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The influence of crop residues in vertical soil mobility of potassium

Mobilidade do potássio no solo em função de diferentes tipos e doses de resíduos vegetais

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Abstract

This study has been developed to evaluate the influence of applying different types and doses of crop residues on potassium (K) mobility in soil columns. Rhodic Haplustox samples were collected at depths of 0.0-0.10, 0.10-0.20 and 0.20-0.30 m and used to create such soil columns, keeping the same profile distribution. The experimental design was randomized with three replications and the tested treatments were organized in a 4x4 factorial arrangement: 4 types of crop residues (brachiaria+sunflower; Mix (cultivated radish+oat+winter vetch); cultivated radish and wheat) and 4 doses of residues (0, 10, 15, and 20 Mg ha^{-1}). The grinded and dried residues were applied to the surface of the columns, which were then irrigated with distilled water and incubated for 10 days to stabilize the reactions. After incubation, the soil columns were disassembled and separated into 0.05 m layers (0.0-0.05, 0.05-0.10, 0.10-0.15, 0.15-0.20, 0.20-0.25 and 0.25-0.30 m). The samples of each layer were dried, sieved and analyzed to determine the amount of exchangeable K. The results obtained indicated that surface application of crop residues alters soil levels of exchangeable potassium, especially in the 0.0-0.05 m layer. Increases in residue doses may cause a significant and linear increase in exchangeable K content in the 0.0-0.05, 0.05-0.10 and 0.10-0.15 m soil layers. Superficial application of residues of cultivated radish and Mix produced the largest increases in levels of exchangeable K, reaching depths of 0.30 m. Increases in potassium adsorption in the soil surface layers reduces the need for potassium fertilization and can reduce production costs and environmental pollution.

Key words: Cover crops, leaching, nutrient cycling, no-tillage, soil fertility

Resumo

O trabalho foi desenvolvido com o objetivo de avaliar a influência da aplicação de diferentes tipos e doses de resíduos vegetais na mobilidade do potássio (K) em colunas de solo. Para tanto, foram coletadas amostras de um Latossolo Vermelho eutroférrico, nas profundidades de 0.0-0.10, 0.10-0.20 e 0.20-0.30 m, que foram utilizados para montagem das colunas de solo, mantendo a mesma distribuição do perfil. O delineamento experimental empregado foi o inteiramente casualizado, com 3 repetições e os tratamentos testados constituíram um fatorial 4x4, em que os fatores foram 4 tipos de resíduos vegetais (B+G = brachiaria + girassol; Mix = nabo forrageiro + aveia-preta + ervilhaca peluda; NF = nabo forrageiro; T = trigo) e 4 doses de resíduos (0, 10, 15 e 20 Mg ha^{-1}). Os resíduos moídos e secos foram aplicados na superfície das colunas que posteriormente foram irrigadas com água destilada e incubadas por 10 dias para estabilização das reações e equilíbrio salino. Após esse período procedeu-se a desmontagem das mesmas separando o solo em camadas correspondente as profundidades de 0.0-0.05,

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0.05-0.10, 0.10-0.15, 0.15-0.20, 0.20-0.25 e 0.25-0.30 m. As amostras de cada camada foram secas, tamisadas e analisadas para determinação do teor de K trocável. Os resultados obtidos indicam que a aplicação superficial de resíduos de culturas altera os teores de potássio trocável do solo, especialmente na camada 0.0-0.05 m. Aumentando as doses de resíduos pode-se aumentar significativa e linearmente os teores de K trocável do solo nas camadas 0.0-0.05, 0.05-0.10, 0.10-0.15 m. Os resíduos da cultura de nabo forrageiro e do Mix (nabo forrageiro + aveia-preta + ervilhaca peluda) foram os que determinaram os maiores aumentos nos teores do K trocável do solo, podendo atingir profundidades de até 0.30 m. O aumento na adsorção do K nas camadas superficiais do solo indica uma menor necessidade de aplicação de adubos potássicos, podendo reduzir os custos de produção e a poluição ambiental.

Palavras-chave: Cobertura vegetal, lixiviação, ciclagem de nutrientes, plantio direto, fertilidade do solo

Introduction

The movement of solutes and nutrients in the soil depends on its mineralogy and organic matter content (SOLLINS; ROBERTSON; UEHARA, 1988), nutrient concentrations and the density of electric charges in the exchange complex (QAFOKU; SUMNER, 2001), water content (FESCH et al., 1998; PADILLA; YEH; CONKLIN, 1999) and predominant environmental conditions (HESTERBERG, 1998; KABATA-PENDIAS, 2004).

