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CHANGES IN CHEMICAL SOIL AND CORN YIELD AFTER APPLICATION OF GYPSUM AND POTASSIUM DOSES.

ALTERAÇÕES QUÍMICAS NO SOLO E PRODUÇÃO DE MILHO APÓS APLICAÇÃO DE GESSO E POTÁSSIO

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ABSTRACT: Soil liming is a common practice in agriculture. It aims to reduce soil acidity and to supply calcium and magnesium. Lime, however, is not easily soluble in the soil, and its reaction products are often concentrated in the application zone, which is mainly the topsoil layer. In order to increase the concentration of nutrients in deeper layers, agricultural gypsum—a byproduct of phosphoric acid production process, rich in calcium and sulfur—is used. In this context, the objective of this study was to evaluate the chemical attributes of the oxysoil and the corn´s yield to the application of gypsum associated with potassium (K) rates. The study was developed in Uberaba city, Minas Gerais state, Brazil. The factorial scheme was used 5x5, with five rates of K (0, 100, 180, 240, 360 kg ha^{-1} K_2O) and five gypsum rates (0, 500, 1000, 2000, 4000 kg ha^{-1}) in a randomized complete block design with four replications. The soil chemical attributes were evaluated at 0.0-0.20 m and 0.20-0.40 m depth and the biometric and productive attributes of corn. The application of gypsum resulted in the increase of calcium (Ca) and sulfur (S) contents in all depths; reduced the levels of pH, manganese, potential acidity (H + Al) in the 0.0-0.20 m depth, and increase the levels of base of saturation and sum of bases on the 0.20-0.40 m depth. Corn yield and biometric attributes no were influenced by the factors evaluated.

KEYWORDS: Gypsum. Gypsum and potassium interaction. *Zea mays.*

INTRODUCTION

In the last decades, the application of industrial waste in agriculture had been characterized as a viable alternative for the nutrient supply of plants and the correction of soil acidity wich minimizing the environmental impacts generated by industrial activities. Gypsum is a derivate product of phosphoric acid production, has shown high potential in the supply of the Ca and S to various crops, as well as reducing the concentration of exchangeable, toxic aluminum to plants (BORKERT et al., 1987).

The potential acidity characterized by the presence of hydrogen and aluminum ions in the soil solution is a limiting factor in agricultural productivity, because it reduces the availability of nutrients to the plants, causing a reduction of the root system, consequently, less absorption of water and nutrients reducing production. The gypsum, properly employed in agriculture, contributes to soil conditioning, promoting the reduction of aluminum saturation and, at the same time, increasing nutrients to soil solution and absorption of plants.

Several authors have demonstrated the beneficial effects of gypsum application in agriculture (AZEVEDO et al., 2004, CAIRES et al., 2004, DEMATTÊ, 2011, CASTRO et al., 2013, CRUSCIOL et al., 2014). The application of gypsum to the soil causes the formation of ionic pairs between SO_4^{2-} and some cations, which (K^+, Ca^{2+}, Mg^{2+}) to depths in the soil. It due to high solubility, it does not change the electric charges of the soil and increase the sulfate anion (SO_4^{2-}) concentration in the soil solution (ERNANI; RIBEIRO; BAYER, 2001). However, considering that gypsum acts as a source of Ca, its indiscriminate use may lead to the reduction of K^+ and Mg^{2+} contents of the soil surface. As a consequence, induce deficiency of these nutrients, especially in soils with low retention capacity of cations and organic matter.

Due to the possibility of significantly reducing the availability of K to plants, the use of gypsum hasn't been recommended in soils with CEC of less than 3,0 cmol$_c$ dm^{-3} or organic matter

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content less than 15 g dm^{-3} in the soil layer superficial (MARTINEZ; CARVALHO; SOUZA, 1999). However, even in soils with low capacity to exchange cations, it is common to the occurrence of high levels of Al^{3+} in depth. For high efficiency of the gypsum, it is necessary to the balance of fertilization and its relationship with the CEC at pH 7.0 and should be maintained at 45%, 15% and 5% of Ca, Mg and K.

