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Potassium Dynamics in Ruzigrass Rhizosphere

Marcelo Raphael Volf[(1)], Tiara Moraes Guimarães[(1)], Daniele Scudeletti[(1)], Igor Vilela Cruz[(1)] and Ciro Antonio Rosolem[(2)*]

[(1)] Universidade Estadual Paulista "Júlio de Mesquita Filho", Faculdade de Ciências Agronômicas, Pós-Graduação em Agronomia, Área de Agricultura, Botucatu, São Paulo, Brasil.
[(2)] Universidade Estadual Paulista "Júlio de Mesquita Filho", Faculdade de Ciências Agronômicas, Departamento de Produção e Melhoramento Vegetal, Botucatu, São Paulo, Brasil.

ABSTRACT: Ruzigrass (*Urochola ruziziensis)* has a large capacity to take up K from the soil, including non-exchangeable forms, and can play an important role in nutrient cycling in integrated production systems. However, K transport to roots of brachiarias is not well known, nor the nutrient dynamics in the rhizosphere, where a concentration gradient may be established towards the non-rhizospheric soil, creating a favorable environment for the release of non-exchangeable K. This study aimed to evaluate the effect of ruzigrass on K dynamics in the rhizosphere and on non-exchangeable K release. Ruzigrass was grown in pots filled with a *Latossolo Vermelho Amarelo* (Typic Hapludox) that was collected at 0.00-0.20 and 0.20-0.60 m layer from a cultivated area and fertilized with 0, 30, and 60 mg kg^{-1} of K, plus a treatment with forest soil, used as control. Thirty days after plant emergence, soil samples were taken at the following distances from the roots: 0.5, 1.0, 1.5, 3.0, 5.0, and 10.0 mm. For the highest exchangeable K rate (60 mg dm^{-3}), the exchangeable K level was higher from 0 to 0.5 mm of the roots for both soils (0.00-0.20 and 0.20-0.60 m). Therefore, more K was transported to the rhizosphere than the plant could take up. A depletion of exchangeable K observed in the rhizosphere resulted in the release of K from non-exchangeable forms, as observed in the soils from 0.00-0.20 (60 mg dm^{-3}) and 0.20-0.60 m (without application of K). Ruzigrass grown on low K soils without fertilizer application results in a larger exchangeable K depletion zone than in soils that were fertilized or originally high in exchangeable K, showing a high potential for K cycling in the system.

Keywords: *Urochloa ruziziensis*, non-exchangeable K, exchangeable K, rhizospheric soil.

*** Corresponding author:**
E-mail: ciro.rosolem@unesp.br

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INTRODUCTION

The available potassium (K) content is usually low in most tropical soils, either by origin or through exhaustion. Therefore, potassic fertilizers are needed for high yields in intensive and extensive agricultural systems (Mueller et al., 2012; Zörb et al., 2014). In Brazil, 85 % of the soils in the Cerrado region present low K availability and in more than 60 % of Brazilian soils, the crops respond to potassic fertilization (Lopes and Cox, 1977).

Diffusion has been considered the main mechanism of K transport to the roots; however, mass flow can have a significant contribution when the K concentration in the soil solution is high (Ruiz et al., 1999; Oliveira et al., 2004). The K availability, as well as the soil supply capacity, depend on the presence of primary and secondary minerals, fertilizer application, and soil CEC (Cation Exchange Capacity), but also depend on the amount of nutrient cycled by plants (Rosolem and Steiner, 2017). The migration of structural or non-exchangeable K to the soil solution is observed when the K level is very low, or after the exchangeable K is depleted (Rosolem et al., 1988). The K content in the soil solution is buffered by the exchangeable K adsorbed with low energy on the exchange sites, and by the non-exchangeable K that is adsorbed with higher energy in the interlayers of clay minerals or primary minerals. The particle size, soil structure, biologic activity, organic acid complex, and inorganic cations in the soil solution affect the release of potassium from the mineral's surface (Singh and Goulding, 1997). The release of K retained in the interlayers of clay minerals (2:1 type) can occur by the action of plant roots once the rhizospheric zone presents a K depletion, occasionally including mineral transformation (Hinsinger and Jaillard, 1993).

The absorption of K by plants decreases its content in the soil solution and in the exchangeable pool, resulting in a chemical gradient towards the rhizosphere (Gommers et al., 2005), thus creating a favorable environment for the release of non-exchangeable K. Ruzigrass (*Urochloa ruziziensis*) is very efficient in taking up non-exchangeable K (Garcia et al., 2008), and since K is not bound to structural compounds in plants (Marschner, 1995), it is quickly released from plant residues to the soil, resulting in an important cycling of this nutrient, and an increase in exchangeable K in the uppermost soil layer (Garcia et al., 2008). Ruzigrass is widely used in integrated systems and as a cover crop under no-till systems. It has been demonstrated that some species, especially ruzigrass, have a high capacity to take up K from soils, including the non-exchangeable forms (Kaminski et al., 2007; Rosolem et al., 2012), and they are also important in integrated production systems as nutrient cyclers (Garcia et al., 2008).