In the case of potassium, vertical movement in the soil depends on cation exchange capacity (CEC) and its relationship with other adsorbed ions, especially basic cations such as Ca^{2+}, Mg^{2+}, NH_4^+ and Na^+ (TISDALE; NELSON; BEATON, 1985). Typically the adsorption of cations on the surface of the colloids occurs obeying preferential exchange series, which are regulated by the amount of positive charge (valence) and size of the hydrated ion, whose force of attraction decreases in the following order: $Al^{3+} > Ca^{2+} > Mg^{2+} > K^+ > Na^+$. However, in tillage areas, surface accumulation of organic residues occurs, which during the decomposition process release large quantities of various organic acids (FRANCHINI et al., 2001). Organic acids of low molecular weight interfere with processes releasing and mobilizing cations in the soil (ZIGLIO; MIYAZAWA; PAVAN, 1999; FRANCHINI et al., 2003; DIEHL; MIYASAWA; TAKAHASHI, 2008). Furthermore, they change the order of adsorption of cations in the colloidal particles of soil, with higher leaching of di-and trivalent cations, such as Al^{3+}, Ca^{2+} and Mg^{2+}, in the form of an organo-metallic hydrosoluble complex (FRANCHINI et al., 1999; MIYAZAWA; PAVAN; FRANCHINI, 2002).

The quality and fertility of soils managed under a no-tillage system is related to the quantity and quality of crop residues produced, their rate of decomposition and the type and amount of nutrients released (TORRES; PEREIRA; FABIAN, 2008). These processes have a positive effect on the chemical properties of the soil (GUIMARÃES et al., 2008), favoring subsequent crops (SANTI; AMADO; ACOSTA, 2003; CALEGARI et al., 2008).

Potassium contained in vegetable residues is easily released, as it is not part of the composition of any organic compound or directly dependent on microbial action for decomposition, a result of its high solubility and ease migrating to the soil (ROSOLEM et al., 2006, 2007; TORRES; PEREIRA, 2008). The release of potassium from organic matter, according Rosolem, Calonego and Foloni (2003), depends more on the frequency and intensity of rainfall.

During biological decomposition of plant residues and straw cover, different organic acids are released that then dissociate, generating negative electric charges in the soil. These organic compounds have a preference for adsorbing cations with a higher positive charge, such as Al^{3+}, Ca^{2+} and Mg^{2+}, leaving potassium to be adsorbed by the negatively charged colloids (MIYAZAWA;

PAVAN; FRANCHINI, 2002). This helps to reduce the movement of this nutrient in the soil profile.

Therefore, to better understand the effects of plant residues in soils managed under a no-tillage system, there is still a need for detailed studies evaluating the influence of organic acids released during decomposition of crop residues on the mobility of nutrients in the soil.

For this reason, this study was carried out to evaluate the influence of different types and doses of plant residues on the vertical mobility of potassium in soil columns.

Material and Methods

The trial was conducted in laboratory premises at the State University of Londrina, in the municipality of Londrina, Paraná State, Brazil.

The soil columns were assembled using samples of a Rhodic Hapludox (containing 630 g kg^{-1} clay) cultivated with napier grass (*Pennisetum purpureum*) over the previous 10 years. Separate samples were collected for layers at 0.0-0.10, 0.10-0.20 and 0.20-0.30 m. Subsequently, subsamples of each layer were air dried, sieved using a 2.0 mm mesh and sent for chemical characterization (SPARKS et al., 1996). The results are presented in Table 1.

Table 1. Chemical characteristics of Rhodic Haplustox in each soil layer prior to setting up the experiment.

Soil layer	pH	P	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	SB	CEC	V
(m)	*	mg dm^{-3}	------------------------------		cmol$_c$ dm^{-3}	------------------------------			%
0.0-0.10	4.8	26.40	0.0	3.8	3.0	0.89	7.69	13.39	57.4
0.10-0.20	5.0	20.00	0.0	4.1	2.4	0.56	7.06	11.96	59.0
0.20-0.30	4.9	6.10	0.0	2.6	2.5	0.38	5.48	10.70	57.0

* $CaCl_2$ 0.01M.
Source: Elaboration of the authors.

