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Silt as K Source for Crops in Tropical Soils

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Abstract

The original soil exchangeable potassium (K) concentrations are at or above critical levels in many Brazilian Cerrado (savanna) soils. Hence, many cropped areas have been fertilized with low K rates, below crop requirements, but yields have not decreased as expected. In these areas, topsoil exchangeable K analyses have shown no decrease, or even some increase. The aim of this study was to evaluate exchangeable and non-exchangeable K forms in soils under different uses and managements in the Vale do Araguaia region of Mato Grosso state, Brazil. Soil samples were taken from 91 sites at depths of 0-20 cm and 20-40 cm, in areas under grain crops, pasture and native vegetation (Cerrado or forest). Silt content ranged from 12 to 175 g kg^{-1} and clay from 90 to 595 g kg^{-1}, and the predominant clays were kaolinite, hematite, goethite and gibbsite. Under pasture, the soils had high levels of exchangeable K in the 0-20 cm layer and high levels of non-exchangeable K from 20 to 40 cm. This can be a result of the absorption of non-exchangeable K by grasses, the main cultivated species, by recycling K to the exchangeable fraction in the topsoil. There was a positive relationship between silt and non-exchangeable K contents. Ratios of exchangeable to non-exchangeable K were over 3 in soils with silt above 70 g kg^{-1}, in which non-exchangeable K was over 100 mg dm^{-3}. Cover crops growing in soils rich in silt take up non-exchangeable K and exchangeable K from deeper layers, which is recycled to the soil as exchangeable K upon plant residue mineralization, which may have been responsible for the maintenance or increase in exchangeable K levels in the 0-20 cm layer in areas where low K rates have been used for grain production.

Keywords: Cerrado soils; Exchangeable K; Vale do Araguaia

INTRODUCTION

More than 90% of the potassium contained in soils is in the structural fraction linked to the material of origin, represented as total K (Coelho & Vilagia, 1988). According to Raji (1991), the main mineral compounds with K are feldspar, potash and mica. The presence of the ionic form of K from this material of origin is due to mineralization, through weathering or “geological reaction of the decomposition of rocks” (Kerbauy, 2013; Kampf et al., 2009). The vermiculites, like micas, contain K between the layers, and in smectites, reduction of iron content facilitates the fixation of K (Curi et al., 2005). The 2:1 feldspars, depending on chemical variations, can form potassium, sodium-calcium and barium minerals. A main characteristic of alkaline feldspars is the large quantities of K or Na and dearth of Ca (Melo et al., 2009). Potassium fractions considered as having low solubility, linked to the mineral of origin, such as the interlayer K or non-exchangeable K, can be a source of K for plants. The action of the rhizosphere can deplete the K present in phlogopite minerals, transforming them into vermiculite (Hinsinger & Jaillard, 1993; Gomers et al., 2005).

As the mineralogy, the soil silt content can be correlated with the levels of K (Medeiros et al., 2014). In this regard, Silva et al. (2008) reported that the silt fraction contains large reserves of non-exchangeable K.

Mato Grosso state is the Brazil's largest producer of grain crops, and the Vale do Araguaia region, in the state's northeast, is an agricultural frontier region that accounts for more than 16% of the state's soybean output (IMEA, 2015). This region contains highly varied soil classes, but three stand out: Dark-Red Latosol (Oxisoil); Red-Yellow Latosol (Oxisol); and Plinthosol (Plinthaquox) and Red-Yellow Argisol (Ultisols) (IBGE, 2014; SEPLAN, 2014). Few studies have been conducted to investigate the influence of production system or silt content in the soil on the potassium nutrition of crops, especially in soils with high concentrations of non-exchangeable K, characteristic of this region of Mato Grosso state. In this region, some areas are fertilized with insufficient K rates to replenish the quantity taken up by the crops, but no declines have been observed in yields or levels of exchangeable K in the arable layer (0-20 cm depth). The objective of this study was to assess the forms of exchangeable and non-exchangeable K in soils under different management systems and uses, as well as the relationship with the soil mineralogy.

