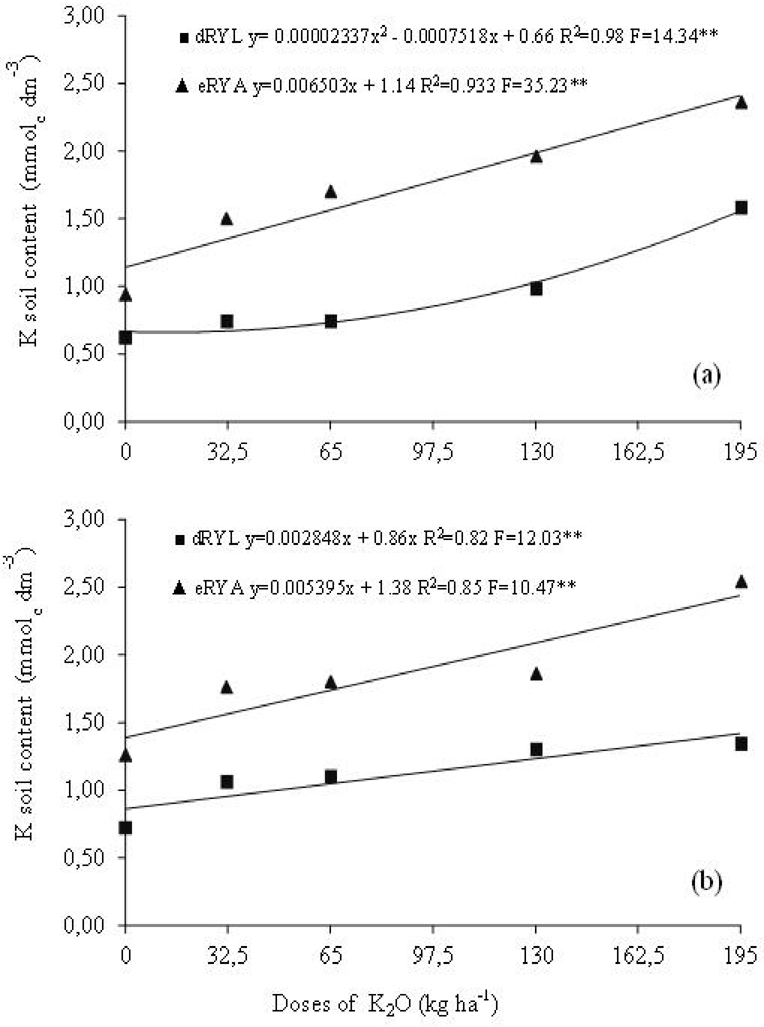

**Fig 2.** Effect of potassium application on the content of K$^{+}$ in the soil at 180 (a) and 360 (b) DAB for the second sugarcane ratoon cultivated in dystrophic Red Yellow Latosol and in eutrophic Red Yellow Agirsol. $^{**}$- significant at 1% ($^{**}$P≤0.01) probability, respectively, by the F-test.

highest yields were generally obtained by the varieties which received the dose of 65 kg ha$^{-1}$ of $K_2O$, representing 45 Mg ha$^{-1}$ and 32 Mg ha$^{-1}$, respectively, for the dRYL and eRYA. It was also observed that the variety SP81-3250 cultivated in the dRYL presented greater straw production in relation to the variety RB855453 in eRYA (Figure 8).

### *Juice quality of the sugarcane*

The potassium doses affect the levels of total soluble solids in the eRYA (F= 4.36$^{*}$) and total recoverable sugar in the dRYL (F =15.54$^{**}$). In the dRYL an average total soluble solids equal to 20 ºBrix was obtained and in the eRYA concentrations varied from 16 to 18 ºBrix. There was a quadratic increase in reducing sugars ($y = 0.00000829x^2 - 0.00152304x + 0.64091684$; $R^2 = 0.99$; $F = 9.91^{**}$) and purity of the broth ($y = 0.00019773x^2 - 0.03958340x + 91.2439232$; $R^2 = 0.87$; $F = 8.5^{**}$) for the variety RB855453 grown in eRYA. The application of K also promoted a quadratic increase in the TRS (sugar production) in variety SP81-3250 cultivated in dRYL ($y = - 0.000188x^2 + 0.03259078x + 151.792367$; $R^2 = 0.88$; $F = 45.35^{**}$), reaching a maximum production of 153 kg Mg$^{-1}$ of sugarcane for the dose of 86 kg ha$^{-1}$ of $K_2O$. Considering the stalk productivities obtained with application of the dose of 65 kg ha$^{-1}$ of $K_2O$ (99 and 101 Mg ha$^{-1}$ in dRYL and eRYA, respectively), it was found that the overall recoverable sugar yield reached 15 and 13 Mg ha$^{-1}$ of ground sugarcane, respectively, for the dRYL and eRYA.