Assuming that diffusion is the main mechanism of K transport to the root in all soils, it would be difficult to attribute important nutrient losses to leaching, as it has been observed (Rosolem et al., 1984; Rosolem and Steiner, 2017). Thus, the K content in both the soil and the cultivated plant can have an important influence in K transport up to the roots, but little is known about K transport up to the rhizosphere as affected by K rates in tropical soils and its consequences in the nutrient dynamics. Therefore, the objective of the present work was to evaluate the effect of ruzigrass on non-exchangeable K release and on the nutrient dynamics in the rhizosphere.

MATERIALS AND METHODS

A greenhouse experiment was carried out in Botucatu, São Paulo State, Brazil, in pots with a *Latossolo Vermelho Amarelo,* Typic Hapludox (Soil Survey Staff, 2010), sandy clay loam, sampled at two layers, 0.00-0.20 and 0.20-0.60 m, from a soybean field that had been cultivated for more than five years in a livestock-crop integration (LCI) system, with ruzigrass (*Urochloa ruziziensis)* grown as a cover crop in the off-season, and a 0.00-0.20 m layer sample from an area with native vegetation. Selected soil chemical and physical properties are presented in table 1.

The experimental design was complete randomized blocks with eight replicates. The treatments were forest soil, soil collected at 0.00-0.20 m, and soil collected at 0.20-0.60 m. The cultivated soils were fertilized with 0.0, 30.0, and 60.0 mg kg^{-1} of K. The experiment was conducted in pots that were built to obtain a planar root mat, simulating a planar rhizosphere. A similar device, called Plant Growth Container (PGC), was described and evaluated by Chen et al. (2002). Each PGC is composed of two compartments (Figure 1). The upper compartment is 0.07 m high and 0.10 m in diameter and filled with sand. A nylon net delimits the compartments, impeding root growth into the soil of the lower compartment. The lower compartment is 0.10 m high and 0.10 m in diameter, and filled with soils according to the treatments, and the bottom was closed with a fabric net to allow water ascension by capillarity. These soils were not limed and received no fertilizer besides K. The sand used in the upper compartment was washed with running water to remove coarse impurities, then it was washed with 0.1 mol L^{-1} hydrochloric acid (HCl) and with deionized water to remove acid residues.

Ruzigrass seeds were placed to germinate in a box with washed sand. Seven days after emergence, three uniform seedlings were transplanted to each PGC, which were arranged in trays with water. Hoagland and Arnon (1950) nutrient solution without K was applied weekly. On the 35th day after transplantation, the PGCs were disassembled. The upper compartment and the nylon net that isolated the compartments were carefully removed, without disrupting the lower soil compartment.

Table 1. Selected soil chemical properties and particle size distribution

Soils	$pH(CaCl_2)$(1)	P(2)	ExcK(3)	Non-excK(4)	Ca^{2+}(5)	Mg^{2+}(5)	OM(5)	Clay(6)	Silt(6)	Sand(6)
		mg dm^{-3}	mmol$_c$ dm^{-3}				g dm^{-3}	g kg^{-1}		
0.00-0.20 m	5.2	20	0.65	3.83	22.2	11.7	17.0	205	112	682
0.20-0.60 m	4.0	5	0.45	4.75	4.5	3.1	6.0	280	100	620
Forest	3.8	6	1.34	5.89	4.1	3.5	12.0	275	175	550

(1) pH in $CaCl_2$ at a ratio of 1:2.5 v/v. (2 and 3) extracted with resin. (4) extracted with boiling HNO_3. (5) Chemical analyses were determinated according to Raij et al. (2001). (6) Clay, silt, and sand were determinated according Claessen (1997).

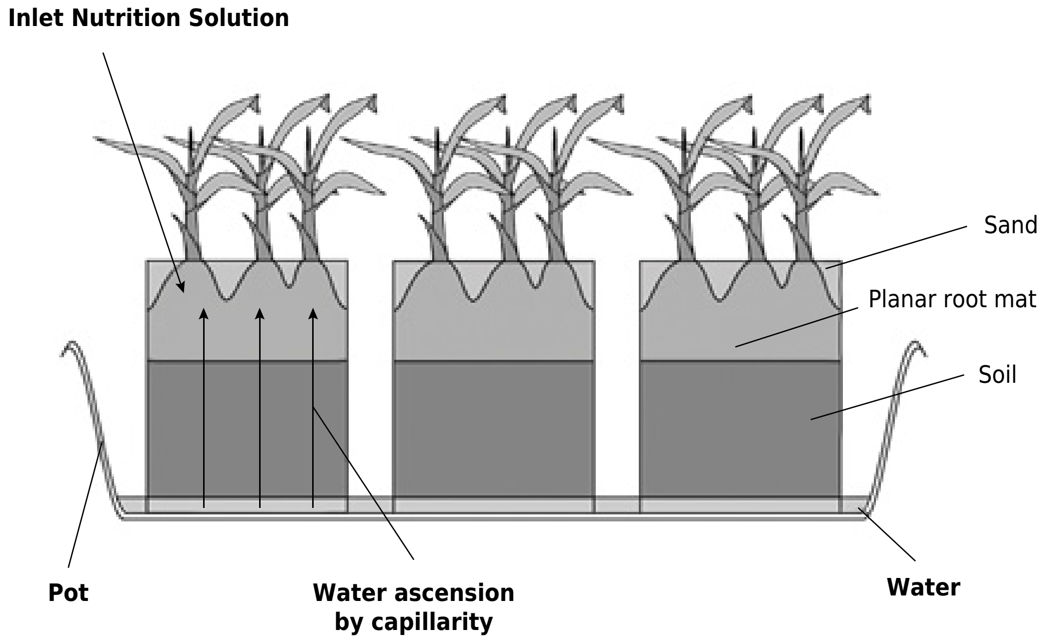

Figure 1. Plant growth containers (PGCs).

