CORN AND GRASS INTEGRATED SYSTEM FERTILIZED WITH MULTIPLE NUTRIENTS SOURCE

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ABSTRACT
Providing an adequate nutrients supply is important for high yields in crop-livestock integrated systems (CLIS). This research aims to evaluate K sources fertilizer's effect on corn Piatã grass yield and nutritional status in the CLFIS. A two-growing season field experiment was carried out in a Typic Hapludox. The CLFIS was sown with corn together with Piatã grass. Treatments comprised two K sources: polyhalite (14%-K_2O, 19%-S, 3.6%-Mg, and 12.1%-Ca), and KCl (60% K_2O) and five ratios of polyhalite: KCl (0:100%; 12.5:87.5%; 50:50%; 87.5:12.5%; 100%) and a control. The treatments were applied in the sowing and topdressing fertilization of corn. Piatã grass used residual soil fertilization for growth. The best results of corn dry matter yield and Piatã grass were obtained with polyhalite ratios. These values were significantly ($p<0.05$) higher than the best yield obtained in control (without fertilization). The treatments were also efficient in increasing S in soil and exporting K, Mg, and S by corn. This study showed polyhalite as an alternative source of K, Ca, Mg, and S and can meet the nutritional requirements of annual crops and pastures in a CLIFS.
Key words: *Zea mays*; *Urochloa brizantha*; Polyhalite

INTRODUCTION

Crop-livestock integrated systems (CLIS) have been used as a sustainable agricultural intensification strategy, integrating annual crops and livestock activities in the same area and the same season. Providing an adequate supply of nutrients is essential for high yields and is necessary to maintain high quality and profitable returns in integrated systems (BALBINO et al., 2011).

The knowledge of the dynamics of nutrients in the soil in ILPF systems is essential to establish adjustments in the recommendation of lime and fertilizers. The nutrients balance in the soil-plant system can be considered an indicator of agricultural land use sustainability (HANÁČKOVÁ et al., 2008). The difference between the amount of nutrient exported with the harvest and applied with the fertilizer indicates the degree of increase or reduction of the nutrient content in the soil and, when the nutrient output is higher than the input in the crop, the condition is unsustainability (OENEMA et al., 2003).

The study of alternative sources and cultivation techniques such as no-till, crop rotation, and integrated systems is essential to make the use of nutrients K, Ca, Mg more efficient (BENITES et al., 2010).

Potassium chloride (58 to 62% of K_2O) is the most used potash fertilizer in Brazil (ANDA, 2016). However, other sulfates-minerals may be considered. Polyhalite ($K_2MgCa_2(SO_4)4.2H_2O$) is a natural occurrence multi-nutrient mineral (11.7%-K, 19%-S, 3.6%-Mg, and 12.1%-Ca), as a fertilizer for crop production (BARBARICK, 1991; PRUD'HOMME & KRUKOWSKI, 2006; VALE & SÉRIO, 2017).

Supplying nutrients at balanced and adequate levels is a critical factor for high quality and efficient yields crop. However, low information is available for the forage and annual crops' response to polyhalite. Acid, low-fertile, high-weathered soils are expected to be benefited from the addition of

K, Ca, Mg, and S nutrients. So polyhalite may provide an alternative to KCl, with the advantage of offering a slow-release fertilizer source of other nutrients like Ca, Mg, and S (BARBARICK, 1991; VALE & SÉRIO, 2017). This research aims to evaluate K sources fertilizer's effect on corn Piatã grass yield and nutritional status in the CLFIS.

MATERIAL AND METHODS

The study area is located at Embrapa Pecuária Sudeste in São Carlos, Brazil (21°57'S, 47°50'W, 860 m alt). The crop-livestock integrated systems (CLFIS) are growing on a Red-yellow Latosol, i.e., Haplortox. The climate is tropical of altitude (Cwa), with minimum and maximum temperature, respectively, of 16.3°C (July) and 23°C (February) and 1502 mm annual rainfall.

Soil chemical analysis (0-0.2m depth), before experiment establishment: pH_{CaCl2} = 5,6; M.O. = 46 g dm^{-3}; P_{resina} = 11 mg dm^{-3}; K = 1.5 $mmol_c$ dm^{-3}; Ca = 36 $mmol_c$ dm^{-3}; Mg = 14 $mmol_c$ dm^{-3}; H+Al = 19 $mmol_c$ dm^{-3}; CTC = 72 $mmol_c$ dm^{-3}; V = 73%; and sand = 550 g kg^{-1}; clay = 386 g kg^{-1}; and silt = 64 g kg^{-1}.