MATERIAL AND METHODS

Studied region was the Vale do Araguaia (Araguaia Valley - Figure 1), which basically contains four soil classes: Dark-Red Latosol (Oxisoil); Red-Yellow Latosol (Oxisol); and Plinthosol (Plinthaquox) and Red-Yellow Argisol (Ultisols) (IBGE, 2014; SEPLAN, 2014). The predominant clay minerals are kaolinite, hematite, goethite and gibbsite, except in the Plinthosol, where hematite is absent (Ker, 1997; Galvão et al., 2007). Soil samples were collected from 91 sites (Table 1). Each collection point was geographically referenced with a GPS device. Soil samples were collected in areas cultivated with soybeans, in a line transversal to the rows, at depths of 0-20 cm and 20-40 cm. At each depth, a portion of soil with thickness of 5 cm and width 50 cm was collected, within a 50 cm wide part of the planted row. Soil samples were also collected in areas of pasture and native vegetation (Cerrado or forest). Cropped areas were chosen for contrast regarding the use before planting soybeans: corn, millet, *Urochloa* (Brachiaria) or fallow (Table 1).

Exchangeable K in the soil was extracted with Mehlich-1 solution. The non-exchangeable K was extracted with a hot solution of HNO_3 and the quantity was determined by subtraction from the exchangeable K value (Rouse & Bertranson, 1949).

The descriptive data on the levels of K were analyzed and the correlations were determined by multiple regression analysis, with a predictive model for the K extractable in HNO_3 based on soil chemistry analysis. The progressive matrices technique was used.

RESULTS AND DISCUSSION

The silt content in the top layer (0-20 cm) varied from 12 to 175 g kg^{-1}, while the organic matter content ranged from 7 to 54 g kg^{-1} and the exchangeable potassium concentration varied from 9.5 to 319 mg dm^{-3}. According to Oliveira Junior et al. (2010), in general the critical level of K in the soil is considered to range from 31 to 51 mg dm^{-3}. In turn, the levels of non-exchangeable K varied from 0.01 to 403 mg dm^{-3} in the top layer. At the depth of 20-40 cm, large amplitudes of the forms of K were observed. The exchangeable K presented a minimum value of 5.0 mg dm^{-3} and maximum of 191.50 mg dm^{-3}, while the non-exchangeable K ranged from 0.78 mg dm^{-3} to 339.13 mg dm^{-3}.

Therefore, the soils in the Vale do Araguaia region presented high levels of non-exchangeable K, but in some cases the concentration of non-exchangeable K was up to 2.39 times more than that of exchangeable K in the top layer, and up to 5.52 times more in the 20-40 cm layer. As can be seen in Figure 2, the slope of the line is steeper in the 20-40 cm layer than in the 0-20 cm layer (2.04 and 1.7 respectively).

Therefore, at the depth of 20-40 cm, twice as much K was extracted in HNO_3 in relation to the exchangeable K.

At sites 24, 32, 41, 42, 43, 64 and 66, the levels of K in HNO_3 were high even though the levels of exchangeable K were low (Figure 2).

Sites 41 and 66 had been cultivated with soybeans for longer than four years, with cover of *U. ruziziensis* between crops. Besides this, these sites had not received potassium fertilization in the past three crops. Nevertheless, the levels of K were above the critical threshold. In these cases, the content of non-exchangeable K was high at both depths. Site 42 is a native Cerrado area, with low exchangeable K and high non-exchangeable K levels at both depths.

Sample 43 came from an area cultivated with pasture for more than 15 years that had never received any fertilization. In the top layer the level of exchangeable K was higher than that of non-exchangeable K, but at the depth of 20-40 cm the content of non-exchangeable K was greater than that of exchangeable K (Figure 2). According to Mielniczuk (2005), the straw from dried cover plants that are efficient in absorbing potassium releases the mineral to the soil, creating different levels from the surface to the lower levels of the profile.

Sample 32 came from a field cultivated with soybeans, without potassium fertilization on the two previous crops. Even with this management, the content of exchangeable K was above the critical level. Nevertheless, the level of non-exchangeable K was low in the top layer (0-20 cm). These results indicate a tendency for transformation of non-exchangeable K to exchangeable K. This is supported by the fact that the soil in the forested areas on this same property (sample 32) presented high non-exchangeable K and low exchangeable K in both layers sampled (Figure 2).