Ruzigrass shoots and roots were collected and dried in a forced air oven at 65 °C up to constant weight to determine the dry matter yield. Then the samples were ground using a Wiley® Mill, and sieved through a 1 mm mesh to analyze the plant K content, according to Malavolta et al. (1997).

To determine the exchangeable K content of the lower compartment soil, the soil was extracted from the PGC and was sliced into layers of 0.0-0.5, 0.5-1.0, 1.0-1.5, 1.5-3.0, 3.0-5.0, and 5.0-10.0 mm, starting from the root plane with the help of a soil slicer that was developed for this purpose. To obtain a larger soil volume for analysis, the replicates were combined in pairs. The exchangeable K was extracted with ion-exchange resin (Raij et al., 2001), and the non-exchangeable K was heat-extracted with HNO_3 1.0 mol L^{-1} (Knudsen et al., 1982) and analyzed with a Flame Photometer. Soil pH was determined in $CaCl_2$ 0.01 mol L^{-1}, according to Raij et al. (2001).

All the results were tested for homogeneity and normality and analyzed considering a randomized complete block design with four replicates. The results of the distances from the rhizosphere were compared within soils (0.00-0.20 m, 0.20-0.60 m, and forest), which were considered fixed variables; and the results of the soils were analyzed within each distance from the rhizosphere, considered as fixed variables. Means were compared by the t test (DMS, $p<0.05$), using SISVAR version 5.5.

RESULTS AND DISCUSSION

The soil pH($CaCl_2$) was not affected by ruzigrass (Table 2). The pH($CaCl_2$) values of the rhizosphere (up to 4.0 mm from the roots) were similar to that of the bulk soil, showing that K absorption or addition did not change the soil acidity.

The 0.00-0.20 m soil showed a higher pH as compared with the 0.20-0.60 m and the forest soil (Table 3). In the 0.20-0.60 m soil, the pH was higher than the other treatments in the 0.5 mm from the roots treatment without K (Figure 2b). This is probably a consequence of a higher K absorption in the fertilized treatments in this soil, and the proton release by the root acidifying the rhizosphere (Römheld and Marschner, 1984). Potassium is taken up by plants as K^+, and protons are exuded to maintain the chemical balance.

Table 2. Summary of the ANOVA results (*p* value) and LSD for pH($CaCl_2$), exchangeable and non-exchangeable K as affected by the distance from the roots of *U. ruziziensis* in each soil treatment

Source of variation	Forest	0.00-0.20 m			0.20-0.60 m		
		no K	30 mg kg^{-1} K	60 mg kg^{-1} K	no K	30 mg kg^{-1} K	60 mg kg^{-1} K
				pH($CaCl_2$)			
Distancefrom roots	0.072	0.180	0.950	0.475	0.625	0.480	0.041
Block	0.000	0.001	0.001	0.470	0.545	0.055	0.006
LSD		0.19	0.12	0.63	0.60	0.12	0.07
				Exchangeable K			
Distancefrom roots	0.029	0.029	0.163	0.004	0.035	0.692	0.122
Block	0.004	0.003	0.619	0.019	0.796	0.797	0.028
LSD	0.12	0.08	0.32	0.18	0.22	0.17	0.19
				Non-exchangeable K			
Distancefrom roots	0.000	0.682	0.001	0.249	0.923	0.004	0.001
Block	0.089	0.012	0.776	0.030	0.997	0.234	0.792
LSD	0.31	0.70	0.50	1.09	1.02	0.45	0.34

LSD = least significant difference.

Table 3. Summary of the ANOVA results (*p* value) and LSD for pH($CaCl_2$), exchangeable and non-exchangeable K as affected by soil treatments within each distance from the *U. ruziziensis* rhizosphere

Source of variation	Distance from the rhizosphere (mm)					
	0.5	1	1.5	3	5	10
			pH($CaCl_2$)			
Treatment	0.000	0.000	0.000	0.000	0.000	0.000
Block	0.622	0.152	0.142	0.347	0.845	0.871
LSD	0.59	0.52	0.17	0.15	0.18	0.14
			Exchangeable K			
Treatment	0.000	0.000	0.000	0.000	0.000	0.000
Block	0.969	0.483	0.356	0.32	0.724	0.604
LSD	0.23	0.24	0.14	0.16	0.19	0.30
			Non-exchangeable K			
Treatment	0.000**	0.000**	0.000**	0.006**	0.002**	0.005**
Block	0.527	0.69	0.195	0.926	0.389	0.272
LSD	0.73	0.75	0.64	0.94	0.80	0.89

LSD = least significant difference.

