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The release of macronutrients from second crop corn straw and their behaviour in a red-yellow latosol

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Abstract

Crop residues left on the soil function as a nutrient reservoir and as a ground cover in agricultural systems. The aim of the present study is to assess the chemical alterations in the soil after the decomposition of different amounts of straw from corn as second crop. The climate of the region is classified as hot tropical and the soil is categorized as Red-Yellow Latosol (*Typic hapludox)* in the cerrado-amazon ecotone. The experiment was set up in randomized blocks in September 2013 after harvesting the second crop corn, comprised of corn straw rates (0, 14.18 and 42.54 t ha^{-1}) with six repetitions. The content of macronutrients, H+Al, pH and base saturation in the soil profile were assessed. The straw rates were added to litter bags and stored on the soil, where they were kept for 154 days throughout the rainy period. Subsequently, the soil characteristics were assessed in layers 0 to 0.05, 0.05 to 0.10, 0.10 to 0.15, 0.15 to 0.20 and 0.20 to 0.40 m. The Ca^{+2} and Mg^{+2} elements were only released by the straw on the first 0.05 m of soil. However, K circulated in the soil profile reaching depth of 0.40 m. There was reduction in K^+ saturation in treatments without straw. No alterations were observed in the other nutrients and studied attributes. According to the results, it is important to distribute the cultural remains of maize homogeneously in the area during harvesting to avoid the appreciation of soil fertility spots, especially of K.

Keywords: culture residues, leaching, savanna soil, vertical and horizontal variability, *Zea mays*.

Introduction

Cultivation of soy as in succession with corn is broadly applied in regions showing the possibility of growing two crops per year, such as state of the Mato Grosso (MT), Brazil. Thus, cover plants are rarely used in these sites. Therefore, corn crop residues (straws) are responsible for the ground cover. The soil covered with straw have benefits that favour soil conservation, such as erosion reduction, temperature maintenance and soil humidity, overall improvement in the physic, chemical and biological environments. Ziech et al. (2015) highlighted the importance of observing the percentage of sites should be covered with the residues and the time these residues remain for the soil protection. Straw is considered as an important reservoir of nutrients that can be either slowly and gradually, or quickly and intensely, becomes available (Cavalli et al., 2018). Nutrients released by cover-plant straw, such as potassium (K), help to improve the agronomical performance of subsequent cultures. As an example, K presents short half-life time in straw and is important to nourish the subsequent culture (Cavalli et al., 2018). The same authors carried out a study in the region of the present study, and observed that after 140 days evaluation, 62% of Mg, 68% of Ca, 97% of K and 69% of N released by the corn straw. In addition, the nutrient output velocity of the material is related to precipitation. The availability of nutrients from the straw such as K, Mg, N and Ca (Pacheco et al., 2011) from the ground cover plants helps the development of soil microbiota for nutrient cycling and ecosystem maintenance, because microbial metabolism is one of the main processes regulating the transformation of nutrients in the soil. Soil covered with vegetal residues protects soil from excess solar radiation, and assures less water loss due to evaporation, keeping the soil humidity and temperature at adequate levels. Sá et al. (2015) showed that Middle Northern Mato Grosso state needs on average 12.5 t ha^{-1} of straw in order to keep balance in the no-tillage system. Accordingly, presence of straw can change nutrient availability and the chemical attributes of the soil. Therefore, the aim of the present study was to assess chemical alterations in soil covered with different amounts of corn straw after the rainy period.

Results and Discussion

Decomposition of straw and release of macronutrients

Decomposition rate was higher for original-straw (14.18 t ha^{-1}), in which 55% of the material decomposed within 154 days. In contrast, only 46% of residue decomposed when