The K is the nutrient normally found in lower levels in the soil. Thus, the association of a direct source of K applied in planting fertilization or coverage can minimize the effect displacement of the K on the soil after the application of the gypsum.

In this context, the objective of this study was to evaluate the effects of the application of gypsum and potassium rates on the chemical attributes an oxysoil and the productivity of maize.

MATERIAL AND METHODS

The experiment was carried out from 02/23/2015 to 07/20/2015, in Uberaba city, Minas Gerais state, Brazil, located at 19°71'50 "S of latitude and 47°93'45" W of longitude, at 800 meters of altitude, in an Distrofic Red Latosol (oxysoil), with medium texture (clay = 15 %). The climate of the region is of type Aw (ALVARES et al., 2013), that is, tropical with dry winter. The mean temperature and precipitation during the experimental period were 21.17 °C and 1053.36 mm, respectively.

The chemical characterization of the soil in the depth from 0.0 to 0.20 m were: pH (H_2O) = 5.9; Organic matter = 12 g kg^{-1}; P (Mehlich-1) = 13.9 mg dm^{-3}; H + Al = 1.9 $cmol_c$ dm^{-3}; Ca = 1.3 $cmol_c$ dm^{-3}; K = 0.16 $cmol_c$ dm^{-3}; Mg = 0.4 $cmol_c$ dm^{-3}; SB = 1.9 $cmol_c$ dm^{-3}; CEC = 3.8 $cmol_c$ dm^{-3}; Cations saturation = 49%; Relations: Ca/Mg = 3.25; Ca/K = 7.94; Mg/K = 2.44 and Ca + Mg / K = 10.63.

In the depth from 0.20 m to 0.40 m was: pH (H_2O) = 5.8; Organic matter = 10 g kg^{-1}; P (Mehlich-1) = 1.8 mg dm^{-3}; H + Al = 1.7 $cmol_c$ dm^{-3}; Ca = 1.1 $cmol_c$ dm^{-3}; K = 0.14 $cmol_c$ dm^{-3}; Mg = 0.3 $cmol_c$ dm^{-3}; SB = 1.6 cmol dm^{-3}; CEC = 3.3 $cmol_c$ dm^{-3}; Cations saturation = 47%; Relations: Ca/Mg = 3.67; Ca/K = 6.94; Mg/K = 1.89.

The experiment was carried out in a randomized block design in a 5x5 factorial scheme, with five gypsum (180 g kg^{-1} of Ca and 150 g kg^{-1} of S) rates (0, 500, 1000, 2000, 4000 kg ha^{-1}) and five potassium rates (0, 100, 180, 240, 360 kg ha^{-1} K_2O) with four replicates. The plots was with 7m length and 8 rows of maize spaced 0.50 m. In this condition, it was considered as border, 0.50 m from the ends and the two lines from the lateral ends of each plot.

The soil was prepared with two heavy harrows and grader harrows. All the gypsum and potassium were applied in the total area of the plots, pre-planting, being incorporated at approximately 0.10 m depth by means of leveling gradient (last preparation operation). In the planting fertilization, it was used 100 kg ha^{-1}, P_2O_5 (triple superphosphate) and 20 kg ha^{-1} N (urea) were applied to the planting groove.

The planting of maize, cultivar AG-1051, was carried out on February 23, 2015, using a population of 60,000 plants per hectare. In the coverage fertilization, it used 140 kg ha^{-1} N (urea). The coverage was divide in twice applications, 50% (70 kg ha^{-1} N) 15 days after planting and 50% (70 kg ha^{-1} N) 30 days after planting. The other cultural treatments were those recommended for the cultivation of maize in this region.

The maize dry mass with husk (MDH), the maize dry mass without husk dry mass (MDWH), cobs dry mass (CDM), grain mass per ears (MGE) and grain yield (PG) were evaluated.