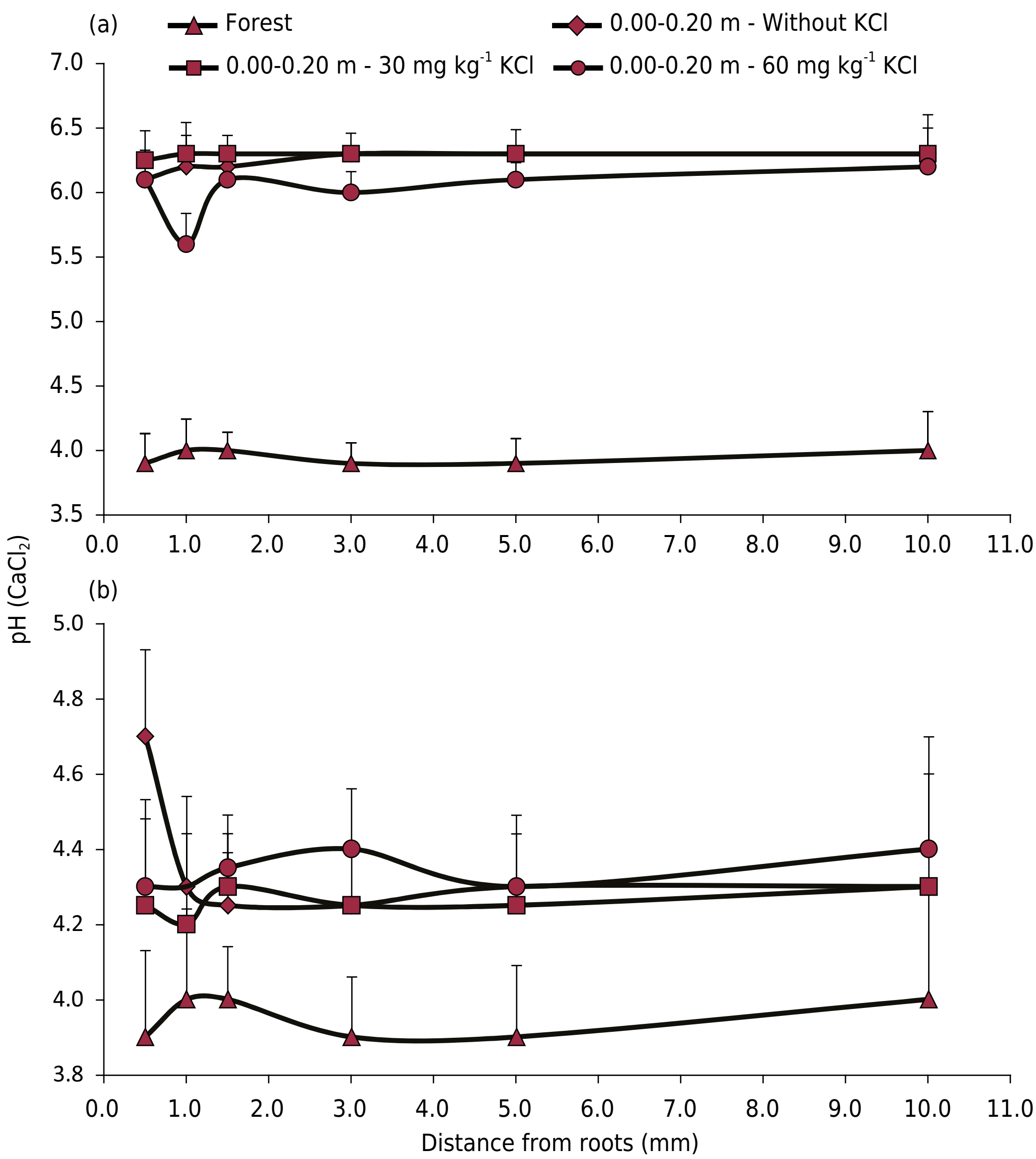

Figure 2. Soil pH($CaCl_2$) as affected by treatments and K fertilization. Vertical bars show the LSD ($p<0.05$), and compare treatments within each distance from the ruzigrass rhizosphere.

Nevertheless, for 1.0, 1.5, and 3.0 mm, the application of 60 mg kg^{-1} of K to the 0.00-0.20 m soil resulted in a lower pH as compared with treatments without K and with 30 mg kg^{-1} of K. This could have released K from exchange sites and caused its migration to the 0.5 mm distance, giving room for H^+ and stimulating root exudation of protons. This is evident in figure 3c, since the exchangeable K at 1.0 mm was lower than at 0.5 mm, showing a likely migration. Potassium sulfate had no influence on the pH of the soil upper layer in the study conducted by Russel (1950), but Catani and Gallo (1954) observed that potassium chloride decreased the soil pH, and stated that, while potassium chloride acidifies the soil through the free Cl^- anion and the released H^+ ion action by K exchange, the effect of the K ion adsorbed on soil colloids tends to compensate those effects.

In the absence of K fertilizer, the forest soil showed higher exchangeable K than the 0.00-0.20 and 0.20-0.60 m soil, and this treatment had higher exchangeable K at 0.5, 1.5, and 3.0 mm than the 0.00-0.20 m soil (Figure 3a). As to the non-exchangeable K, in the treatments without K, the level in forest soil was higher than the 0.20-0.60 m soil, which was higher than the 0.00-0.20 m soil, for all of the layers of sampling (Figure 3b). The exchangeable K in the 0.20-0.60 m soil was influenced by the application of the K. However, for the non-exchangeable K there was a difference only at 0.5, 1.0, and 1.5 mm from the rhizoplane (Figure 3). Soil with initial high contents of non-exchangeable K may have received less influence of the fertilizer, because of the buffering capacity of the soil. Therefore, in this treatment the action of the rhizosphere is more evident, with K depletion at 1.0 and 1.5 mm.