The areas with pastures (sites 43 and 66) presented the same tendency, in which the concentration of exchangeable K was high in the 0-20 cm layer and that of non-exchangeable K was low at the 20-40 cm depth. It can be stated that Brachiaria extracts potassium from the non-exchangeable fraction and transfers it to the exchangeable fraction of the higher soil layers. The highest concentration of Brachiaria roots was found in the 0-20 cm layer. These roots are responsible for depletion of non-exchangeable K and its transformation into exchangeable K (Hissinger et al., 1993; Gomers et al., 2005), and the deposition of exchangeable K occurs from senescence of the plants with the action of rain, causing this K to be deposited on the soil surface (Rosolem et al., 2006). This can be explained because Brachiaria extracts a large amount of K and exports very little, and because of the form of the K^+ ions in the plant, where it is not part of any cell constituent. Then it is rapidly leached from the dried grass after senescence and deposited in the soil. This increases the fraction of exchangeable K in the surface layer. Besides this, livestock activity also exports very little K from the system, as reported by Vilela et al (2007). Garcia et al. (2008) identified absorption of the non-exchangeable K fraction by Brachiaria grown together with corn, because the non-exchangeable K in the soil declined in the parts covered with Brachiaria and the exchangeable K increased. Calonego et al. (2005) found that the release of K from dried grass cover occurs in rising quantities after drying, due to the loss of turgescence of the cells.

Cultivated areas with Brachiaria between crops and soybeans in the summer presented distinct results: at site 24 the exchangeable K was higher than the non-exchangeable K while at site 41 the exchangeable K was lower than the non-exchangeable K. The area of site 24 received K fertilization all years, while that of site 41 did not. This indicates that the plants only access the less soluble source when there is no addition of readily available sources. Growing of cover plants in the winter, without fertilization, causes depletion of the non-exchangeable forms of K, with corresponding enrichment of the solution in the soil, a pattern than is more pronounced in plants with high extraction capacity, such as grasses (Benites et al., 2010).

There was a positive and significant correlation (at 1%) between the levels of silt and non-exchangeable K (Table 2), at both depths, such that the higher the silt content, the greater the concentration of non-exchangeable K. Similar results were reported by Medeiros et al. (2014) and Silva et al. (2008), indicating that the silt fraction contains large reserves of non-exchangeable K.

The levels of non-exchangeable K were only higher than 120 mg dm^{-3} in the soils with silt concentration greater than 70 g kg^{-1} (Figure 4). Hence, it can be inferred that in this region, non-exchangeable K will only be found in soil with silt content higher than 7% (70 g kg^{-1}).

The highest levels of non-exchangeable K observed were 339.1 mg dm^{-3}, with silt content of 100 g kg^{-1} (sample 18), and 203.1 mg dm^{-3}, with silt content of 150 g kg^{-1} (sample 41). According to Melo et al. (2003) reported higher quantities of total K in sand and silt fractions, while Castilho et al. (2002) concluded that the silt fraction, in the majority of soils studied, was the main source of K.

Samples 2, 21, 39 and 88 contained high silt contents (Figure 3), but the levels of non-exchangeable K were low. The soils in samples 2, 21 and 88 were reddish, indicating a high quantity of iron oxide, which is an excellent cementing agent of silt in clay. This may have hampered the dispersion during analysis of the silt and can generate a functional silt. As pointed out by Melo et al. (2000, 2003), it can be hard to analyze the silt in soils with high concentrations of iron oxide, particularly because of the cementing effect in Latosols. Sample 39 might have come from a soil with low silt content, because soils under native Cerrado vegetation in the study region typically have low levels of non-exchangeable K. Therefore, the material of origin might have been poor in potassium.

Figure 4 shows the ratio between non-exchangeable K and exchangeable K in relation to the levels of silt. It can be seen that the levels or silt are correlated with higher levels of non-exchangeable K in these samples.

The samples with silt contents higher than 70 g kg^{-1} corresponded to the highest ratios between non-exchangeable K and exchangeable K. All of these ratios were higher than 3 (Figure 4). The highest ratios between non-exchangeable K and exchangeable K were found in the samples from sites 41, 42 and 64, all of which were in the range of 5. In these cases, the silt contents were higher than 100 g kg^{-1} (Figure 4).