Samples of the aerial parts of brachiaria (*Brachiaria ruziziensis*), sunflower (*Helianthus annuus*), lopsided oat (*Avena strigosa*), winter vetch (*Vicia villosa*), cultivated radish (*Raphanus sativus*) and wheat (*Triticum aestivum*), grown in the university's experimental area (23º22' S, 51º10'W; elevation 585 m), were collected in full flower, with the exception of wheat, which was collected during the final cycle (after grain harvesting). The plant material collected was then dried in a stove at 65°C for 48 hours, ground (2 mm) and chemically analyzed to determine K levels (MALAVOLTA; VITTI; OLIVEIRA, 1997). Average K levels for plant residue dry matter and doses applied to the soil are shown in Table 2.

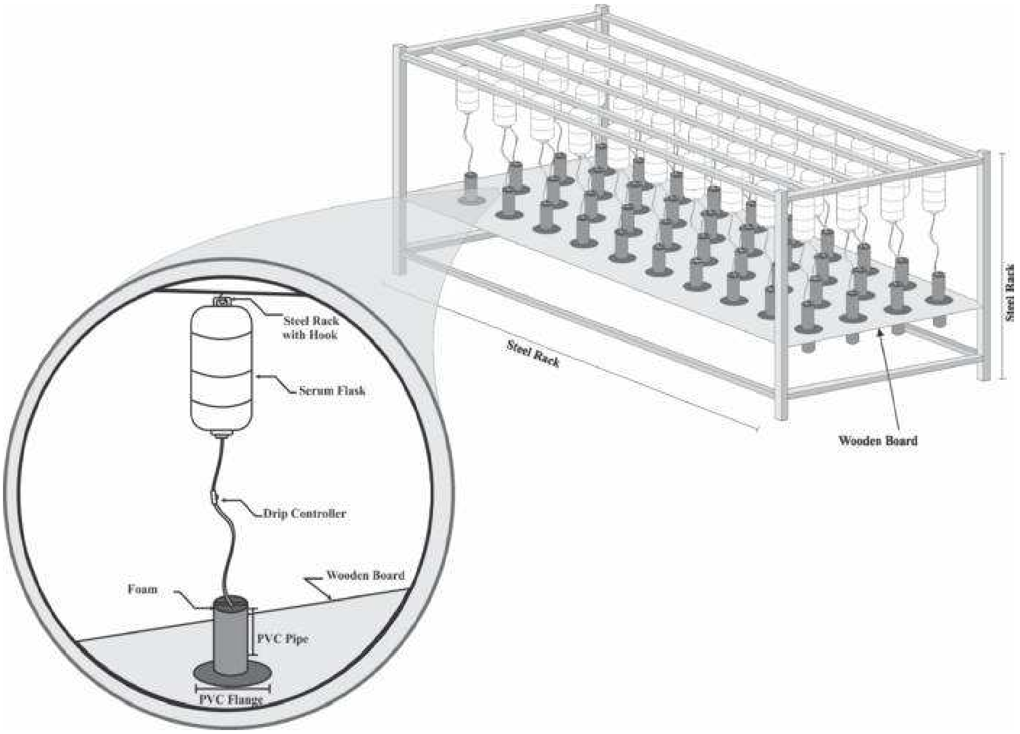
Table 2. Potassium levels in the plant dry matter and quantities applied to the soil.

Plant residue	K level in residue	Dose of plant residue (Mg ha^{-1})			
		0	10	15	20
	(g kg^{-1} MS)		K (kg ha^{-1})		
B+S	23.42	0	234.2	351.3	468.4
Mix	28.68	0	286.8	430.2	573.6
Cultivated radish	31.38	0	313.8	470.7	627.6
Wheat	18.77	0	187.7	281.5	375.4

B+S = brachiaria + sunflower. Mix = mixture of cultivated radish + lopsided + oat + winter vetch.
Source: Elaboration of the authors.

In order to conduct the experiment, columns of PVC (0.35 m high and 0.0508 m, or 2” inner diameter) lined with plastic bags were prepared. The columns were filled according to sample collection depth in an attempt to reproduce the natural distribution of the soil. The soil columns were then arranged in a steel rack (Figure 1).

Figure 1. Diagram of the rack used in the experiment.



Source: Elaboration of the authors.

The ground (2.0 mm) residues were placed on the top of the soil columns in doses equivalent to the tested treatments (Table 2). The soil was then irrigated by dripping distilled water in a quantity equivalent to twice the pore volume, corresponding to an application of 192 ml and equivalent to 95 mm rainfall per column. This was done by setting up drips at 30 drops per minute for approximately 4 hours.