42.54 t ha^{-1} of residue was applied (Table 2). The larger amount of straw over the soil caused washing the elements, possibly due to the effect from the mechanical protection of the straw, or "umbrella" effect, which reduces insolation effect, straw degradation and even less microbial attacks. Existence of more straw over the soil suspended distribution of elements and cause localized accumulation. Based on this condition, daily decomposition rate of 51 and 127 kg ha^{-1} day^{-1} of straw was observed at the 154-day period for the initial straw amounts of 14.18 and 42.54 t ha^{-1}, respectively.
The decomposition over time can be seen in Cavalli et al. (2018), where part of the work was carried out in the same period and in the same area of the present study, where daily decomposition rate of 55 kg ha^{-1} day^{-1} of straw at the 140-day period was observed. These values were above those described in the literature, which are approximately 30 kg ha^{-1} day^{-1} in Savanna areas (Lange et al., 2008; Lara Cabezas, 2001). The high decomposition rate herein observed is linked to high mean temperature conditions in the period (25.2°C), to high rainfall rates (2100 mm - accumulated) and to the initial large amount of material on the soil (14.18 and 42.54 t ha^{-1}).
The decomposition rate was reflected on nutrient release. Each element followed a trend depending on its function in the plant (Marschner, 1995). Nutrient exit from the straw through washing, or even through material decomposition met the following order in relation to the initial total found in the material: K with 97% and 57%, S with 75% and 66%, N with 70% and 59%, Mg with 69% and 41%, Ca with 63% and 36%, and P with 38% and 26% for rates of 14.18 and 42.54 t ha^{-1} of initial straw, respectively.

Chemical changes in soil

The amount of straw on the soil had a significant effect on the content of Ca^{2+} and Mg^{2+} on the soil only in the soil layer up to 0.05 m deep, whereas this effect on K^+ was much more expressive. All the soil layers presented alterations in their content (Table 3). It is possible that nutrient accumulation could have happened in deeper layers followed by nutrient displacement; however, these layers were not assessed.
Losses due to leaching are closely related to the soil capacity to retain cations and anions. Any nutrient that is not retained in the minerals, or in the organic soil fraction, can move along with the water percolated through the soil. The capacity to retain nutrients is related to cation exchange capacity (CEC), anion exchange capacity (AEC), and to pH (Novais and Mello, 2007), soil nutrient content (Sharma and Sharma, 2013), texture (Marchuk and Marchuk, 2018), electric conductivity and to the capacity to retain water in the soil. Phillips and Burton (2002) observed better N-NH_4^+ and K^+ leaching in the soil profile. There was K^+ accumulation in the sub-surface, the fact that is justified by the preference for multivalent cations in CEC.
The amount of K^+ released by straw would be enough to increase the mean content in the 0 to 0.40 m soil layer to 39 and 70 mg dm^{-3}, respectively in treatments 14.18 and 42.54 t ha^{-1}. Thus, based on the treatment without straw, we would have the theoretical mean values 78.4 and 109.4 mg dm^{-3} in the 0 to 0.40 m layer, which is higher than the ones found in the soil analysis (58.5 and 96.8 mg dm^{-3}), although they are very close.
A high displacement K^+ in the soil was found in the study by Neves et al. (2009), who studied K^+ displacement in different soil classes subjected to the application of four K rates. The soils were assessed seven days after application. They found 59, 50, 34 and 16 mg kg^{-1} increase for each kg ha^{-1} of K_2O applied to the soils in soil located 1, 2, 3 and 4 cm away from the application site, respectively. In the same period, displacement of approximately one centimeter per day at the dose of 200 kg ha^{-1} of K_2O was observed.
The K^+ contents were influenced by straw deposition on the soil in all assessed layers (Table 3). In layers up to 0.20 m deep, all treatments differed from each other, and the treatment presenting the highest contents was the 42.54 t ha^{-1}, followed by the 14.18 t ha^{-1}, and the control with the lowest content. With regard to the 0.20 to 0.40 m layer, there was no difference between treatments without straw. However, the treatment 42.54 t ha^{-1} showed the highest content at this depth, reaching almost the double of the other treatments. The increase of mineral content in this layer was accompanied with lack of K^+. We believe that K content was not found in a reasonable amount due to leaching in to deeper layers, evidencing that under the same conditions of clay soil (542 g kg^{-1}) and gradual release, there is K^+ displacement. This fact suggests that in the case of mineral fertilization, in which leaching is much faster and soybean roots are not well developed; there would be vertical displacement of K^+. It also applies to cases in which corn straw is not well-distributed on the surface after harvesting and accumulations in points set behind the harvester, the fact that will certainly cause a nutrient loss in the soil profile. This condition might deteriorate each year in the region since harvesters have bigger platforms that cannot uniformly distribute the straw on the soil.
Another observation to be done concerning K^+ saturation in CEC, in which we observed relatively low initial value of 1.9% (Table 1). There was high K^+ leaching in without-straw treatment in 0.10 m, in which it was dropped to less than 1% (Table 3). However, in deeper layers, K^+ saturation remained the same due to K supply from upper layers. On the other hand, the treatment with 42.54 t ha^{-1} of straw showed K saturation increase, which overpassed 4% in the layer from 0.10 to 0.20 m and with vertical displacement in higher contents. This fact suggests re-evaluation of recommended corrective fertilization with K, such as that proposed by Lopes (1999), who suggested increasing saturation to the level 3% and 5% of CEC; and that by Vilela et al. (2004), who recommended the limit of 3% to Savanna soils, mainly to sandy soils. As it was observed, even for clay soil with low K saturation, there was a great lixiviation of K^+, thus increasing K saturation to the levels higher than 3% of CEC, which may not be the ideal situation in regions with extreme rainfall after the fertilizer application. This is suggesting its fractionation in the production system, and to consider that in sandy texture soils the losses can be increased.
Observation of initial contents of K^+ in the soil confirmed (Table 2) that after 154 days of the experiment (Table 3), the straw will release significant amount of K^+ to the soil that can be used by the soybeans culture in synchrony. However, it is also evident that there are great leaching due to rainfall, in the current year (2100 mm) within 154 days. It was a rainfall above the regional average (but not uncommon), thus emphasizing the occurrence of seven rain events higher