## Discussion

The increase in the levels of exchangeable potassium in both soils and assessment times occurred due to the supply of K doses and possibly due to the intense release of this nutrient by straw. It is known that K remains almost entirely in the ionic form within the plant tissue (Hawkesford et al., 2012); this facilitated its exit from the cell after breakdown of the plasma membrane, thus contributing to increase of this nutrient in the soil. Another explanation for the increase in $K^+$ contents in topsoil is the increase in CEC, resulting from increased organic matter in the soil and saturation of K in the colloidal exchange complex, since the release of organic acids by the straw alters the order of cation leaching. This allows for the accumulation of $K^+$ in the topsoil, mainly due to increased leaching of divalent and/or trivalent cations (Franchini et al., 1999; Ziglio et al., 1999). It is believed that the lack of effect on growth variables of the second sugarcane ratoon would be the consequence of lower soil water availability during the period in which the analyses were performed (Fig.1), because most $K^+$ in the soil is transported to the root surface via diffusion, a process highly dependent on soil water (Kuchenbuch, et al., 1986). Thus, it may be stated that the presence of water in the soil provides ideal hydraulic conditions in the vicinity of roots, improving the appearance and growth of tillers in the sugarcane crop (Berding et al., 2005; Bonnett et al., 2005; Widenfield, 1995). The lack of an effect on ratoon growth may also be due to the low nutritional requirement in the initial sugarcane growth phase (Flores et al., 2014 c). The results of plant height in eRYA corroborate with those found by El-Tilib et al. (2004), who also observed the effect of K on height of the sugarcane ratoon. These authors found that the greatest height was obtained with application of 86 kg ha$^{-1}$ of $K_2O$. The greater plant height obtained in eRYA, compared to that found in dRYL, may result from genotypic differences between the sugarcane varieties used in this study. Increase in foliar potassium content in the variety SP81-3250 grown in dRYL probably occurred due to the increase in potassium intake in the region of root absorption, therefore allowing that the culture maintain its nutritional status in the proper range. The absorption of calcium and magnesium was competitively inhibited by increasing concentrations of $K^+$ in the absorption region of the root (Hawkesford et al., 2011). Therefore, it is interesting to note that high doses of potassium fertilizer may

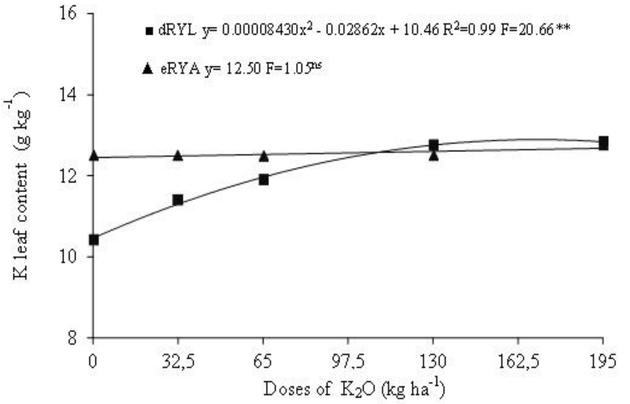

**Fig 3.** Effect of potassium application on K concentration in the leaf +1 at 240 DAB for the second sugarcane ratoon cultivated in dystrophic Red Yellow Latosol and eutrophic Red Yellow Agirsol. $^{**}$ and $^{ns}$ – significant at the probability level of 1% ($^{**}P \leq 0.01$) and non-significant, respectively, by the F-test.