Once watered, the columns were incubated for 10 days to allow reactions and saline balance to stabilize. After this period, the columns were disassembled and the earth was separated into layers corresponding to depths of 0.0-0.05, 0.05-0.10, 0.10-0.15, 0.15-0.20, 0.20-0.25 and 0.25-0.30 m. The samples obtained from each depth were dried and sieved (2.0 mm mesh) to determine levels of exchangeable K (SPARKS et al., 1996).

The experimental design was randomized, with 3 replications, and treatments were organized in a 4x4 factorial arrangement: 4 types of plant residue: B+S (brachiaria and sunflower); Mix (cultivated radish + lopsided oat + winter vetch); cultivated radish; wheat; and 4 doses of K (0, 10, 15 and 20 Mg ha^{-1}).

The results obtained for each soil layer were submitted to analysis of variance and the means were compared using Tukey’s test at 5% probability, or adjusted to equations by regression analysis using Statistical Analysis Software (SAS).

Results and Discussion

K-content for the various soil layers was influenced ($p \leq 0.05$) by the type and dose of plant residue (Table 3).

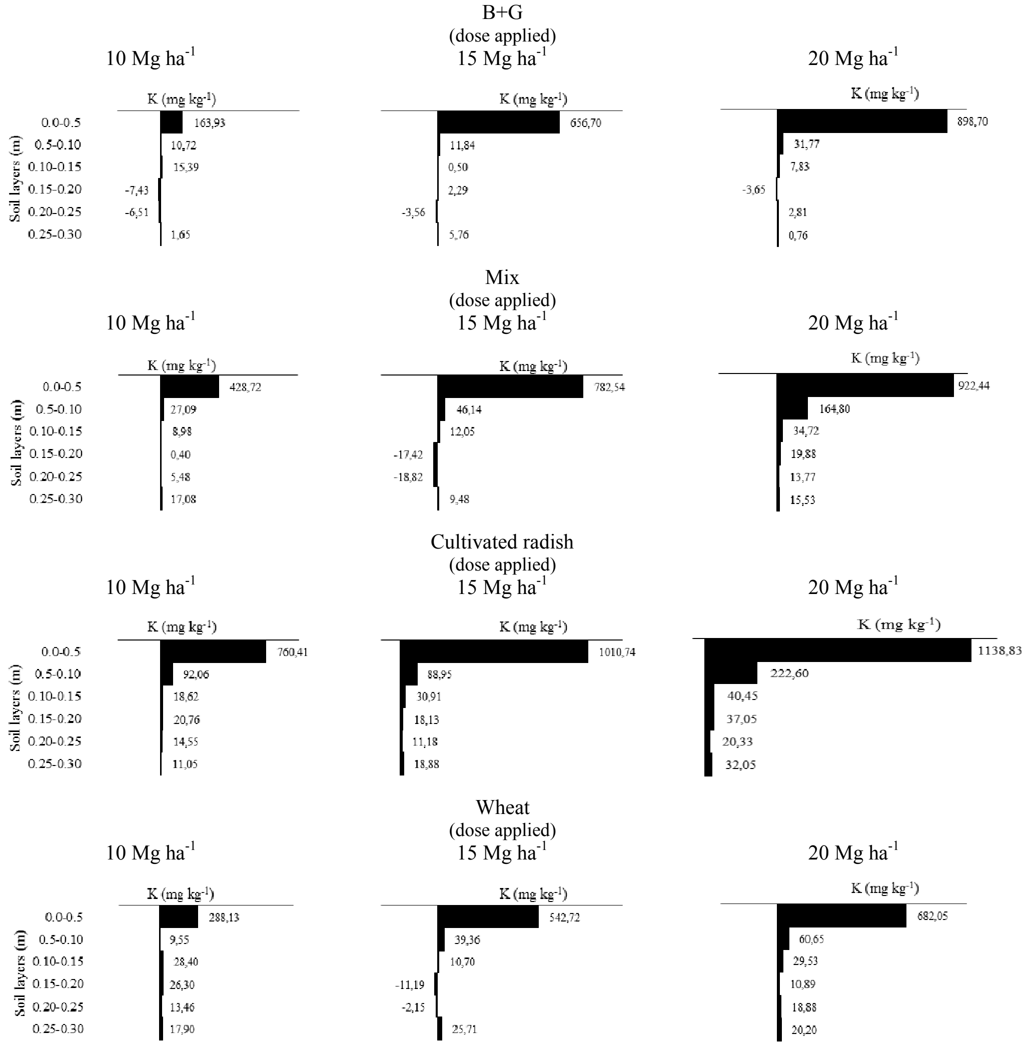
Table 3. Potassium levels in the soil layers as a function of type and dose of plant residue.