Corn for silage (*Zea mays* cv. AG 8690-Pro3) and Piatã grass (*Urochloa brizantha*) were sowed together in a CLIFS in two crop seasons (2016–17, and 2017-18). The experiment was carried out in 12.8-m^2 plots, formed by planting four 4-m-long rows, with a 0.8 X 0.2 m spacing. Piatã grass was simultaneously sowed with the corn in a 0.4 m spacing at a rate of 10 kg of seeds per ha.

Treatments comprised two K sources: polyhalite (14%-K_2O, 19%-S, 3,6%-Mg, and 12,1%-Ca.) and KCl (60% K_2O), five ratios (polyhalite: KCl) with 4 replications: i) Control (no K, S, Mg or Ca); ii) KCl 100%; iii) KCl 87.5% + Polyhalite 12.5%; iv) KCl 50% + Polyhalite 50%; v) KCl 12.5% + Polyhalite 87.5%; vi) Polyhalite 100%. The treatments were applied in the sowing and topdressing fertilization of corn.

Due to high V (73%), liming was not necessary. Experimental plots were fertilized uniformly at planting with N, 40 kg ha^{-1}; P_2O_5, 140 kg ha^{-1}; K_2O, 80 kg ha^{-1}; and Zn, 4 kg ha^{-1}. Topdressing fertilizer was broadcast applied 45 days after planting in100 kg ha^{-1}; P_2O_5, 25 kg ha^{-1}; K_2O, 100 kg ha^{-1}.

Corn leaf sampling for nutrient analysis was done when 50% of the plants were in the whole flowering stage, randomized sampling five plants per plot. Silage corn was harvested in March 2017 and March 2018, when whole-plant water concentration was between 600 and 700 mg kg^{-1}. Two 2-m length rows were harvested per plot. After corn silage harvesting, the grass developed, and the pasture was formed. The biomass evaluation of Piatã grass has begun in June 2017 and June 2018 and was periodically repeated for seven cuts. To that end, a metallic 0.5×0.5 m square frame was used at each experimental plot, and the grass inside the frame was cut in three different points at 0.15 m-aboveground level and weighed. Aliquots of corn and grass biomass samples were dried at 65 ºC for 72 h for dry matter yield (DMY) determination. Afterward, corn and grass DM samples were used to determine total K, Ca, Mg, and S concentrations, according to Nogueira et al. (2005). Macronutrient exportation was obtained using the silage corn and grass DMY and macronutrient concentration tissue data. Soil testing for samples collected at 0-20 and 20-40cm depths was conducted following Primavesi et al. (2005). The data collected were evaluated by variance analysis of, and when the Duncan test separated significant means of the treatments at 0.05 probability test considering the different K sources.

RESULTS AND DISCUSSIONS

Table 1 presents the dry matter yield (DMY) of corn harvested for silage and Piatã grass due to the nutrient sources. The maximum corn DMY result agrees with those that are commonly observed with hybrid corn in Brazil. The best results for corn were obtained with the different polyhalite ratios mixed with KCl. These values were 17 to 22% higher than the best production achieved in control, without the addition of multiple nutrient fertilizers. For Piatã grass, the differences between sources and relationships were more striking and followed the same trend of corn. The DMY values were 30 to 45% higher than the control.

The leaf diagnosis principle compares the concentration of nutrients in the leaves with standard values, corresponding to the varieties or species with high productivity and appropriate vegetative development. Thus, the relevant content ranges for macronutrients in the corn leaf proposed by Cantarella & Camargo (1997) are K, from 17 to 35 g kg^{-1}; Ca, 2.5 to 8.0 g kg^{-1}; Mg, 1.5 to 5.0 g kg^{-1}; S, 1.5 to 3.0 g kg^{-1}. For the Piatã grass, the values considered adequate (WERNER et al., 1997) are K, 12 to 30 g kg^{-1}; Ca, 3 to 6 g kg^{-1}; Mg, 1.5 to 4.0 g kg^{-1}; S, 0.8 to 2.5 g kg^{-1}. Based on these interpretation ranges, K, Ca, Mg, and S levels observed in this experiment can be classified as adequate.

Potassium is an essential element for plants. However, K is not a constituent of any organic molecule in the plant; however, it contributes to various biochemical activities, activates many enzymes, and regulates osmotic pressure (water entering and leaving the cell), opening and closure of stomata. Potassium is essential in photosynthesis, fruit formation, resistance to cold, and diseases (MALAVOLTA et al., 1997). Considering the treatments, there were no significant differences in the contents of K in corn leaves. For the Piatã grass, significant differences were observed between control and the treatments with nutrient supplying.

