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Residual effect of KCl coated by polymeters incorporated in a corn crop

Efecto residual de la aplicación de KCl recubierto por polimeros en un cultivo de maíz

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ABSTRACT

The use of polymer-coated potassium fertilizers may reduce the leaching of potassium (K) in the soil, increasing the availability of this nutrient to plants for a long period. In this context, the residual effect of doses and sources of potassium chloride (KCl) application on K nutrition, production components and corn grain yield in two sequential crops were investigated in this study. The experiment was conducted in a clayey Oxisol. The experiment was arranged in a randomized complete block design with four replicates in a 4 × 4 factorial scheme: four potassium doses (0, 40, 80 and 120 kg ha^{-1} of K_2O) and four KCl sources [uncoated fertilizer (conventional) and three sources of fertilizer coated with different polymers]. The KCl sources showed the same residual effect for most production components, leaf K content and corn grain yield in both crops. The increase of K fertilizer doses in the previous crop provided residual effect on the second-harvest corn crop, resulting in linear increase in leaf K content, weight of 100 grains and grain yield up to the dose of 77 kg ha^{-1}, whit the use of any source of KCl.

Keywords: *Zea mays L.*, fertilizer with enhanced efficiency, potassium fertilizer, grain yield.

RESUMEN

El uso de fertilizantes potásicos recubiertos con polímeros puede reducir la lixiviación de potasio (K) en el suelo, poniendo a disposición del cultivo este nutriente por un mayor tiempo. Se evaluó el efecto residual de la dosis de K2O y las fuentes de cloruro de potasio (KCl) sobre el contenido de K foliar, componentes de producción y productividad de granos de maíz en dos cultivos consecutivos. El experimento se realizó en un suelo tipo oxisol (Ferralsol) de textura arcillosa. El modelo experimental fue de bloques al azar, con cuatro repeticiones, dispuestos en esquema factorial 4 x 4. Se aplicaron cuatro dosis de K2O (0, 40, 80 y 120 kg ha^{-1}) y cuatro fuentes de KCl (una convencional y tres recubiertas con diferentes polímeros). Las fuentes de KCl presentaron el mismo efecto residual para la mayoría de los componentes de producción, el contenido de K foliar y la productividad de los granos de maíz. El incremento de las dosis de K2O en el cultivo anterior proporcionó un efecto residual en la cosecha del cultivo de maíz segundo periodo, aumentando linealmente el contenido de K foliar, la masa de 100 granos y la productividad de granos hasta la dosis de 77 kg ha^{-1}, independiente de la forma de KCl. Sin embargo, no hubo efecto residual de dosis de K2O para productividad de granos de maíz en el segundo cultivo.

Palabras clave: Zea mays *L., fertilizante de eficiencia mejorada, fertilización potásica, productividad de granos.*

Introduction

Brazil is the third largest corn producer and the second largest exporter, but in order to obtain high corn grain yield it is necessary to apply high doses of fertilizers, such as nitrogen (N) and potassium (K), mainly because soils do not supply the crop demand along its growth cycle and also due to inadequate use of liming and fertilization (Rodrigues *et al*., 2014).

Potassium has a great impact on crop quality, having a positive influence on the individual grain mass and the number of grains per ear. After N, K is the element absorbed in greater quantities by corn crop, for example, 30% of K applied is removed by grains. However, until recently the responses to K fertilizer obtained in field trials with corn crop were, in general, less frequent and lower than those observed for P and N due mainly to the low yield levels obtained (Rodrigues *et al*., 2014).

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Insufficient application of K fertilizer may lead to depletion of soil K reserves and excessive application can intensify leaching losses even in soils with medium and high cation exchange capacity (Ernani *et al.*, 2007). Therefore, several economic and environmental drawbacks associated with the use of conventional fertilizers become a focus of concern worldwide (James and Sojka, 2008; Ni *et al.*, 2009). Therefore, the correct management of potassium fertilization can minimize losses and avoid K depletion in soil (Werle *et al.*, 2008).

Among potassium fertilizers, potassium chloride (KCl) is the most widely used in Brazil, however, K losses by leaching between 50-70% have been reported in the literature (Wu and Liu, 2008), mainly in sandy soils and in regions with high rainfall rates. A possible alternative to minimize the leaching of this nutrient would be the use of slow-release fertilizers (Xie *et al.*, 2011), such as polymer-coated KCl.