For all sampling distances, the 0.20-0.60 m soil with 60 mg kg^{-1} of K showed a higher exchangeable K content, except for 1.0 and 5.0 mm, which were similar to the forest soil. Overall, at 10.0 mm, treatments with K application and the forest soil showed the highest exchangeable K content (Table 4), and the treatments resulting in the lowest exchangeable K were those that did not receive any K. Irrespective of the soil, non-exchangeable K contents were modified by the treatments within each sampling distance from the rhizosphere (Table 5). For the 0.00-0.20 m soil with K, the non-exchangeable K was higher than the initial non-exchangeable K.

Non-exchangeable K can be increased with residual K doses (Rosolem et al., 2012), because part of the K from the fertilizer is quickly reversed to non-exchangeable forms (Rosolem et al., 1993; Werle et al., 2008). Note that, for the 0.20-0.60 m treatment, no increase was observed with this K application. This soil, as well as the forest soil, initially had a high non-exchangeable K content, CEC, and a higher clay content than the 0.00-0.20 m soil. The soil texture can affect non-exchangeable K, and the silt content may be related to non-exchangeable K levels (Volf et al., 2017).

Overall, a higher content of non-exchangeable K was observed in the forest soil up to 0.5 mm from the root mat (Table 5). From 0.5 to 1.0 mm from the rhizosphere, the forest soil showed a higher non-exchangeable K content. At 3.0 mm, it had the highest content, and the 0.00-0.20 m treatment without K addition showed the lowest (Table 5). For the farthest distance from the rhizosphere, as it had happened for the exchangeable K, it is evident that the rhizosphere interfered in the non-exchangeable K, since the highest content was observed in the 0.00-0.20 m treatments with 60 mg kg^{-1} of K for both 5.0 and 10 mm distances. This may be a result of organic acid exudation or rhizosphere acidification releasing non-exchangeable K from clay interlayers. The rhizosphere environment shows a large quantity of organic acids, which have an important role as solubilizers of ions bound to the solid fraction of the soil (Marschner, 1995).

The main exchangeable K depletion points in relation to the root mat were at 5.0 mm in the forest soil, at 1.0, 1.5, and 3.0 mm in the 0.00-0.20 m soil, and only at 1.0 mm in the 0.20-0.60 m soil, both without K application. For the 0.00-0.20 m in both applied rates of K and 0.20-0.60 m with 60 mg kg^{-1} of K at 0.5 mm from the roots, the exchangeable