In the plant, Ca participates in enzymatic functions, is a constituent of pectates (giving resistance to cell walls), an activator of several enzymes (MALAVOLTA et al., 1997). Magnesium is a constituent of the chlorophyll molecule necessary for various enzymatic reactions (MALAVOLTA ET AL., 1997). The were no significant differences between treatments and Ca levels, just between the control and the treatments. Concerning Mg levels in corn leaves, the significant differences were between the higher level of polyhalite and KCl. The exception was in the control treatment with significantly higher levels of these nutrients, and the explanation lies in the competitive inhibition between these cations (MALAVOLTA et al., 1997) because as there was no K supply, it facilitated the absorption of Ca and Mg in the treatment control for both corn and Piatã grass (Table 1). Sulfur (S) is required to form amino acids and proteins and photosynthesis (MALAVOLTA et al., 1997). Despite S importance for the proper plant nutrition, there were slight differences in corn leaves, and there were no differences for Piatã grass foliar diagnosis.

The extraction of nutrients was obtained from corn samples at harvest, which was analyzed for the total contents of K, Ca, Mg, and S in the material collected for silage. The extraction by Piatã grass was the sum of extractions at the seven cuts. There were significant differences in the extraction of K by the corn biomass produced according to the treatments used. The most significant extractions of K were obtained in the treatments and the control in silage corn. For the K extraction by Piatã grass, there were significant differences between treatments, and the trend indicates higher K uptake as more polyhalite was used (Table 1).

There were no differences for Ca or Mg extractions by corn depending on the treatments (Table 1). Regarding the extracted Ca by the grass, there was a significant trend to extract higher amounts with the highest polyhalite ratios, with the largest removals obtained in polyhalite treatments in the proportions of 100%, 87.5%, and 50%. Mg extraction by grass, the most remarkable significant difference was between the polyhalite and KCl sources. There were also significantly higher values for S extraction with the highest polyhalite ratios for both corn and Piatã grass. With the reduction in S (present in polyhalite) supply, there was significantly less extraction of this vital macronutrient (Table 1).

Table 1. Dry matter yield (DMY), leaf levels, and extraction of K Ca, Mg and S by corn and Piatã grass fertilized with K sources in a CLIS in São Carlos – SP, Brazil.

Treatments	DMY	Leaf analysis (g kg^{-1})				Nutrient extraction (kg ha^{-1})			
	kg ha^{-1}	K	Ca	Mg	S	K	Ca	Mg	S
Corn									
Polh100%	13,846.7 a	21.09	3.11 b	2.01 b	2.12 ab	140.3 a	20.9 -	15.6 -	16.3 a
KCl12.5% + Polh87.5%	13,215.8 a	21.33	3.00 b	1.94 bc	2.19 a	137.9 a	20.2 -	15.9 -	15.0 ab
KCl50% + Polh50%	12,679.7 ab	21.38	2.92 b	1.79 bc	1.94 ab	132.7 a	19.5 -	16.0 -	14.4 ab
KCl87.5% + Polh12.5%	12,983.1 ab	21.14	2.85 b	1.81 bc	1.67 b	132,6 a	19.4 -	14.4 -	13.3 ab
KCl100%	12,805.1 ab	21.07	2.85 b	1.73 c	1.64 b	132.2 a	18.3 -	14.8 -	12.6 b
Control	11,343.4 b	18.63	3.59 a	2.48 a	2.03 ab	86.2 b	20.2 -	15.2 -	12.4 b
Piatã grass									
Polh100%	6,049.3 a	20.31 ab	4.13 ab	3.10 b	1.72 -	182.4 a	39.7 a	27.9 a	15.9 a
KCl12.5% + Polh87.5%	5,513.8 ab	21.25 a	3.64 b	2.87 b	1.61 -	165.2 ab	33.8 abc	25.2 ab	13.7 ab
KCl50% + Polh50%	5,419.3 ab	18.18 bc	4.25 ab	3.09 b	1.62 -	155.7 bc	36.6 ab	24.4 ab	13.2 ab
KCl87.5% + Polh12.5%	5,147.9 abc	20.71 ab	3.84 b	2.94 b	1.52 -	155.3 bc	32.2 abc	22.5 ab	11.8 bc
KCl100%	4,650.5 bc	20.87 ab	3.78 b	2.97 b	1.47 -	133.7 c	28.5 bc	19.5 b	10.1 c
Control	4,168.4 c	16.44 c	4.79 a	4.11 a	1.62 -	98.9 d	27.6 c	23.3 ab	9.6 c

Different letters indicate statistical differences by Duncan's test ($p<0.05$).