The harvest was realized on 07/20/2015, 147 days after planting. After the harvest, using auger threaded hole, held soil sampling was performed to evaluate soil chemical attributes. In each plot, 15 simple samples were collected in the depths from 0.0 to 0.20 m and 0.20 to 0.40 m. The levels of Al, macro and micronutrients, potential acidity (H + Al) and, relations between Mg/K, Ca/Mg, Ca/K, according to the methodology described by Raij et al. (2001).

The data were submitted to analysis of variance by the F ($\alpha \leq 0.05$) test, and according to the need, multiple regression analysis was performed to select the best model by the backward stepwise selection method (James et al., 2013). In addition, t-tests were performed for the coefficients of the adjusted model in order to verify if these were significant. All analyzes were performed using the R (R Core Team, 2014) software using the MASS, LEAPS, EXPDES packages.

RESULTS AND DISCUSSION

Chemical attributes

In the depth 0.0-0.20 m there were significant interactions between gypsum and potassium doses for the variables K content and Mg/K ratio. In the depth 0.20-0.40 m, significant interactions were observed for variables: K and Ca content, Ca/Mg and Ca/K ratios. For the other variables, when a significant effect was observed the factors were evaluated separately.

Increasing levels of gypsum and K didn´t influence the organic matter contents, with average values of 20.70 and 15.60 g dm^{-3} of OM, respectively, in the depths 0.0-0.20 m (Table 1) and 0.20-0.40 m (Table 2).

The fertilization with up to 360 kg ha^{-1} K_2O the soil, reduced linearly the pH values ($CaCl_2$ mol L^{-1}) after five months in the 0.0-0.20 m depth (Table 1). The lowest value was 4.73 (Figure 1-A). This reduction can be attributed to the binding of K^+ to the negative charges of the soil, which can cause the displacement and the higher concentration of free H^+ ions in the solution, resulting in a reduction in the values of this attribute. In the 0.20-0.40 m depth (Table 2), the application of gypsum and potassium didn't influence pH ($CaCl_2$ mol L^{-1}) values, corroborating with the results reported by Foloni et al. (2008), Rocha et al. (2008) and Rampim et al. (2011) regarding the application of gypsum. A mean value of 4.74 for ($CaCl_2$ mol L^{-1}) in the 0.20-0.40 m depth (Table 2) was found.

The levels of P in the depth, 0.0-0.20 m and 0.20-0.40 m, (Tables 1 and 2) weren't not influenced by the application of gypsum and K, disagreeing with the results of Rampim, Lana and Frandoloso (2013), when evaluating the doses of gypsum of 1000, 2000, 3000, 4000 and 5000 kg ha^{-1} in an oxisol of higth clayey and verified the increase in concentrations of P in the depth 0.0-0.10 m, 0.10-0.20 m and 0.20-0.40 m. The authors attributed this increase to the exchange of $H_2PO_4^-$ by SO_4^{-2} at the adsorption sites, which increased the availability of P. Average values of 62.48 and 46.80 mg dm^{-3} of P were in depth of 0.0-0.20 and 0.20-0.40 m, respectively, which are considered adequate for Alvarez et al. (1999).

The application of up to 4000 kg ha^{-1} of gypsum and 360 kg ha^{-1} of K_2O resulted in linear increases in the K contents in the 0.0-0.20 m depth (Table 1), an effect related to higher availability of K in this depth, after the percolation of calcium, which, consequently, result the excellent distribution of this nutrient. The maximum potassium content in the 0.0-0.20 m depth was 0.37 cmol$_c$ dm^{-3} (Figure 1-B).

Regarding the application of gypsum, Caires et al. (2004) didn't observe significant effects of the application of this residue on potassium contents in depth 0.0-0.20 m, probably due to the fact that the authors studied only gypsum rates, different this study, that in addition to gypsum rates of K_2O, aiming the non-impoverishment of the superficial layer in potassium, considering that the soil of the experimental area is of medium texture.