Table 1. Chemical and physical properties of the soils used in the experiments in Mato Grosso State, Sorriso County.

	Layers (m)		
	0 to 0.1	0.1 to 0.2	0.2 to 0.4
Chemical [1]			
pH (H_2O)	5.44	5.42	5.21
M.O. (g dm^{-3})	38.30	37.30	26.30
$P_{Mehlich}$ (mg dm^{-3})	17.50	5.40	3.30
$K_{Mehlich}$ (mg dm^{-3})	94.50	71.00	65.00
S (mg dm^{-3})	17.66	16.87	8.78
Ca ($cmol_c$ dm^{-3})	3.78	2.23	1.21
Mg ($cmol_c$ dm^{-3})	1.79	0.88	0.83
SB ($cmol_c$ dm^{-3})	5.81	3.28	2.21
CEC ($cmol_c$ dm^{-3})	13.06	9.77	8.40
V (%)	44.48	33.59	26.30
K saturation (%)	1.85	1.86	1.98
Physics (1)			
Clay (g kg^{-1})	530	553	584
Sand (g kg^{-1})	307	297	272
Silt (g kg^{-1})	163	150	144
Density (g cm^{-3})[2]	1.17	1.00	-
Hydric (2)			
Total porosity (m^3 m^{-3})	0.52	0.49	-
Macro-porosity (m^3 m^{-3})	0.11	0.10	-
Micro-porosity (m^3 m^{-3})	0.41	0.39	-
Hydraulic conductivity (mm h^{-1})	76.12	-	-

[1]Mean of three composed samples; each composed sample derived from ten sub-samples. [2]the mean of 10 samples.

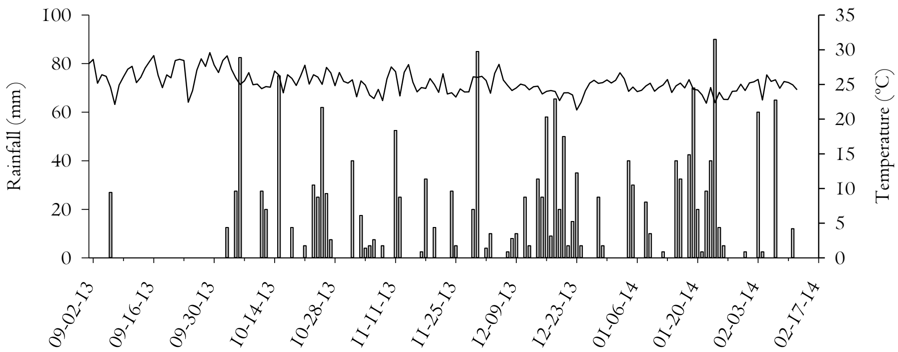

Fig 1. Rainfall and average temperature for the Sorriso county in 2013-14 (source: Mato Grosso Foundation).

Table 2. Initial and final straw amount and nutrients stored in the straw in 3 treatments: mean straw amount from corn crop (14.18 t ha^{-1}), and three times the mean amount (42.54 t ha^{-1}), in Mato Grosso State, Sorriso County, 2013-14 crop.