Brazilian soils generally have high levels of non-exchangeable K, with ratios between non-exchangeable and exchangeable K ranging from 1 to 3 (Benites et al., 2010).

Figure 5 shows a multiple regression of the variables observed K in HNO_3 and the expected level, based on two variables: level of silt and level of exchangeable K. To estimate the concentration of K extracted in HNO_3 in the top layer (0-20 cm), the following equation can be used (1):

$$\text{(1)} \qquad \text{K } HNO_3 = -31.7746 + 1.6980 \text{ exchangeable K} + 0.2635 \text{ silt } (R^2=0.82)$$

Equation (1) explains 82% of the variation of the levels of K extracted in HNO_3. The equation is highly significant, with an estimated error of 28. Using this equation with the concentrations of exchangeable K and silt (parameters routinely analyzed in soil laboratories), it is possible to estimate the content of K that would be extracted in HNO_3.

Figure 5 was plotted with data from the soil samples collected at the 91 sites in the Vale do Araguaia region. Note that only three data points are outside the 95% confidence interval. Therefore, equation (1) can be used for this region to predict the content of K that would be extracted in HNO_3, since analysis using this extractant is more difficult and expensive than determining the content of exchangeable K (Mehlich-1).

CONCLUSIONS

The levels of silt were directly correlated with the levels of non-exchangeable K and based on the values of exchangeable K and the silt concentration, the levels of non-exchangeable K (extractable in HNO_3) can be estimated.

Forage species used as cover between crops or as pasture in silt-rich soils absorb exchangeable K and non-exchangeable K from the subsoil, recycling K to the arable layer with mineralization of residues. This can explain the maintenance or even increase in the levels of K in the surface layers, even without application of potassium fertilizer.

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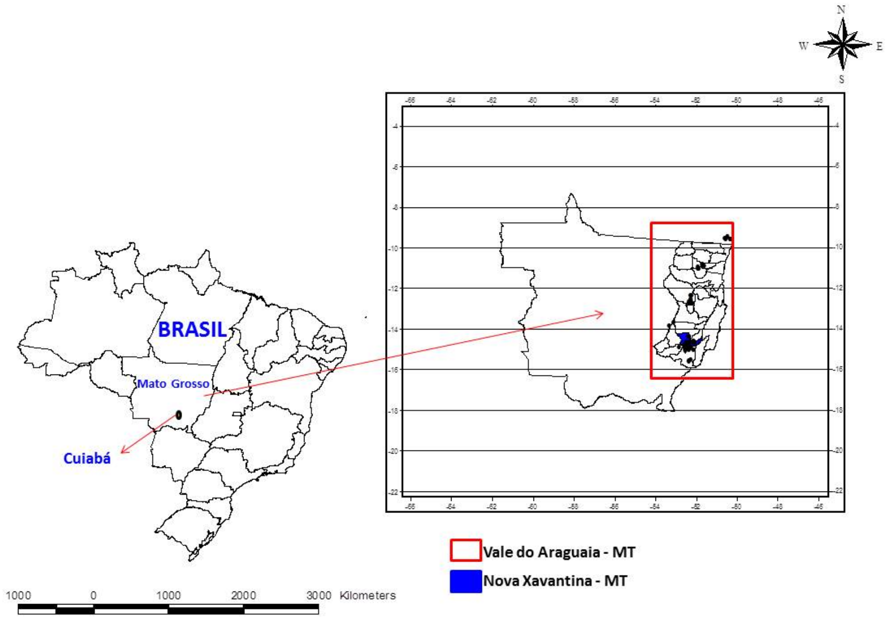

Figure 1. Map indicating the region where the soil samples were collected.