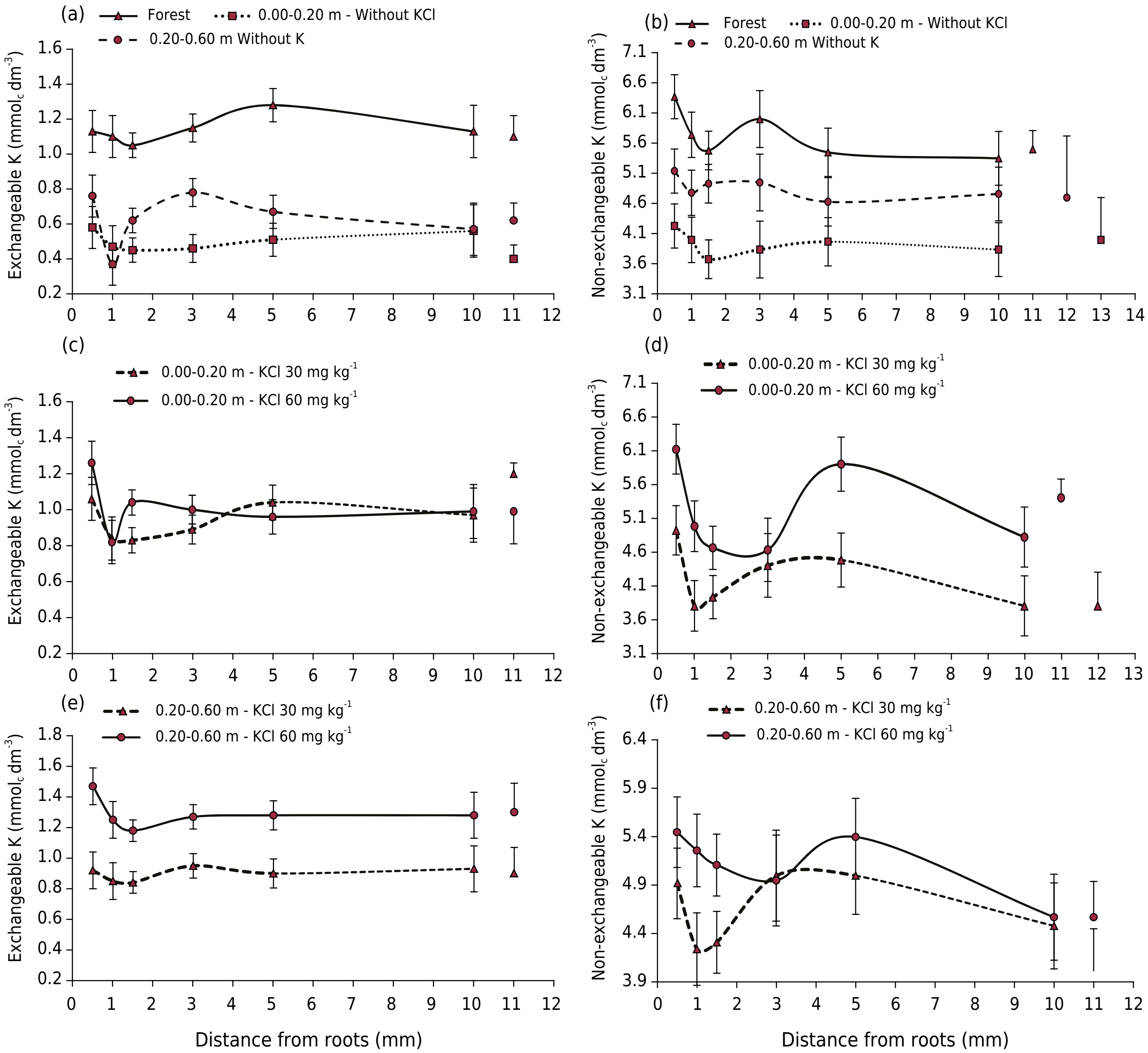

Figure 3. Exchangeable K (a, c, and e) and non-exchangeable K (b, d, and f) in cultivated soils as affected by K fertilization. Vertical bars in black show the LSD ($p<0.05$), and compare distances within each treatment, and vertical bars in gray show the LSD ($p<0.05$) and compare between each distance.

Table 4. Exchangeable K contents in the soils from the forest and from cultivated fields sampled at 0.00-0.20 and 0.20-0.60 m, as affected by K rates. Treatments compared within each distance from the rhizosphere

TreatmentSoil/K rate	Distance from the rhizosphere						Average
	0.5 mm	1.0 mm	1.5 mm	3.0 mm	5.0 mm	10.0 mm	
Forest	1.13 bc	1.09 ab	1.04 b	1.15 ab	1.28 a	1.13 ab	1.13
0.00-0.20 m – no K	0.58 e	0.47 d	0.45 e	0.46 e	0.51 c	0.56 c	0.50
0.00-0.20 m - 30 mg kg^{-1} K	1.06 bc	0.84 c	0.83 c	0.89 c	1.04 b	1.2 ab	0.96
0.00-0.20 m - 60 mg kg^{-1} K	1.26 ab	0.82 c	1.04 b	1.00 bc	0.96 b	0.96 ab	0.10
0.20-0.60 m - no K	0.76 de	0.37 d	0.65 d	0.71 d	0.61 c	0.57 c	0.63
0.20-0.60 m - 30 mg kg^{-1} K	0.92 cd	0.85 bc	0.84 c	0.95 c	0.90 b	0.93 b	0.91
0.20-0.60 m - 60 mg kg^{-1} K	1.47 a	1.25 a	1.18 a	1.27 a	1.28 a	1.28 a	1.28
LSD	0.23	0.24	0.14	0.16	0.19	0.3	

LSD = least significant difference ($p<0.05$). Lower case letters compare treatments within columns.

Table 5. Soil non-exchangeable K as affected by soils and K fertilization. Soils are compared within each distance from the ruzigrass rhizosphere

Treatment	Distance from the rhizosphere						Average
	0.5 mm	1.0 mm	1.5 mm	3.0 mm	5.0 mm	10.0 mm	
Forest	6.37 a	5.74 a	5.48 a	6.04 a	5.45 ab	5.35 ab	5.61
0.00-0.20 m - no K	4.23 d	4.00 d	3.68 c	3.84 c	3.97 e	3.84 c	3.90
0.00-0.20 m - 30 mg kg^{-1} K	4.92 cd	3.80 d	3.93 c	4.44 bc	4.48 de	3.80 c	4.20
0.00-0.20 m - 60 mg kg^{-1} K	6.05 ab	4.98 bc	5.11 a	5.09 b	5.88 a	5.43 a	5.27
0.20-0.60 m - no K	5.14 c	4.78 bc	4.93 ab	4.95 b	4.63 cde	4.76 ab	4.85
0.20-0.60 m - 30 mg kg^{-1} K	4.92 cd	4.24 cd	4.31 bc	5.00 b	5.03 bcd	4.48 bc	4.70
0.20-0.60 m - 60 mg kg^{-1} K	5.45 bc	5.26 ab	5.11 a	4.95 b	5.40 abc	4.57 abc	5.18
LSD	0.73	0.75	0.64	0.94	0.8	0.89	

LSD = least significant difference ($p<0.05$). Lower case letters compare treatments within columns.