Inhibitory or stabilizing fertilizers are products that reduce nutrient losses by delaying the conversion of the original forms of the fertilizer into forms that can be easily lost (Blaylock, 2007). However, in Brazil, there is still little research with polymer-coated fertilizers when compared to other countries, which makes it necessary to conduct experiments in Brazilian soil and climatic conditions, especially in regions such as cerrado, which presents great potential for grain production, such as corn. These studies are extremely important because they allow us to establish cost-benefit relationships, as well as to quantify the agronomic efficiency of fertilization, thus validating the use of this type of fertilizer (Rodrigues *et al.*, 2013).

The use of polymer-coated KCl in crop production systems with annual crops may be of interest to increase the residual effect of K on soil, thus providing this nutrient for a longer period of time, and may even meet nutritional needs of crops in succession. The objective of this study was to evaluate the residual effect of doses and sources of potassium chloride application (uncoated or coated with different polymers) on K nutrition, production components and corn grain yield in two sequential crops.

Material and Methods

The study was conducted under no-till in an area with a two-year history in this system), in the municipality of Selvíria-MS, Brazil (22º 22 ‘S and 51º 22’ W, with altitude of 335 m). The soil of the experimental area, according to the classification of Embrapa (2013), is a Latossolo Vermelho distrófico (Oxisol), with 420, 50 and 530 g kg^{-1} of sand, silt and clay, respectively. The climate, according to the classification of Köppen, is the fundamental type Aw - humid tropical with a rainy season in the summer and dry in winter, and the average annual rainfall is of 1,370 mm. The values of rainfall, average temperature and relative air humidity recorded during the conduction of the experiment are shown in Figure 1.

The chemical characteristics of soil were determined before the installation of the experiment in 2010, according to methodology proposed by Raij *et al.* (2001), with the following properties, in the 0.0-0.20 m depth: P (resin) = 22 mg dm^{-3}; organic matter = 32 g dm^{-3}; pH ($CaCl_2$) = 5.4; K, Ca, Mg, H + Al = 2.2; 30.0; 16.0 and 31.8 $mmol_c$ dm^{-3}, respectively and soil base saturation of 60%.

The experiment was arranged in a randomized complete block design with four replicates, in a 4 × 4 factorial scheme: four K doses (0, 40, 80 and 120 kg ha^{-1} of K_2O) and four KCl sources [uncoated fertilizer (conventional) and three sources of coated fertilizer with different polymers (“plastics”)]. These treatments were applied to corn sowing in the first crop (2010/11) and second crop (2011). In order to evaluate the residual effect of this potassium fertilizer on the subsequent corn crop in the first crop (2011/12) and on the second crop (2012), the sowing was carried out exactly in the sowing line of the previous corn crop. The dimensions of the plots were 5.0 m in length with four rows spaced 0.90 m.

The AGROCERES AG 8088, an early cycle simple hybrid, was mechanically sow with 5.4 seeds per meter (corresponding to 55,000 plants ha^{-1}) on November 06th, 2011 (First crop) and May 27th, 2012 (Second crop). The soil was then irrigated using a center pivot irrigation system with application rate of 14 mm to promote seed germination. Seedlings emerged 5 days after sowing in both crops.

The sowing fertilization was performed with 30 kg ha^{-1} of N (urea) and 100 kg ha^{-1} of P_2O_5 (simple superphosphate), for all treatments, based on the soil analysis and the fertilization recommendation for irrigated corn (Cantarella *et al.*, 1997). The nitrogen fertilization was applied