Soil layer (m)	Residue dose (Mg ha^{-1})	Plant residue			
		B+S	Mix	Cultivated radish	Wheat
		------------------------------ cmol$_c$ dm^{-3} ------------------------------			
0.0-0.05	0	0.76 a	0.80 a	0.80 a	0.85 a
0.05-0.10		0.77 a	0.81 a	0.81 a	0.84 a
0.10-0.15		0.57 a	0.59 a	0.59 a	0.65 a
0.15-0.20		0.53 a	0.55 a	0.55 a	0.59 a
0.20-0.25		0.44 a	0.43 a	0.43 a	0.50 a
0.25-0.30		0.39 a	0.41 a	0.41 a	0.43 a
0.0-0.05	10	1.20 b	1.88 ab	2.56 a	1.45 b
0.05-0.10		0.82 a	0.87 a	0.99 a	0.85 a
0.10-0.15		0.62 a	0.64 a	0.65 a	0.66 a
0.15-0.20		0.53 a	0.56 a	0.59 a	0.59 a
0.20-0.25		0.43 a	0.46 a	0.46 a	0.49 a
0.25-0.30		0.41 a	0.45 a	0.44 a	0.45 a
0.0-0.05	15	2.28 ab	2.64 ab	3.05 a	2.06 b
0.05-0.10		0.82 b	0.92 ab	1.03 a	0.90 b
0.10-0.15		0.61 a	0.64 a	0.66 a	0.66 a
0.15-0.20		0.55 a	0.51 a	0.58 a	0.55 a
0.20-0.25		0.45 a	0.43 a	0.47 a	0.45 a
0.25-0.30		0.42 a	0.42 a	0.46 a	0.45 a
0.0-0.05	20	2.81 ab	2.97 ab	3.41 a	2.41 b
0.05-0.10		0.89 c	1.18 ab	1.30 a	0.94 cb
0.10-0.15		0.62 b	0.67 a	0.70 a	0.68 a
0.15-0.20		0.55 a	0.58 a	0.62 a	0.57 a
0.20-0.25		0.45 a	0.47 a	0.49 a	0.48 a
0.25-0.30		0.41 a	0.44 a	0.48 a	0.45 a

B+S = brachiaria + sunflower. Mix = mixture of cultivated radish + lopsided + oat + winter vetch. Means followed by the same letter in the row did not differ according to Tukey's test at 5%.
Source: Elaboration of the authors.

Plant residue influenced potassium content in the different soil layers, but the effects were only observed up to the 0.10-0.15 m layer (Table 3). However, if we consider the initial levels of potassium in the soil (Table 1), it can be inferred that increases occurred up to the 0.25-0.30 m layer, indicating that vertical mobilization of potassium varies as a function of the doses and residues considered. As the largest increments in exchangeable potassium were restricted to surface layers of the soil, this can be taken as an indication of the differential effects of the waste applied. According to Rosolem et al. (2006), the millet straw left on the surface releases potassium, which is leached up to 0.04 m deep by rainfall exceeding 30 mm but does not exceed 0.08 m deep for rainfall of 50 mm. In our study we applied a quantity of water equivalent to that of a 95 mm rainfall on top of the plant residues, and the vertical movement of potassium was observed up to a depth of 0.30 m. This can also be observed in Figure 2, which indicates increases in K in the different layers evaluated. Moreover, research by Franchini et al. (1999, 2001, 2003), Amaral, Anghinoni and Deschamps (2004) and Diehl, Miyasawa and Takahashi (2008) indicates that the potassium content of the residue and the amount and type of organic acids it releases can affect the mobility of cations in the soil. In addition to the decomposition of plant residues, organic acids are released and new negative charges are generated in the topsoil. These charges have a preference for adsorbing cations with a higher positive charge, such as aluminum, calcium and magnesium. Parallel to this process, an adsorption of the potassium released from the plant residues takes place. This phenomenon differs to the traditional model for the mobility of cations in the soil, but indicates that for areas where a no-tillage system is adopted, further studies should be conducted to assess more accurately the effects of accumulated mulch on the surface of the soil on the behavior of soil nutrients, especially those that are cationic.

Figure 2. Increases in potassium compared with initial levels in different soil layers as a function of dose and type of plant residue applied to the surface.



Source: Elaboration of the authors.