K content was higher than those in the other distances, showing that the amount of K transported to the rhizosphere was greater than the plant's ability to take it up (Figure 3). Higher K rates increase the transpiration rate (Zain and Ismail, 2016), thus increasing the mass flow contribution for K supply. Although diffusion is the most accepted form of K transport up to the roots, resulting from the concentration gradient originated by the nutrient absorption, mass flow is important when transpiration is high, as well as the quantity of K in the soil (Ruiz et al., 1999). In soils without K application, diffusion is more important than mass flow, as a depletion zone results from the transport of K to the absorption zone (0.5 mm). As diffusion is slow, this K is not replenished. It is worth observing that in treatments with K application, mass flow transported more K than the plant could absorb, resulting in a higher K content at the 0.5 mm zone as compared with other distances .The 0.00-0.20 m soil with 60 mg kg^{-1} K showed a higher dependence on mass flow than the same soil with 30 mg kg^{-1} K (Figure 3c). Because the depletion was just at 1.0 mm, K was rapidly replenished by the other depths of soil, while with 30 mg kg^{-1} K, the depletion was observed up to 3.0 mm, and the replenishment was slower. In a study performed by Oliveira et al. (2004), they observed that the application of higher K rates in drier soils, the contribution of diffusion was decreased while that of mass flow increased.

Non-exchangeable K was depleted at 1.0 and 1.5 mm from the root mat, except in the soil from 0.20-0.60 m with 30 mg kg^{-1} K, where a depletion was observed at 3.0 mm (Figure 3). A rhizosphere effect on the non-exchangeable K is clear in these treatments, since K contents at 10.0 mm were lower than at 5.0 mm, which is close to the considered rhizosphere limit of 4.0 mm. There was no exchangeable K accumulation at 0.5 mm in the forest soil and in the treatment of 0.20-0.60 m with 60 mg kg^{-1} (Figures 3a and 3e). However, non-exchangeable K was accumulated in these regions (Figures 3b and 3f). In this case, exchangeable K was high, and the applied rate was high, showing that exchangeable K was the main source of the nutrient. Conversely, in the soils from 0.00-0.20 and 0.20-0.60 m without K application the opposite was observed, with accumulation of exchangeable K and not non-exchangeable K (Figure 3).

This increase in non-exchangeable K may be due to chemical weathering caused by root exudation of organic acids. When a mineral such as feldspar undergoes an acid solution attack, usually coming from organic acids, there is feldspar dissolution and K release. The process of mica hydration or hydrolysis can be responsible for the K release from minerals (Werle et al., 2008), and plants grown for long periods could be using the non-exchangeable and structural K fractions (Rosolem et al., 1988). Brachiaria results in increased soil exchangeable K, coming from non-exchangeable fractions, since this species can release K from non-exchangeable forms (Garcia et al., 2008). Plant roots can release K that is withheld in the interlayers of clay minerals, which would not occur without the action of the roots (Hinsinger and Jaillard, 1993). These authors observed that the depletion of exchangeable K in the rhizosphere changes the source mineral, thus modifying the soil mineralogy. A K depletion was observed from 1.0 to 1.5 mm for 30 mg kg^{-1} of K (Figure 3), and for the treatment of 0.20-0.60 m with 60 mg kg^{-1} of K (Figure 3d) this depletion occurred at 3.0 mm. For these cases, the non-exchangeable K content was higher at 0.5 mm than in the previously mentioned distances and lower at 3.0 and 5.0 mm. This could also be the region responsible for maintaining the absorption zone (0.5 mm). As shown in figure 3, there was a depletion in exchangeable K in this region, and an increase at 0.5 mm, thus characterizing a depletion zone that does not follow a gradient, possibly because in this region non-exchangeable K may have been solubilized into exchangeable K. As reported by Hinsinger and Jailard (1993), when a decrease occurs in soil solution K, there is a greater mineralogy change because of the K released from the interlayers, and the change in the clay mineralogy with K release from the interlayers is intensified at 32 days of ryegrass cultivation and a rhizosphere distance up to 2.0 mm.

For the forest soil, there was evidence of a mass flow contribution in the exchangeable K migration (Figure 3a), and rhizosphere action on the increase of non-exchangeable K (Figure 3b). For the exchangeable K (Figure 3a), the content increased at 10.0 to 5.0 mm, followed by a decrease closer to the roots. Probably this region was depleted because K was taken up by the plants. As the plant growth and K content were low in this treatment (Figure 4a), K flow may not have occurred, increasing the K concentration at 0.5 mm. The flow can occur when there is a large plant absorption and, to maintain the chemical balance, roots can exude protons such as H^+ or even K^+, increasing its content in this region. For the non-exchangeable K, a depletion occurred again at 1.0 and 1.5 mm, and an increase at 3.0 mm distance. This demonstrates once more the rhizosphere action upon the increase of non-exchangeable K.

There was no difference in ruzigrass dry matter yields between the forest and the 0.20-0.60 m soils (Figure 4a), but the yield was higher in the 0.00-0.20 m soil irrespective of K fertilizer application. Similar results were observed for the K content by the plants (Figure 4b), which were affected only by the soils, and not by K fertilization. The larger plants grown in the 0.00-0.20 m soil probably had a greater root growth, increasing K absorption. This may be a result of the difference of organic matter content, as the 0.00-0.20 m soil presented a higher content, which may have been a preponderant factor favoring plant growth. The K accumulated in the plant responded to the K rates (Figure 4c), with the greatest content in the 0.00-0.20 m soil, regardless of the K dose, and in the 0.20-0.60 m soil with 60 mg kg^{-1} of K.

The 0.00-0.20 and 0.20-0.60 m soils had been cropped to soybean in rotation with ruzigrass (summer soybean and ruzigrass in the off-season) without potassic fertilization for more than four years, resulting in low soil exchangeable and non-exchangeable K levels. The lower values when compared with the forest soil (Table 1) show that the absence of potassic fertilization led to the release and depletion of non-exchangeable K, similar to what has been shown in corn (Garcia et al., 2008), where ruzigrass was able to take up non-exchangeable K in the soil profile and then release it into the soil arable layer where it was available for corn.