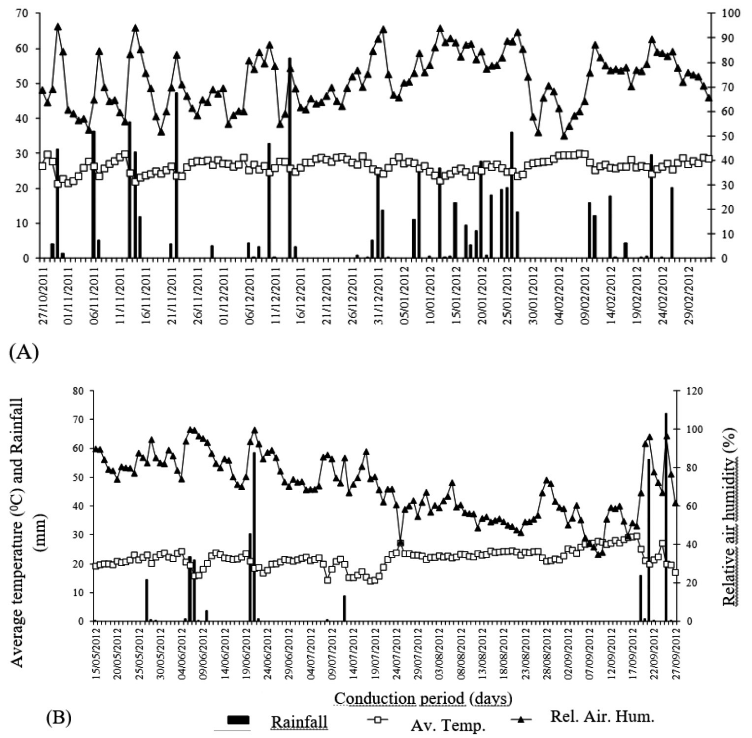

Figure 1. Rainfall, average temperature and relative air humidity recorded during the conduction of the experiments with the corn crop. First crop (A) and second crop (B). Selvíria-MS, Brazil 2011/12 and 2012.

in topdressing without incorporation at the dose of 80 kg ha^{-1} of N (urea) when the plants had six completely unfolded leaves, for all treatments, positioning the manure in leading to a distance of 0.20 m from the crop row. The area was irrigated to minimize N losses by volatilization of the ammonia.

The water supply was carried out when necessary using a center pivot irrigation system. The water application rate was 14 mm, with irrigation time of approximately 72 hours. The weed control was effected with the application of tembotrione herbicide (84 g ha^{-1} active ingredient - a.i.) and atrazine (1000 g ha^{-1} a.i.), plus the addition of vegetable oil (720 g ha^{-1} a.i.), in post-emergence. Pest control was performed with methomyl (215 g ha^{-1} a.i.) and triflumuron (24 g ha^{-1} a.i.). Corn was harvested manually at each experimental unit, in 2011/12 (First crop) at 118 days and in 2012 (Second crop) at 128 days, after the emergence of the plants.

The following evaluations were carried out: a) leaf K content, with the collection of 20-leaf middle third of the main stalk insertion in the female flowering of the plants, according to the methodology described in Cantarella *et al.* (1997) and determined in the laboratory following the methodology of Malavolta *et al.* (1997); b) stalk diameter was measured in the second internode, using a manual caliper; c) height of first ear insertion; d) plant height defined as being at distance (m) from the soil level to the apex of the corn tassel; e) number of grains per row; f) number of rows per ear; g) mass of 100 grains, determined in a precision scale of 0.01 g, and h) grain yield, determined by the collection of the corn ears contained in the two central rows of each plot. The material was subjected to drying in full sun and after the mechanical track, the grains were quantified and the data transformed in kg ha^{-1}, at 13% humidity (wet basis).

The evaluated traits were submitted to analysis of variance (test F) and the means of the KCl sources were compared by the Tukey test at 5% probability level and regression analysis was used for the K fertilizer doses, and significant equations (F-test;

$p \leq 0.05$) with the highest coefficients of determination were adjusted. The analyses were performed using the SISVAR program (Ferreira, 2011).

Results and discussion

The KCl sources were not different for stalk diameter, plant height, height of first ear insertion, leaf K content, number of grains per row and rows per ear, mass of 100 grains, and corn grain yield in the 2011/12 harvest (Tables 1 and 2). In the 2012 harvest, similar results were obtained in the assessments of stalk diameter, height of first ear insertion, leaf K content, number of grains per row and rows per ear and corn grain yield (Tables 1 and 2).

In the 2012 harvest, KCl coated with polymer 0057 provided higher plant height compared to polymer 0047, although not differing from KCl coated with polymer 0048 and conventional KCl (Table 1). In turn, KCl coated with polymer 0048 provided a larger mass of 100 grains than conventional KCl (0045) and KCl coated by polymer 0057 (Table 2), thus demonstrating that the coated KCl did not overlap with conventional KCl in terms of residual effect on subsequent crop cultivation.