Thus, as in the 0.0-0.20 m depth, there was a significant interaction between the causes of variation for the K content in the depth 0.20-0.40 m (Table 2). However, there was a reduction in the content of this nutrient with the application of up to 2883.87 and 240.96 kg ha^{-1} of gypsum and K_2O, respectively, resulting in the minimum content of 0.21 cmol$_c$ dm^{-3} of potassium (Figure 2-A).

The decreases of the K whit the application of the gypsum in the layer of 0.20-0.40 m, are related to the increased availability of Ca in solution. The Ca of the solution exchange potassium electrical loads from the soil, resulting in the formation of ionic pairs between K^+ and SO_4^{2-} (RAIJ, 2008). The observed K contents are classified as adequate in the depth 0.0-0.20 m, Alvarez et al. (1999).

The content of Ca in the depath 0.0-0.20 m increased linearly with application of up to 4000 kg ha^{-1} of gypsum (Figure 1-C), corroborating with the works of Caires et al. (2003, 2004) and Pauletti et al. (2014). In the this study, the gypsum used has 180 g kg^{-1} of Ca in its composition, which justifies the increases of this nutrient in depth. The maximum content of Ca (1.49 cmol$_c$ dm^{-3}) observed in the 0.0-0.20 m depth (Figure 1-C) is considered medium, according to Alvarez et al. (1999), wich is 1.21 and 2.4 cmol$_c$ dm^{-3} of Ca in the soil.

In the 0.20-0.40 m (Table 2), there was significant interaction between the gypsum and K rates for the Ca content (Figure 2-B). However, the maximum Ca content (1.53 cmol$_c$ dm^{-3}) observed in this depth is close to that observed in the 0.0-0.20 m depth (1.49 cmol$_c$ dm^{-3}), which can be attributed to the high mobility of $CaSO_4^0$, ion pair in the soil profile, which consequently increased the availability of Ca in depth. Studies have demonstrated the increase in Ca content in depth due to the application of gypsum (CAIRES et al., 1998; RAMOS et al., 2013).

In a dystrophic Red-Yellow oxysoil, Pauletti et al. (2014) didn't observed significant effects of the application of gypsum in the 0.20-0.40 m, with 0.40 cmol$_c$ dm^{-3} of calcium and 12000 kg ha^{-1} of gypsum rate. The authors attributed this result to the low calcium mobility in the soil profile, considering that calcium accumulated in the 0-0.10 m (2.8 cmol$_c$ dm^{-3} of calcium). This effect were caused by the retention of this nutrient in the negative charges of clay and organic matter (VITTI; LIMA; CICARONE, 2006).

Table 1. Chemical characteristics of soil 0.0-20 m treated with the different K and gypsum rates at corn crop.