After ruzigrass cultivation, the mean interchangeable K level decreased (Table 4) relative to the initial soil content of 0.00-0.20 m, without K application (Table 1). This could have happened due to a higher uptake by plants at this depth (Figure 4b). The same was not observed for the forest soil, which was also not fertilized, and the interchangeable and non-exchangeable K levels after cultivation were similar to the initial values. In this treatment, the plants had the lowest K uptake (Figure 4b), showing that the higher the K uptake by plants, the higher the K requirement of the non-exchangeable fraction, especially in situations with low soil content or no K fertilization.

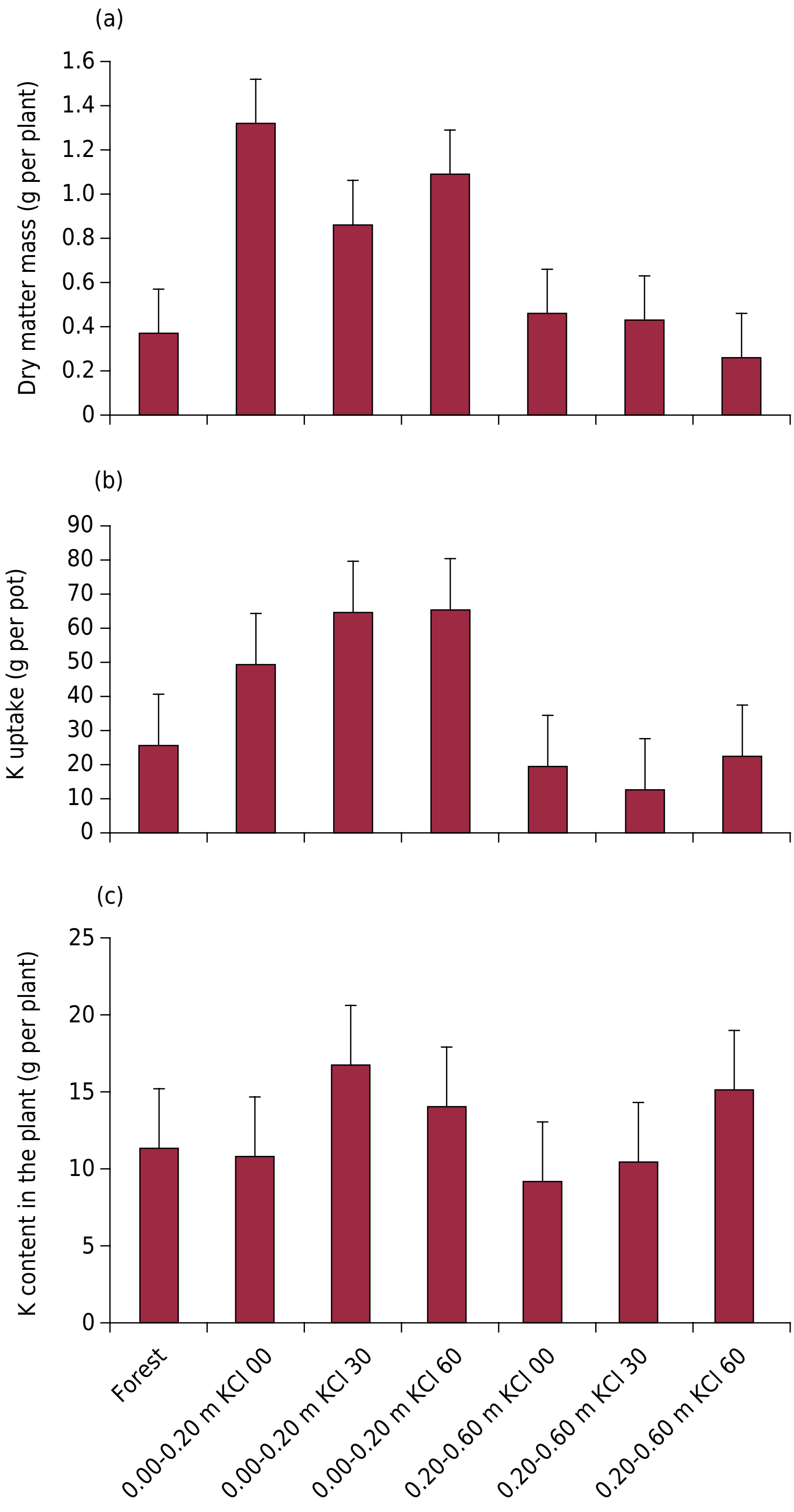

Figure 4. Dry matter yields (a), plant K content (b), and K uptake by *Urochloa ruziziensis* (c). Vertical bars show the least significant difference ($p<0.05$).

CONCLUSIONS

Under low K, soil exchangeable K is depleted in the ruzigrass rhizosphere, which may be avoided by K fertilization. A depletion zone appearing in the rhizosphere could be the driving force to release soil non-exchangeable K in this soil region.

An increased K content in the rhizosphere under high K availability results from the contribution of mass flow on K transport towards the roots, and can be greater than the plant's ability to take it up.

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