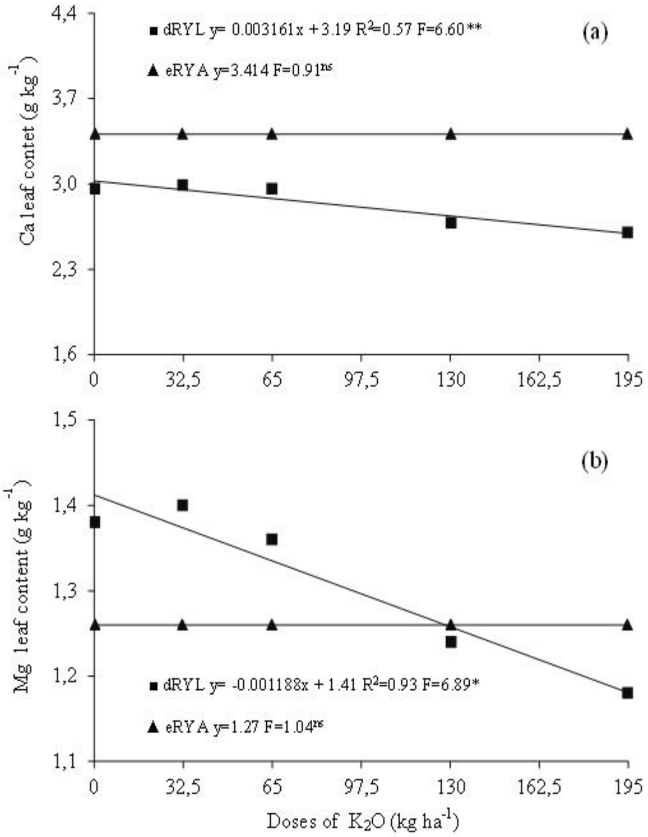

**Fig 4.** Effect of potassium application on contents of Ca (a) and Mg (b) in the leaf +1 at 240 DAB for the second sugarcane ratoon cultivated in dystrophic Red Yellow Latosol and eutrophic Red Yellow Agirsol. $^{**}$, $^{*}$ and $^{ns}$ – significant at the probability level of 1% ($^{**}P \leq 0.01$), 5% ($^{*}P \leq 0.05$) and non-significant, respectively, by the F-test.

have caused leaching of $Mg^{2+}$ (Shone, 1967) and $Ca^{2+}$ to deeper layers of the soil profile, outside the region of greatest absorption by roots and thus reducing their foliar contents. The low level of soil moisture in the initial months of crop development may have also caused the decrease in absorption of these two nutrients, since there would have occurred less transport of $Ca^{2+}$ and $Mg^{2+}$ to the root surface by the mass flow process, the mechanism responsible for increasing contacted of bivalent cations with the roots.

Increased potassium accumulation in straw, stalks and shoots may be due to the high yield obtained by the varieties used in the study. Facilitated transport of K from the root to the reserve organs, due to its high mobility in plants, may also have influenced these results, thus indicating that absorption of this nutrient is a determining factor in sugarcane production. Therefore, this high potassium demand of sugarcane would be related to its role in several physiological and metabolic processes such as photosynthesis, osmoregulation, nutrient transport, nitrogen absorption and synthesis of proteins and starch (Hawkesford et al., 2011). The increased accumulation of K in the straw and stalks can also be linked to the capacity of sugarcane to absorb K quantities exceeding its needs, especially when the nutrient is supplied in excess (luxury consumption). The results obtained corroborate with those found by Flores et al. (2014a). The effect of potassium levels on increased stalk productivity would be a result of low levels of $K^+$ found in the topsoil prior to initiating the experiments. These levels are considered limiting to high productivity, considering that the critical level of $K^+$ in soil indicated for 90% relative production is 1.5 $mmol_c\ dm^{-3}$ (Raij et al., 1997). Moreover, in the absence of K application there was lower participation of this nutrient in the soil sorption complex, since saturation of the element in the CEC was 2.3 and 1.9% for dRYL and eRYA, respectively, where these results also considered the critical level to obtain high yields (Orlando Filho et al., 1993). In both experiments the dose of 65 kg $ha^{-1}$ of $K_2O$ showed high yields (average of 100 Mg $ha^{-1}$ of stalks) with reduced use of potassium fertilizer, a reduction of 50% compared to the recommended dose for conventional cultivation of sugarcane in the country. These results confirm the favorable effect of straw and potassium on the nutrition and productivity of sugarcane ratoons in conservation management systems (Flores et al., 2014). The decreases in growth with regards to height and productivity of stalks, observed in the plants treated with the dose of 195 kg $ha^{-1}$ of $K_2O$, may have been caused by the high salinity of potassium chloride, excess absorption of chlorine or in function of the variety SP81-3250 having reached its maximum capacity, since the productivity decrease in dRYL was only 24%. Toxicity caused by excessive nutrient absorption may be related to the specific conditions of each site in relation to the soil, climate and crop characteristics. Studies published in literature indicate the lack of an effect on sugarcane juice quality as a function of potassium fertilization (Shukla et al., 2009; Flores et al., 2014 b). As observed in the present study, Otto et al. (2010) also observed a quadratic effect on sugarcane reducing sugars, inversely proportion to K doses. The total recoverable sugar yield improved with increasing content of K in the soil. This result may be related to increased productivity and potassium accumulation in sugarcane leaves and stalks, since this nutrient acts in the transport and storage of carbohydrates, because of its ability to depolarize the plasma membrane (Hawkesford et al., 2011). The differences encountered between the two experiments may have resulted from the use of two varieties with different genetic characteristics. The greater K content