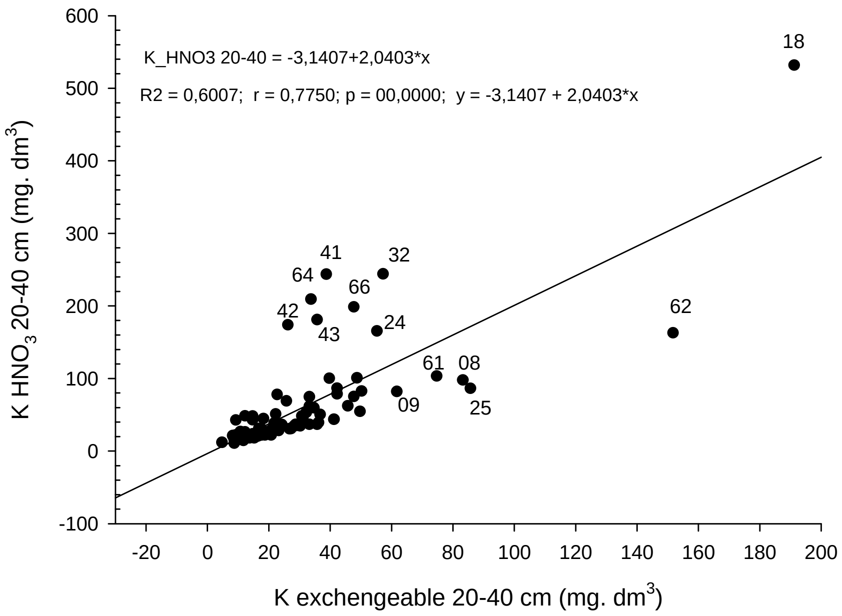

Figure 2. Relation of levels of exchangeable K and K extracted in nitric acid (HNO_3) at the depth of 20-40 cm at the 91 collection sites in the Vale do Araguaia region.

Table 1. Simple pairwise linear correlation coefficients between the levels of exchangeable K, non-exchangeable K and silt in the two soil layers (0-20 cm and 20-40 cm).

Variable	Non-exch K (0-20cm)	Exch K (20-40 cm)	Non-exch K (20-40 cm)	Silt (0-20 cm)	Silt (20-40 cm)
Exchangeable K (0-20 cm)	0.66*	0.77*	0.58*	0.12	0.20
Non-exchangeable K (0-20 cm)		0.66*	0.95*	0.28*	0.35*
Exchangeable K (20-40 cm)			0.53*	0.10	0.13
Non-exchangeable K (20-40 cm)				0.26	0.39*

*significant at the level 1% of probability.

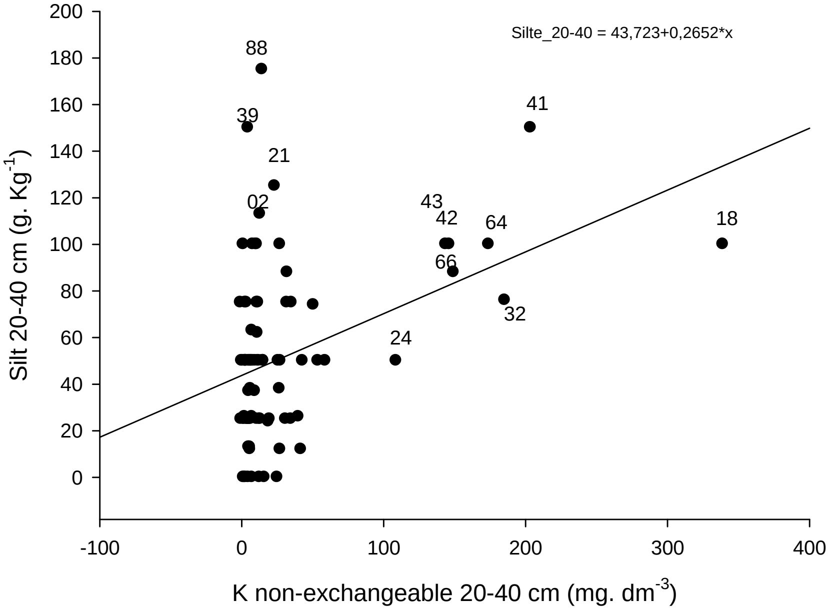

Figure 3. Relation between levels of non-exchangeable K and silt in the 20-40 cm layer in soil samples from the 91 collection sites in the Vale do Araguaia region.