From the application of 10 Mg ha^{-1} (Table 3), it was possible to observe significant variations in the amount of soil exchangeable potassium. This effect was more pronounced in the 0.0-0.05 m layer, especially with cultivated radish and Mix, which led to the biggest increases in levels of soil exchangeable potassium, differing from other plant residues tested.

For doses between 10 and 20 Mg ha^{-1}, it was observed that increasing the amount applied increased the amount of potassium reaching progressively deeper layers, but significant effects only occur in the 0.01-0.25 m layer (Table 3), keeping the emphasis on the cultivated radish and Mix residues.

For soil layers below 0.15 m, no significant differences were found between residues regardless of the dose considered.

These results are in agreement with those presented by Rosolem et al. (2006) in a study on changing the levels of exchangeable potassium restricted to upper soil layers. Furthermore, they also agree with the results obtained by Franchini et al. (1999), who found that crop residues of cultivated radish determined the greatest increases in exchangeable potassium in the soil surface layer (0.0-0.05 m).

In general, it can be concluded that crop residues of cultivated radish provided the largest increases in soil exchangeable potassium, followed by Mix and B+S, regardless of dose and soil layer considered. Cultivated radish residues increased potassium levels from 0.80 to 3.41 cmol$_c$dm^{-3} in the 0.0-0.05 m surface layer (Table 3), corresponding to an increase of 326%. The underperformance of wheat residues in increasing levels of exchangeable potassium in the soil is directly related to lower potassium content of these residues (Table 2).

According to observations by Franchini et al. (1999), this occurs because the decomposition of cultivated radish residues releases various organic acids that are able to remove the Al^{3+} and Ca^{2+} from colloidal particles of soil, releasing negative charges that adsorb potassium and promote a greater accumulation of this nutrient in the soil surface. This effect is very important, as according to Rosolem and Nakagawa (1985), potassium applications exceeding 80 kg ha^{-1} yr^{-1} of K_2O result in leaching of potassium to the lower layers of the soil, which depending on soil type may reach the water table and contaminate groundwater supplies.

For the dose of 10 Mg ha^{-1}, variations in levels of soil exchangeable potassium were observed. This effect was more pronounced in the 0.0-0.05 m layer and the cultivated radish and Mix crop residues caused the largest increases in soil exchangeable potassium levels compared with initial values. Generally speaking, vertical mobility of potassium increased as the amount of residues applied was increased, reaching deeper soil layers. More pronounced effects were observed up to a depth of 0.15 m, and mainly for cultivated radish crop residues (Figure 2). In general, one can say that the cultivated radish crop residue provided the largest increases in soil exchangeable potassium, followed by Mix and B+S, regardless of dose and soil layer considered. Cultivated radish residues increased potassium levels from 0.80 to 3.41 cmol$_c$dm^{-3} in the 0.0-0.05 m surface layer (Table 3), corresponding to an increase of 326%.

To evaluate the effect of the dose, regression equations were adjusted (Table 4). It was found that for the first three layers evaluated (0.00-0.05, 0.05-0.10 and 0.10-0.15 m), significant adjustments for increases of soil exchangeable potassium were linear. These results are in agreement with those presented by Franchini et al. (1999) and Rosolem et al. (2006).

Therefore, it can be concluded that application of organic waste to the soil surface can contribute to increased soil potassium levels, reducing the need for application of inorganic fertilizers.

Table 4. Regression equations for changes in potassium levels in the different soil layers as a function of residue dose.

Soil layer (m)	**Equation**	**R^2**
0.0-0.05	$y = 0.1079x + 0.7816$	0.9918
0.05-0.10	$y = 0.0122x + 0.7835$	0.8504
0.10-0.15	$y = 0.0032x + 0.6009$	0.9513

y = Potassium level (kg ha^{-1}), x = dose of crop residue applied (Mg ha^{-1}).
Source: Elaboration of the authors.

Conclusions

Surface application of crop residues alters the level of soil exchangeable potassium, particularly in the 0.0-0.05 m layer.

Increases in residue dose may significantly and linearly increase the level of exchangeable K in the 0.0-0.05, 0.05-0.10 and 0.10-0.15 m soil layers.

Superficial application of cultivated radish and Mix (cultivated radish + oat + winter vetch) residues led to the largest increases in exchangeable K levels, reaching layers of soil of 0.30 m deep.

Increases in potassium adsorption in the soil surface reduce the need for potassium fertilization and can reduce production costs and environmental pollution.

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