	Treatments (t ha^{-1})			
	14.18	42.54	14.18	42.54
	Initial (kg ha^{-1})		Final	
Straw cover	14180	42540	6450	23220
Potassium	162.17	486.51	4.47	208.96
Calcium	53.51	160.53	17.24	102.17
Magnesium	41.68	125.04	13.15	74.30
Phosphor	4.30	12.90	2.68	9.58
Sulfur	4.54	13.61	1.15	4.60
Nitrogen	113.50	340.50	34.80	140.13

Table 3. Content of nutrients found in the different soil layers below the litter bags in treatments: straw-free surface (0), the mean straw amount from corn crop (14.18 t ha^{-1}), and three-times the mean amount (42.54 t ha^{-1}), in Mato Grosso State, Sorriso County, 2013-14 crop.

	Treatments (t ha^{-1})								
Layer (m)	0	14.18	42.54	0	14.18	42.54	0	14.18	42.54
	K (mg dm^{-3})			Ca (cmol$_c$ dm^{-3})			Mg (cmol$_c$ dm^{-3})		
0 to 0.05	32.50 c	54.75 b	96.33 a	4.60 b	5.73 a	5.26 ab	1.77 b	2.23 ab	2.62 a
0.05 to 0.10	32.00 c	80.83 b	142.83 a	2.52 ns	2.69	2.50	0.89 ns	1.22	1.08
0.10 to 0.15	42.20 c	78.50 b	143.17 a	2.10 ns	1.86	2.00	0.67 ns	0.66	0.73
0.15 to 0.20	47.00 c	72.25 b	119.23 a	1.46 ns	1.18	1.60	0.57 ns	0.59	0.69
0.20 to 0.40	40.33 b	45.50 b	68.20 a	1.12 ns	0.68	0.75	0.55 ns	0.57	0.49
	P (mg dm^{-3})			S-SO$_4$ (mg dm^{-3})			H + Al (cmol$_c$ dm^{-3})		
0 to 0.05	18.49 ns	20.93	19.63	17.93 ns	17.77	17.25	5.29 ns	4.77	5.18
0.05 to 0.10	5.11 ns	5.43	5.02	18.03 ns	17.44	16.83	7.32 ns	6.90	6.70
0.10 to 0.15	4.40 ns	4.42	2.94	17.92 ns	17.69	17.40	6.56 ns	6.90	6.48
0.15 to 0.20	1.90 ns	1.77	1.72	18.00 ns	17.60	17.58	5.53 ns	5.87	5.80
0.20 to 0.40	1.80 ns	1.71	1.66	9.39 ns	8.46	9.09	5.20 ns	5.56	5.50
	pH			K saturation (%)			Base saturation (%)		
0 to 0.05	5.83 ns	5.94	5.83	0.70 b	0.98 b	1.83 a	55.31 ns	63.75	59.62
0.05 to 0.10	5.76 ns	5.91	5.85	0.93 b	1.50 b	3.45 a	32.57 ns	35.27	36.95
0.10 to 0.15	5.72 ns	5.77	5.94	1.25 b	1.88 b	4.20 a	30.81 ns	28.22	32.58
0.15 to 0.20	5.67 ns	5.67	5.86	1.83 b	2.20 b	4.12 a	28.42 ns	24.89	29.24
0.20 to 0.40	5.25 ns	5.17	5.32	1.52 b	1.73 b	2.82 a	24.35 ns	19.85	20.85

ns = not significant. Means followed by different letters on the lines for the content of each element in the soil differ from each other in the Tukey's test ($p < 0.05$).

than 70mm day^{-1}. This has possibly optimized the K^+ displacement process in the soil profile and corroborates Mendes et al. (2016), who observed an increase in the leaching of K^+ with the increase in the applied water depth. Such event tends to get worse in relation to mineral fertilization, in which nutrient release is much faster into the soil, causing faster displacement under intense rainfall conditions in the region.