According to Rodrigues *et al.* (2014), the responses of improved efficiency fertilizers depend on the microbial action; the chemically altered ones will convert part of the nutrients into insoluble forms that will be available to the plants gradually; while the coated or encapsulated, which were used in this research, consist of soluble compounds surrounded by a water-permeable resin that will regulate the nutrient delivery process. Therefore, the release will depend on the temperature and humidity of the soil. It is noteworthy that the rates of release and dissolution of water-soluble fertilizers also depend on the coating materials (Jarosiewicz and Tomaszewska, 2003).

In addition, the thickness and chemical nature of the coating resin, the amount of microcracks on its surface and the size of the fertilizer granules determine the release rate of nutrients over time (Rodrigues *et al.*, 2013). Therefore, the types of polymers used as a coating of KCl were not efficient in the gradual release of K, probably due to the edaphoclimatic conditions of the region, which presents high temperatures (Figure 1), clay soil and high microbial activity, which may have favored the rapid degradation of these coating polymers in addition to the fact that the crop was irrigated, which may have attenuated the release of K as a function of soil moisture, since KCl is a high water-soluble salt (58% solubility), and can be easily leached (Leal *et al.*, 2015).

Table 1. Stem diameter, plant height, height of insertion pin and K foliar content in function of the residual effect of forms of KCl and doses of potash. Selvíria - MS, Brazil, 2011/12 and 2012.

Treatment	Stem diameter (cm)		Plant height (m)		Height of insertion pin (m)		K foliar content (g kg^{-1} D.M.)	
	2011/12	2012	2011/12	2012	2011/12	2012	2011/12	2012
				KCl forms				
0045[(1)]	2.04 a	2.07 a	2.58 a	2.60 ab	1.14 a	1.14 a	16.65 a	15.31 a
0048	2.05 a	2.08 a	2.59 a	2.59 ab	1.16 a	1.17 a	15.83 a	15.00 a
0057	2.06 a	2.08 a	2.55 a	2.62 a	1.13 a	1.18 a	15.84 a	14.25 a
0047	2.08 a	2.13 a	2.59 a	2.54 b	1.13 a	1.21 a	16.21 a	15.50 a
L.S.D. (5%)	0.20	0.18	0.09	0.07	0.07	0.15	1.95	0.97
				K_2O doses (kg ha^{-1})				
0	2.04	2.10	2.60	2.59	1.12	1.17	15.25	16.00
40	2.02	2.03	2.59	2.60	1.17	1.22	16.43	14.93
80	2.15	2.16	2.58	2.60	1.15	1.16	16.31	14.87
120	2.06	2.07	2.57	2.57	1.13	1.16	16.46	13.75
C.V. (%)	10.15	9.14	3.61	3.18	6.73	13.31	6.02	4.53
Overall Mean	2.06	2.09	2.58	2.59	1.14	1.18	16.11	15.01

(1) The code 0045 refers to uncoated potassium chloride and the others to potassium chloride with the coatings.
Means followed by letters equal, in the column, do not differ among themselves by the Tukey test, at a 5% probability level.

Table 2. Number of grains per row, number of rows per spike, mass of 100 grains and corn grain yield in function of the residual effect of forms of KCl and doses of potash. Selvíria - MS, Brazil, 2011/12 and 2012.

Treatment	Number of grains per row		Number of rows per spike		Mass of 100 grains (g)		Grain Yield (kg ha^{-1})	
	2011/12	2012	2011/12	2012	2011/12	2012	2011/12	2012
				KCl forms				
0045[1]	36.6 a	36.6 a	18.0 a	16.65 a	29.36 a	25.06 b	92.29 a	73.37 a
0048	37.1 a	37.1 a	18.1 a	17.05 a	29.55 a	27.16 a	92.94 a	70.62 a
0057	36.8 a	36.8 a	18.1 a	16.93 a	29.09 a	25.12 b	94.86 a	72.65 a
0047	36.5 a	36.5 a	18.1 a	16.98 a	28.99 a	25.98 ab	95.11 a	69.87 a
L.S.D. (5%)	1.4	1.4	0.7	0.69	1.14	1.81	7.30	9.66
				K_2O doses (kg ha^{-1})				
0	37.0	34.35	18.1	16.60	28.74	24.81	82.25	70.18
40	37.3	32.55	18.1	17.08	29.29	26.24	97.25	72.40
80	36.0	30.94	18.0	17.08	29.19	25.83	100.35	71.10
120	36.7	31.51	18.1	16.85	29.77	26.44	95.36	72.83
C.V. (%)	4.05	7.32	4.36	4.32	4.12	7.44	8.25	14.30
Overall Mean	36.8	32.34	18.1	16.90	29.25	25.83	93.80	71.63

[1] The code 0045 refers to uncoated potassium chloride and the others to potassium chloride with the coatings.
Means followed by letters equal, in the column, do not differ among themselves by the Tukey test, at a 5% probability level.