Soil colloids retain K^+, Ca^{2+}, and Mg^{2+} through the negative charges of soil colloids (RAIJ, 1991), so there were significantly more K and Mg in the 0-20cm layer in the 20-40cm layer (Table 2). Ca levels did not vary, probably due to the liming historical of the area. Comparing the nutrient sources, the results indicated no differences between the K, Ca, and Mg contents between sources. From the limits established for the interpretation of soil fertility levels by Raij et al. (1997), the soil's K content can be considered low for all treatments, including the control, which did not receive potassium fertilization.

In Table 2, the levels of Ca^{2+} and Mg^{2+} are considered high in all treatments, with all samples of depth 0-20cm being in the classes considered high (ALVARES VENEGAS et al., 1999). In the depth of 20-40cm, Ca was also regarded as high. The Mg content was classified as medium (5 to 10 $mmol_c$ dm^{3-}). The results also indicate no differences in Ca and Mg levels due to the sources of K tested, even though polyhalite has these elements in its composition. Possibly, this effect occurred due to the previous liming done on this soil before planting the experiment establishment, indicating that this input probably supplied Ca in sufficient quantities so that there were no differences between treatments at both depths studied. The movement of cations like calcium in the profile is influenced by limestone application (RHEINHEIMER et al., 2000). This is also due to the soil correction and fertilization program used in the area, which has made it possible to correct and maintain soil fertility, as previously described by Bernardi et al. (2019).

In the soil, the sulfur leaching process in the form of sulfate is quite intense, resulting in the accumulation of sulfate in the subsurface layers, where the $S\text{-}SO_4^{2-}$ content is higher than in the surface layer (RAIJ, 1991). The results in Table 2 confirmed a significant increase in the $S\text{-} SO_4^{2-}$ concentration in the deepest layer of the soil (20-40cm) with polyhalite. The interpretation of results for the content of $S\text{-}SO_4^{2-}$ in the soil proposed by Raij et al. (1997) indicates the classes: low from 0 to 4 $mmol_c$ dm^{3-}; an average of 4 to 10 $mmol_c$ dm^{3-}; and high> 10 $mmol_c$ dm^{3-}. Thus, the values are considered average in the 0-20 cm layer and top in the 20-40 cm layer. After applying the tested nutrients' sources, the content of S- SO_4^{2-} in the soil was higher for the polyhalite treatments at 100%, 87.5%, and 50% ratios, indicating that this fertilizer is an efficient source macronutrient.

Table 2. Soil levels of K^+, Ca^{2+}, Mg^{2+}, and SO_4^{2-} due to K sources in a CLIS in São Carlos – SP, Brazil.

Treatments	K				Ca		Mg				S-SO4			
	---------- $mmol_c$ dm^{-3} ----------										---------- mg dm^{-3} ----------			
	0-20		20-40		0-20	20-40	0-20		20-40		0-20		20-40	
Polh100%	1.25	A	1.0	B	31.0	27.0	11.8	A	7.5	B	9.0	Ba	24.5	Aab
KCl12.5% + Polh87.5%	1.08	A	0.9	B	37.5	41.3	10.3	A	7.3	B	9.0	Ba	31.0	Aa
KCl50% + Polh50%	1.15	A	0.7	B	27.8	31.3	8.8	A	6.0	B	8.0	Bab	25.0	Aab
KCl87.5% + Polh12.5%	1.18	A	0.88	B	40.0	29.0	11.0	A	7.0	B	5.3	Bb	19.0	Abc
KCl100%	1.50	A	0.93	B	26.3	28.5	10.8	A	7.5	B	6.3	Bab	16.3	Ac
Control	0.98	A	0.95	A	31.3	27.0	10.8	A	7.8	B	7.0	Bab	18.5	Abc

Different letters indicate statistical differences by Duncan's test ($p<0.05$). Uppercase letters indicate differences between depths, and lowercase letters indicate differences between nutrients sources.

CONCLUSIONS

The best results of corn dry matter yield and Piatã grass were obtained with polyhalite ratios. These values were significantly ($p<0.05$) higher than the best yield obtained in control (without fertilization). The treatments were also efficient in increasing S in soil and exporting K, Mg, and S by corn. This study showed polyhalite as an alternative source of K, Ca, Mg, and S and can meet the nutritional requirements of annual crops and pastures in a CLIFS.

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