Comparison of initial K^+ content in the soil (Table 1) and the content after 154 days (Table 3), showed lack of straw and decrease of nutrient content from 94.5 to 32 mg dm^{-3}, in the 0 to 0.10 m layer, and from 71 to 44.6 mg dm^{-3} in 0.10 to 0.20 m. The treatment 14.18 t ha^{-1} of straw kept the values close to control, meaning a decrease of ~26 mg dm^{-3} in the 0 to 0.10 m layer and an increase of ~4 mg dm^{-3} in the 0.10 to 0.20 m layer. Sá et al. (2015) found that it is necessary to have an annual dry mass yield between 11.3 and 13.7 t ha^{-1} in order to keep balance in the no-tillage system. These data are in accordance with those recorded in the current study.

With regard to the high straw dose (42.54 t ha^{-1}), there was an increase in K^+ content in the soil with an increase of ~25 to 60 mg dm^{-3} in the 0 to 0.10 m and 0.10 to 0.20 m layers, respectively. It is noteworthy that this treatment also had more than 200 kg ha^{-1} of K^+ against 4 kg ha^{-1} of treatment 14.18 t ha^{-1} at the end of the experiment (Table 2). Lange et al. (2008) conducted an experiment in a Dystrophic Red Latosol area - Minas Gerais State in a high clay texture (650 g kg^{-1} of clay) for 10 years. They annually added to the soil up to 12 t ha^{-1} of corn straw to the soil. They observed an increase in the K content up to 0.20 m layer.

The behavior of Ca^{2+} and Mg^{2+} in the soil remained within the expectations, because of their low rates of displacement in the soil and lower leaching; thus, reaching the surface layer down to 0.05 m within 154 days. The greatest K^+ displacement in the soil profile can be explained by the energy retention of cations energy in the colloids or by the lyotropic series, in which Ca^{2+} is the most retained element, followed by Mg^{2+} and finally by K^+ (Novais and Mello, 2007). Higher levels of K application resulted in higher losses of K. Apparently, more quantity of K was available for reaction with soil, which resulted in higher amounts of K moving out of soil column (Sharma and Sharma, 2013). The Ca^{2+} content was higher in the treatment of 14.18 t ha^{-1}. This value was above the theoretical amount provided by straw. The released Ca^{2+} remained in the 0 to 0.05 m layer. We observed 0.37 and 0.58 cmolc dm^{-3} increase in treatments 14.18 and 42.54 t ha^{-1}, respectively, compared to without straw resulted in 4.97 and 5.18 cmolc dm^{-3}. However, the observed values were 5.73 and 5.26 cmolc dm^{-3}, respectively. The value recorded for treatment 14.18 t ha^{-1} was higher than that released from the straw. However, in treatment 42.54 t ha^{-1} this value was compatible to the one was available.

The Mg^{2+} values were calculated according to the exit of nutrients from the straw and by taking into consideration its total permanence in the 0 to 0.05 m layer, which practically were the same to those found in the chemical analysis of the soil (2.23 and 2.62 cmolc dm^{-3}). The Mg^{2+} values for treatments 14.18 and 42.54 t ha^{-1} were 2.24 and 2.61 cmolc dm^{-3}, respectively. Table 3 shows significant difference only between treatments using zero (0) and 42.54 t ha^{-1} of straw. Application of 14.18 t ha^{-1} of straw did not show any increase from the others.

Even with alterations in soil's Ca^{2+} and Mg^{2+} contents, no significant alteration was not observed in Ca^{2+}/Mg^{2+} relation. The high oscillation of Ca^{2+} and Mg^{2+} contents was observed in the soil, regardless of treatment and layer assessed, by observing coefficient of variation higher than 60%.

For other assessed elements (P and S), we observed no significant alteration, due to relatively low amount of straw. Approximately 3 kg ha^{-1} of P, became available under highest straw dose. The study site has been subjected to a no-tillage system for more than 15 years, in which the fertilizer application has been performed by spreading. Therefore, there has been accumulation of fertilizers in the surface layer, where the 0.05 m layer had four times more P than the 0.05 to 0.10 m layers (Table 3). The low availability of P supply by straw, vertical variability of P in AEC (Schlindwein and Anghinoni, 2000), with high content in the surface layer and low displacement in the soil profile, as well as the great horizontal variability have been reported by Zanão Júnior et al. (2010). The maximum value observed was 8.1 times higher than the minimum, all the added conditions considerably increased the coefficient of variation; thus, enabling significant P increase in the soil.