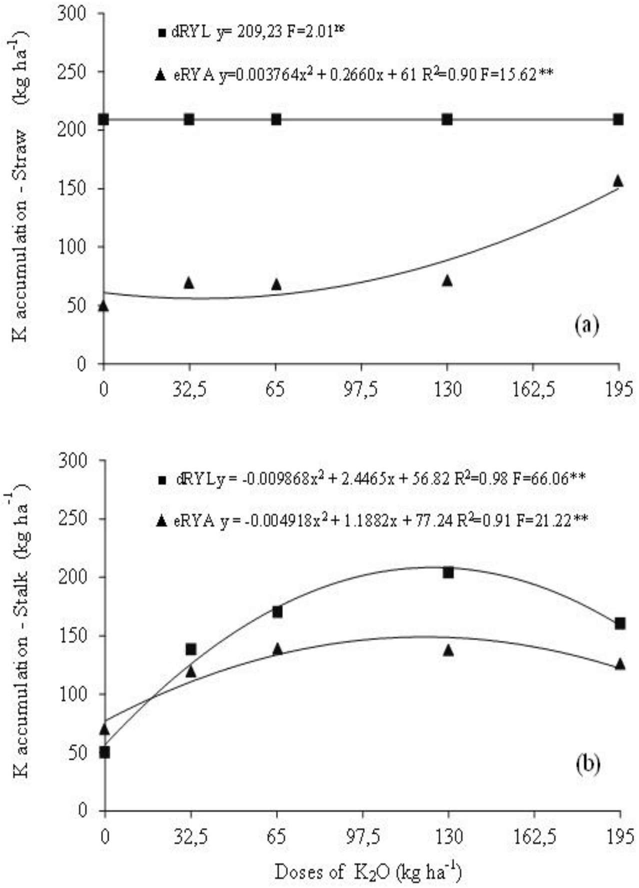

**Fig 5.** Effect of potassium application on K accumulation in the straw (a) and in the stalk (B) at 360 DAB for the second sugarcane ratoon cultivated in dystrophic Red Yellow Latosol and eutrophic Red Yellow Agirsol. ** and ns – significant at the probability level of 1% (**P≤0.01) and non-significant, respectively, by the F-test.

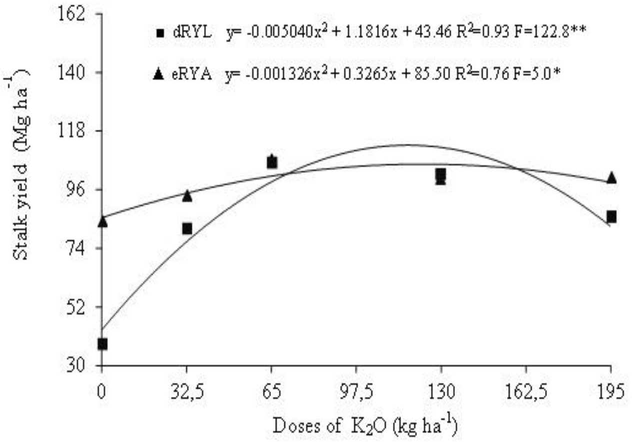

**Fig 6.** Effect of potassium application on stalk yield at 360 DAB for the second sugarcane ratoon cultivated in dystrophic Red Yellow Latosol and eutrophic Red Yellow Agirsol. * and ** - significant at the probability levels of 1% (**P≤0.01) and 5% (*P≤0.05) respectively, by the F-test.