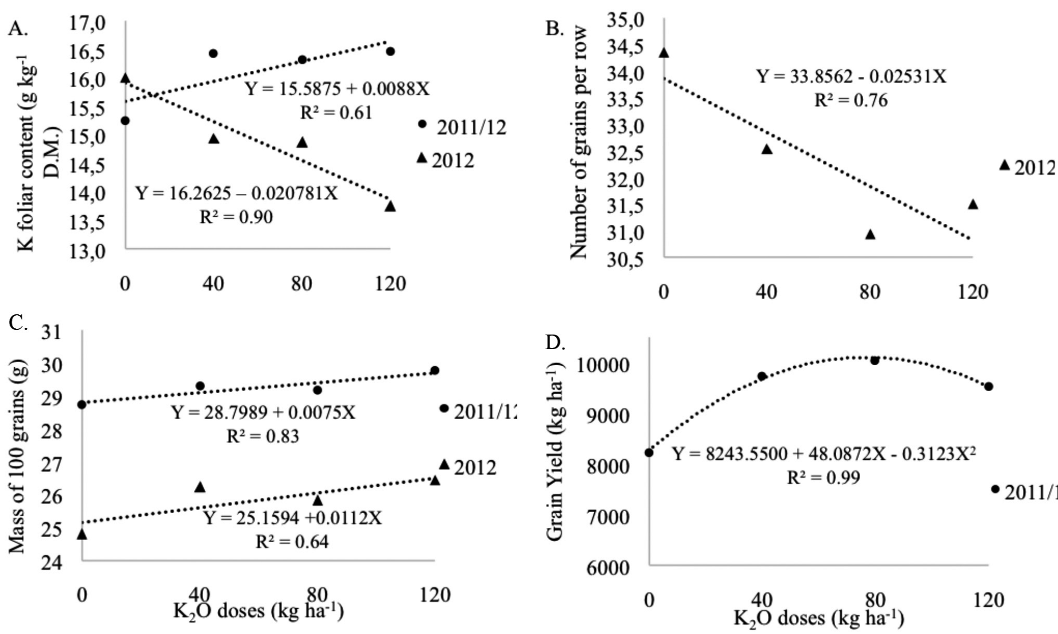

Figure 2. K foliar content, 2011/2012 and 2012 crops (A), number of grains per row, 2012 crop (B), mass of 100 grains, 2011/2012 and 2012 crops (C), corn grain yield, 2011/2012 crop (D) in function of K_2O doses. Selvíria – MS, Brazil.

This can be confirmed by the similar leaf K contents obtained for the KCl sources, in both crop harvest (Table 1), which were below the appropriate range for corn (17 to 35 g kg^{-1} of K in the dry matter), in relation to that described by Cantarella *et al.* (1997) irrespective of the K dose applied, and although irrigation was performed to minimize the negative effect of water deficit on plant development, the water rate applied of 14 mm and the irrigation shift of approximately 72 hours would not be sufficient to promote the leaching of K causing deficiency in the nutrition of corn crop with this nutrient.

The results obtained corroborate with Valderrama *et al.* (2011) and Rodrigues *et al.* (2014), evaluating the production components and corn grain yield under the same Cerrado soil conditions, also found that the polymer-coated KCl did not stand out in relation to the conventional KCl when applied to the sowing and in the same crop. Similarly, Rodrigues *et al.* (2013) found that polymer-coated KCl had the same residual effect as conventional KCl for leaf K contents, production components and grain yield in irrigated common bean crop in Cerrado.

Gazola *et al.* (2013) reported that mono-ammonium-phosphate (MAP) fertilizer coated with polymers provide the same residual effect of the conventional MAP, for production components and corn grain yield in irrigated crop diverging from the results of Guareschi *et al.* (2011), who working with KCI coated with polymers which have found better plant nutrition when the fertilizer was applied in advance in a Oxisol with haul application of polymer-coated KCl, and further dry matter yield, number of pods per plant and soybean yield compared to conventional KCl, and Leal *et al.* (2015), who found by evaluating the conventional KCl application in topdressing and three types encapsulated KCl in soybean crop, greater efficiency of K fertilizer with KCl coated with polymers.