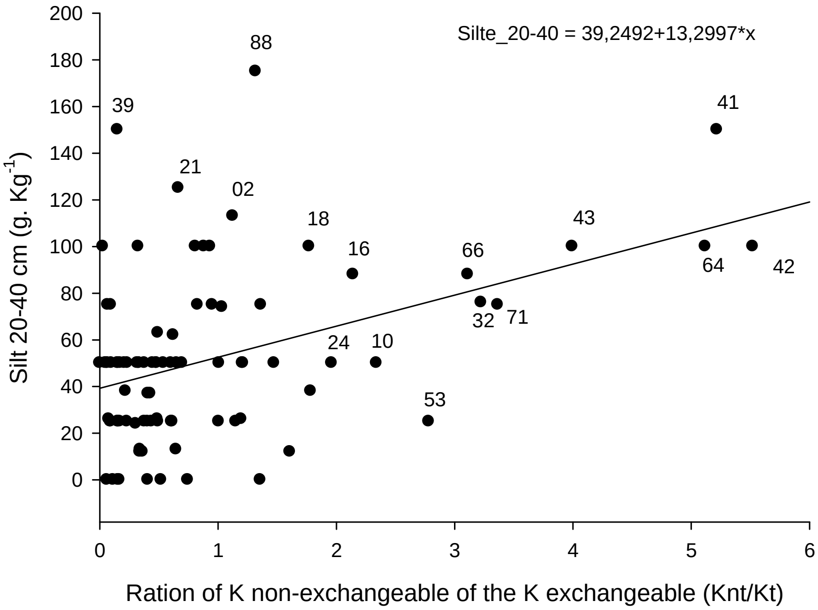

Figure 4. Ratio between levels of non-exchangeable K and exchangeable K in relation to silt levels in the 20-40 cm layer in samples from 91 sites in the Vale do Araguaia region.

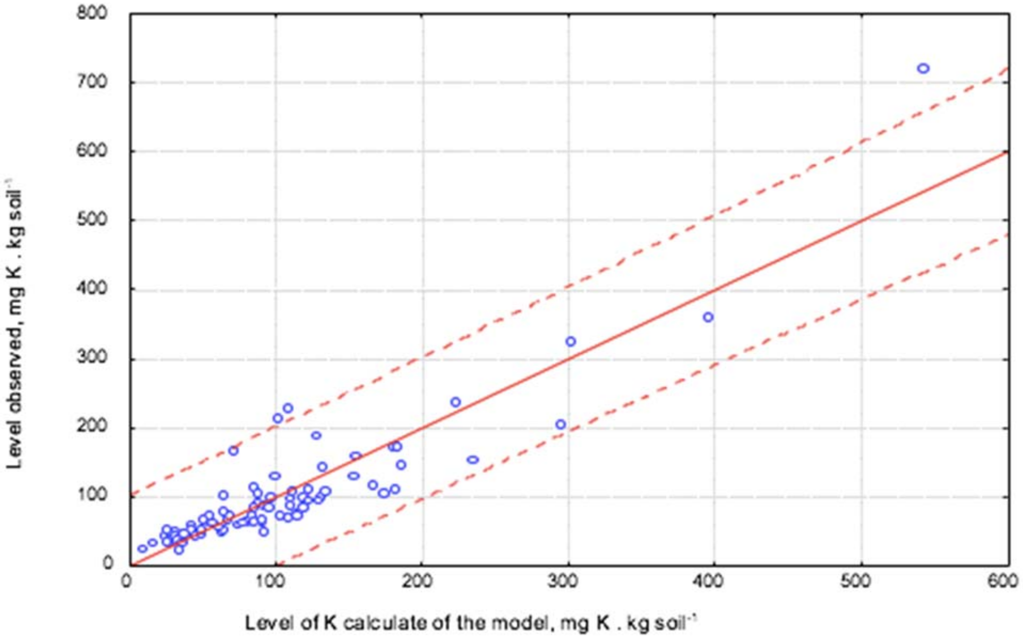

Figure 5. Multiple regression of K extracted in nitric acid (HNO3), generated by the observed levels of exchangeable K and silt in the soil samples from the 91 sites in the Vale do Araguaia region.