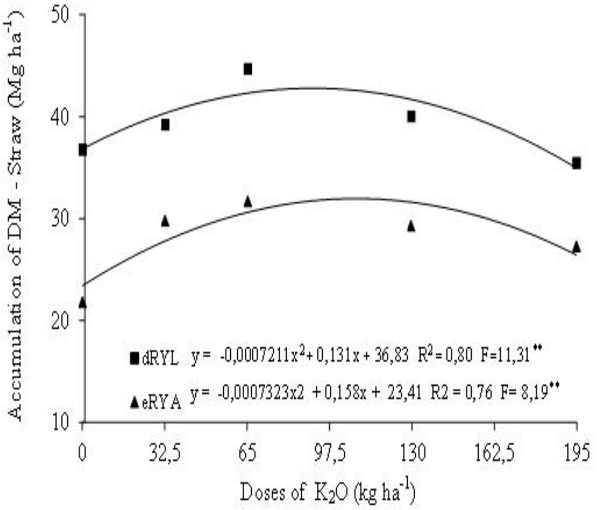

**Fig 7.** Effect of potassium application on accumulation of dry straw mass at 360 DAB for the second sugarcane ratoon cultivated in dystrophic Red Yellow Latosol and eutrophic Red Yellow Agirsol. ** - significant at the probability levels of 1% (**P≤0.01) by the F-test.

in straw of the variety RB855453 in eRYA compared to straw of the variety SP81-3250 in dRYL may also have contributed to differences in results between the studied soils. Additionally, the greater water retention capacity of Argisols compared to Latosols potentially contributed to the differences observed between experiments.

## Materials and Methods

### *Experimental site, soil and plant characteristics*

Two field experiments were conducted in the second sugarcane ratoon cultivated in the conservation management system, from the period of June 2011 to May 2012. One experiment was installed at the Fazenda Santa Maria (21º07'29"S and 48º25'40"W), in Dystrophic Red Yellow Latosol (Embrapa, 2013) (Oxisols - USDA, 1999) with the SP81-3250 variety, while the other was installed at the Fazenda Santa Ofélia (21º07'47"S and 48º25'36"W) in Eutrophic Red Yellow Agirsol of medium texture (Embrapa, 2013) (Ultisols - USDA, 1999) with the RB855453 variety. These experiments were implanted and conducted under the same climatic conditions. The local climate was classified as Aw Tropical rainy with dry winter and the coldest month presents an average temperature greater than 18ºC. It was observed that the driest month presented precipitation lower than 60 mm, with rainy season that started in October (Fig.1). Before application of the treatments in the second sugarcane ratoon, 15 soil subsamples were collected from the control plots at the depth of 0 to 0.2 m. The resulting composite sample was used for chemical analysis, to evaluate fertility (Raij et al., 2001) and particle size (Camargo et al, 2009) (Table 1). In the same period the quantification of biomass straw was performed, based on collection of one square meter at four random points in the two experiments separately. Dry straw masses of 17 and 13Mg $ha^{-1}$ were obtained in the dRYL and eRYA, respectively. Subsequently, the samples were analyzed to determine the macronutrient levels (Bataglia et al., 1983) for each experiment separately. Next, the accumulation of macronutrients was calculated, obtaining values of 273, 17, 62, 193, 42 and 32 kg $ha^{-1}$ of N, P, K, Ca, Mg and S for the variety SP81-3250 cultivated in dRYL, respectively, and for the variety RB855453 cultivated in eRYA values of 127, 7, 104, 60, 13 and 13 kg $ha^{-1}$ for N, P, K, Ca, Mg and S, respectively.

### *Treatment details and fertilizer application*

Initial preparation of the soil for cultivation of the sugarcane plants was carried out based on soil analysis and requirements of the crop in 2009. The treatments were implanted after harvesting the sugarcane plant in May 2010. After harvest of the first ratoon, the same treatments were applied in the same plots in June 2011. For both experiments five treatments were determined based on the reference dose equal to 130 kg $ha^{-1}$ of $K_2O$ (Spironello et al., 1997). Thus, the doses 0 (control), 32.5, 65.0, 130.0 and 195.0 kg $ha^{-1}$ of $K_2O$ corresponded to 0, 25, 50, 100 and 150% of the reference dose, respectively. The experimental design consisted of randomized blocks with five repetitions. Each plot consisted of five rows measuring 10 m long, with spacing of 1.5 m between rows, totaling 75 $m^2$ per plot. The three central rows were considered useful for sampling, where the two meters from each edge were considered borders. Potassium chloride (60% $K_2O$) was used as a source of potassium. Also applied to both experiments were 100 kg $ha^{-1}$ of nitrogen in the form of urea and 30 kg $ha^{-1}$ of $P_2O_5$ in the form of triple superphosphate. The fertilizers were applied alongside the sugarcane ratoons (fertilization range), without incorporation. Liming was performed three months before planting the sugarcane and immediately after the harvest of each crop cycle with lime (PRNT: 100%) broadcasted across the entire area, seeking to increase base saturation to 60%. Control of weeds was not necessary because straw present on the soil surface impeded their appearance.