The best plant performance when applying these fertilizers is due to the regular and continuous supply of nutrients to the plants and reduction of K losses by leaching. The highest rainfall rate in Rio Verde (GO) and Água Clara (MS) regions, linked to lower temperatures compared to the region of Selvíria (MS), where the present study was conducted, were possibly the limiting factors in the slow, regular and continuous release of the coated KCl, culminating in the reduction of K losses by leaching.

Regarding the residual K doses, the increase resulted in higher leaf K content, mass of 100 grains and corn grain yield in the 2011/12 harvest. There was an adjustment of increasing linear function for leaf K content and mass of 100 grains and adjusted the quadratic function for grain yield up to the dose of 77 kg ha^{-1} of K_2O (Tables 1 and 2; and Figures 2A, 2C and 2D), regardless of KCl source applied in the previous crop. With this estimated dose, a grain yield of 10,095 kg ha^{-1} was obtained, which corresponds to an increase of 23% in relation to the control (without application of K), thus demonstrating the feasibility of taking advantage of the residual K fertilization in subsequent cultivation. Rodrigues *et al.* (2013) evaluating the residual effect of KCl doses applied in the corn crop, also verified a positive response, but with linear adjustment for irrigated common beans.

On the other hand, in second-harvest corn crop no effect of K doses was observed in most of the production components and grain yield (Tables 1 and 2), which may be due to the higher K export by grains infers in a lower K supply of soil to the plants, since K contents in the leaves decreased with increasing doses of this nutrient (Figure 2A), thus reducing the number of rows (Figure 2B) and grains per ear, and consequently, an increase in mass of 100 grains (Figure 2C). However, it was 3.4 g lower when compared to the corn crop (Table 2). According to Büll (1993), K has an impact on crop quality and positive influence on individual grain mass and number of grains per ear.

Gommers *et al.* (2005) state that there are greater absorption and accumulation of K in the plants with the increase of K doses, corroborating with the results obtained for the corn crop. On the other hand, according to Borkert *et al.* (1997), K content in leaves smaller than 15.5 g kg^{-1} decreases corn grain yield, which explains the lower yields verified for the second harvest corn, which are not common in this region when irrigation is done, since at this time of year the nocturnal temperatures are lower and favor the accumulation of carbohydrates of this plant C4.

According to Kaminski *et al.* (2007) and Rosolem *et al.* (2012), the exhaustion of available K forms of soil during the development of crop impairs plant nutrition and that the K supply capacity depends more on the newly added K than on the K fertilization historic. However, Rosolem *et al.* (2012) also verified that the residual K of previous fertilizations increased the K content absorbed and accumulated in the *Brachiaria ruziziensis* plants.

According to Brunetto *et al.* (2005), several studies indicated that the responses of numerous agricultural crops to K fertilization were low when the exchangeable K contents in the arable layer (0 to 20 cm) of the soils were larger than 1.5 to 2 mmol$_c$ dm^{-3}, mainly in management conditions that favored the increase of K, as in the no-tillage system for example, and/or in soils with high concentration of primary and secondary minerals rich in K minerals. However, Kaminski *et al.* (2007) and Fraga *et al.* (2009), reported accumulation of K in plants due to the residual effect and/or potassium fertilization in soils with low K contents. In the present study, there was an average K content (2.2 $mmol_c$ dm^{-3}).

In general, the utilization of residual K fertilization of corn crop seems to be feasible for only a subsequent crop, under the edaphoclimatic conditions studied, whose soil K content was adequate (average content). However, the non-application of K fertilizer in the following crops can lead to the depletion of soil reserves, with negative effects on crop nutrition and grain yield.

Conclusions

The polymer-coated KCl had the same residual effect as conventional KCl for most of the production components, leaf K content and corn grain yield in first and second corn harvest.

The increase of potassium fertilizer doses in the previous crop provided residual effect on the corn second-harvest crop, resulting in linear increase in the leaf K content, mass of 100 grains and corn grain yield up to the dose of 77 kg ha^{-1} of K_2O, regardless of KCl source.

In the second-harvest corn and without K fertilizer application, there is no residual effect of K doses for grain yield due to the reduction of leaf K content, which resulted in a decrease in the number of grains per row and ear.

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