Although straw residue has released 9 kg ha^{-1} of S in the highest dose (almost double of P) but we did not observe a significant effect on the soil. On the other hand, there was a trend of S content due to straw rate increase in practically all assessed layers (Table 3). It is possible that sulfur leached together with the K released from the straw; thus, the higher the straw dose, the greater the K release and the higher the amount of S leached in the form of potassium sulfate.

The straw on the soil also did not influence H + Al content, pH and base saturation (V%). This fact was actually expected due to the short time between implementation of experiment and the soil collection. One of the main factors that straw could alter indirectly is organic matter. However, it is known that it would be necessary to have a longer period under proper soil management. Even with great K^+, Ca^{2+} and Mg^{2+} release in the layer up to 0.05 m deep, such amount was not enough to significantly increase V%. It corroborates with Lange et al. (2008), who conducted an experiment for ten years. They annually added 12 t ha^{-1} of corn straw to the soil and observed changes in the K^+ content in the soil. There was no influence on the other elements.

Based on these results, it is possible to observe the relevance of regulating the harvester to uniformly distribute the corn harvest residues on the soil. It is worth emphasizing that this issue can get worse over the years, since certain sites perform their harvests always with the same machinery, "the same track", at the same harvest platform width. When the distribution is not uniform, it may cause a large nutrient horizontal variability, mainly of K^+. This fact must be observed at the time to collect soil samples, in order not to underestimate the real content in locations with few straws or without it overestimate by collecting in areas of high straw deposition. Moreover, there is the relevance of a proper straw-distribution in order to avoid losses caused by leaching or improving K by soybean cultivated after corn in the region.

Materials and Methods

Study site

The study was conducted in the field, in Middle Northern Mato Grosso State, Sorriso County, Brazil (S = 12°31'06"; W = 55°40'22", altitude 365 m) during the 2013/2014 crop. Climatic data collected during the experiment are shown in Fig 1.

The climate in the region is classified as Aw, hot tropical, according to Köppen's classification, with two well-defined seasons: rainy summer and dry winter (Alvares et al., 2014). The soil is categorized as Red-Yellow Latosol (*Typic hapludox*), and its physic-chemical characteristics are presented in Table 1.

Land uses and characterization

The field used for the study has been in use for more than 15 years as a no-tillage system. It is often cultivated through crop succession system: soybeans in summer; and second crop corn in fall/winter, which is typical of the region. With regard to the agricultural year (2012/2013 crop), the corn variety DKB 390 VTpro2 was sown at the end of February and harvested in the second half of July 2013, when there is no more rain in the region. It is also common to have corn in the field for few more days after it is ready to be harvested. Grain yield was approximately 9000 kg ha^{-1} in the chosen site. Straw was collected from the plot limited for the experiment, fractionated with the aid of a machete, and stored in litter bags, according to the adapted methodology by Torres et al. (2008). The initial phytomass determination of 14.18 t ha^{-1} was performed through the random throw of a 0.25 m^2 gauge (0.5 x 0.5 m), which was hurled fifteen times within a plot of approximately 150 m^2.

Traits measured

After corn harvest, all the straw remaining on the soil was collected and the randomized block design was implemented. The treatments were composed of the amount of straw on the soil (zero, one and three times the amount of original corn straw left after the harvest); totally three treatments with six repetitions. The straw was placed in litter bags (1 m^2); each bag was treated as a fraction. The litter bags were placed on the soil and tight through rebar handles to unable their displacement by external agents.

The litter bags were left on the soil for 154 days. The only managements performed throughout this period were weed control and straw removal brought by the wind to the experiment.

After 154 days, the soil was collected under the litter bags, from layers 0 to 0.05, 0.05 to 0.10, 0.10 to 0.15, 0.15 to 0.20 and 0.20 to 0.40 m, in the trench system, on the center of the litter bag area (0.3 x 0.3 x 0.4 m). Three sub-samples were collected per trench, one in the frontal side, and two in its sides, where they were grouped. The soil was air-dried and assessed according to the methodology by Silva et al. (2009).

Statistical analysis

Results were subjected to variance analysis, and when they were significant, the means resulting from the treatments were compared through Tukey test ($p < 0.05$).

Conclusion

The total amount of 14.18 t ha^{-1} of straw was able to replace the potassium leached through rainfall. The higher amounts of straw created potassium surplus in the system, which resulted in leaching. Potassium leaching happens even in soils present high clay content and low potassium saturation in the CEC of the soil.

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