### *Plant, soil sampling and chemical analysis*

Growth was evaluated at 120 DAB by determining the number of tillers within a 1.5 m length of the row, considering three locations of the useful area for each plot. On the same date measurements of the stalk diameter (first internode) were obtained with a digital caliper, as well as plant height, corresponding to the distance between the soil and the completely visible atrium of the first leaf from top to bottom of the stalk (leaf +1), in ten plants per plot. In each experiment soil samples were collected at 180 and 360 DAB (days after budding of the second sugarcane ratoon), alongside the row of sugarcane ratoons (fertilization range), in the depth of 0 to 0.2 m at 10 random points in the three central rows of each plot. Determination of the exchangeable potassium content was performed using the methods described by Raij et al. (2001). To assess the nutritional status of the plants, at 240 DAB in full development of the culture, the middle third of fifteen leaves +1 were collected and the midrib excluded (Raij et al., 1997). The samples were then subjected to decontamination, dried in an oven at 65º C until reaching constant mass, and later ground in a Wiley mill. Measurements of all macronutrients and micronutrients (Cu, Zn, Fe and Mn) in the plant tissue were performed according to the methods described by Bataglia et al. (1983).

### *Production, juice quality and accumulation of potassium in the sugarcane*

Harvest was performed at 360 DAB, collecting the plants in an area of three square meters from two random points in the useful area of each plot, separating the stalks from the straw (dry and green leaves, sheaths and tops). Next, the stalks and straw were weighted separately corresponding to each plot. Calculations of average productivity were then performed and their estimates were expressed per hectare. Also at harvest, 10 contiguous stems were cut from the central lines in each plot to assess the technological quality of sucarcane (total soluble solids - ºBrix, industrial fiber, apparent sucrose - % Pol of the juice, purity of the extracted juice; %Pol of the sugarcane - PC and sugarcane reducing sugars - RS), according to the methods described by Consecana (2006). The TRS (theoretical recoverable sugar) was obtained by the following equation:

TRS (kg of sugar $Mg^{-1}$ of ground stalks) = (10 x 0.905 x 1.0526 x PC%) + (10 x 0.905 x RS%)

Where the value of 0.905 corresponds to losses of 9.5% in the industrial process, excluding fermentation and distillation, and the value 1.0526 corresponds to the stoichiometric factor of sucrose conversion into reducing sugars (Consecana, 2006). At harvest dry matter accumulation in the straw and stalks of the plants was obtained. For this 400 g samples were collected in each fraction, which were dried in an oven at 65 $^oC$ for 72 hours and then weighed. Dried samples were ground in a Wiley mill and soon after the K content in stalks and straw was determined (Bataglia, 1983). Then, accumulation of potassium in the straw, stalks and shoots (straw + stems) was calculated for sugarcane based on the following formulas:

$Ac\ K_{(straw)} = Ac\ DM_{straw}$ (kg $ha^{-1}$) × Content of $K_{straw}$ (kg $kg^{-1}$)

$Ac\ K_{(stalk)} = Ac\ DM_{stalk}$ (kg $ha^{-1}$) × Content of $K_{stalk}$ (kg $kg^{-1}$)

Where Ac = accumulated and DM = dry mass. Potassium accumulation in the shoots was calculated by summing K accumulation in the straw and stem.

### *Statistical analysis of the data*

Estimates of the variables studied in both soils were subjected to individual analysis of variance by the F-test. The means of each treatment were compared by the tukey test at 5% probability. To study the effect of K doses on the variables analyzed we used the polynomial regression analysis with the highest coefficients of determination ($R^2$).

## Conclusion

The dose of 65 kg $ha^{-1}$ of $K_2O$, which corresponds to 50% of the recommended dose for conventional cultivation, promoted the acquisition of 88 and 95% of the maximum sugarcane yield in dRYL and eRYA, respectively. This dose maintains the adequate nutritional status of ratoons and allows the accumulation of potassium in the stalk at satisfactory levels to achieve high yields. Adequate foliar K levels in sugarcane are related to acquisition of high stalk yields. Application of K has little effect on the technological quality of sugarcane.

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