G (kg ha^{-1})	OM (g dm^{-3})	pH (CaCl$_2$)	P	K	Ca	Mg	Al	H+Al	SB	CEC	V	S	B	Cu	Fe	Mn	Zn	Ca/Mg	Ca/K	Mg/K
			mg dm^{-3}	cmol$_c$ dm^{-3}							%	mg dm^{-3}								
0	20.30	4.76	59.90	0.27	1.47	0.36	0.41	2.71	2.11	4.82	45.00	1.75	0.25	0.62	47.00	7.92	2.14	4.16	6.36	1.82
500	20.70	4.80	63.80	0.29	1.27	0.26	0.41	2.48	1.82	4.31	39.64	8.34	0.25	0.61	50.15	7.99	2.61	4.82	4.03	1.28
1000	21.85	4.76	75.65	0.30	1.63	0.22	0.33	2.29	2.12	4.42	51.11	9.70	0.24	0.63	35.80	7.64	2.24	8.03	7.57	1.10
2000	19.65	4.76	61.30	0.33	1.62	0.17	0.36	2.11	2.10	4.22	44.50	8.35	0.29	0.61	37.95	6.83	2.32	10.17	6.32	1.08
4000	21.00	4.78	51.75	0.26	1.25	0.30	0.38	2.39	1.81	4.21	45.50	12.86	0.21	0.56	41.40	7.47	2.02	4.24	8.15	1.83
K (kg ha^{-1})																				
0	20.40	4.81	64.50	0.22	1.38	0.27	0.36	2.30	1.83	4.14	42.00	1.75	0.25	0.62	45.65	7.92	2.14	6.03	6.36	1.82
100	21.15	4.73	57.25	0.30	1.44	0.27	0.41	2.43	2.00	4.43	44.50	8.74	0.29	0.73	45.60	8.80	2.42	6.03	6.15	1.68
180	19.65	4.87	63.20	0.35	1.46	0.28	0.29	2.33	2.09	4.42	46.25	9.24	0.23	0.56	33.50	8.11	2.39	5.61	5.01	1.18
240	21.60	4.73	69.95	0.29	1.51	0.23	0.43	2.42	2.03	4.45	47.50	8.50	0.25	0.57	51.70	5.90	2.04	7.24	7.19	1.19
360	20.70	4.71	57.50	0.29	1.46	0.26	0.41	2.49	2.01	4.51	45.50	12.75	0.24	0.56	35.85	7.11	2.37	6.51	7.77	1.25
Average	20.70	4.77	62.48	0.29	1.45	0.26	0.38	2.39	1.99	4.39	45.15	8.20	0.25	0.60	42.46	7.57	2.27	6.28	6.49	1.42
F_G	1.13^{ns}	0.40^{ns}	2.03^{ns}	6.30^{ns}	9.96^{*}	26.80^{*}	2.49^{ns}	13.65^{*}	2.44^{ns}	4.91^{*}	6.25^{ns}	33.17^{*}	64.76^{*}	6.60^{ns}	3.41^{*}	2.98^{*}	6.10^{ns}	40.39^{*}	4.28^{ns}	49.02^{ns}
F_K	0.94^{ns}	1.79^{*}	0.76^{ns}	17.90^{ns}	1.18^{ns}	2.01^{ns}	7.59^{ns}	1.69^{ns}	0.89^{ns}	1.60^{ns}	1.16^{ns}	3.69^{ns}	4.18^{ns}	5.11^{ns}	5.37^{ns}	6.70^{ns}	0.91^{ns}	2.15^{ns}	9.98^{*}	8.69^{ns}
F_{GxK}	0.99^{ns}	1.14^{ns}	0.95^{ns}	1.44^{*}	3.38^{ns}	1.68^{ns}	1.19^{ns}	0.76^{ns}	1.27^{ns}	0.78^{ns}	1.92^{ns}	9.87^{ns}	2.48^{ns}	3.64^{ns}	1.01^{ns}	3.20^{ns}	3.20^{ns}	1.77^{ns}	2.55^{ns}	2.64^{*}

G = gypsum rates; K = K$_2$O rates; ns = not significant; “*” significant at 5% by F test; C.V. = coeficiente of variation.

Table 2. Chemical characteristics of soil 0.20-0.40 m treated with the different K and gypsum rates at corn crop.

G (kg ha^{-1})	O.M. (g dm^{-3})	pH (CaCl$_2$)	P	K	Ca	Mg	Al	H+Al	SB	CEC	V	S	B	Cu	Fe	Mn	Zn	Ca/Mg	Ca/K	Mg/K
			mg dm^{-3}	cmol$_c$ dm^{-3}							%	mg dm^{-3}								
0	15.00	4.83	44.25	0.28	0.87	0.32	0.39	2.06	1.47	3.45	43.25	4.50	0.13	0.58	30.00	6.03	1.40	2.61	3.25	1.23
500	17.50	4.58	41.75	0.36	1.35	0.35	0.43	2.07	1.97	4.17	46.75	5.25	0.28	0.83	41.50	7.67	1.54	3.95	5.28	1.42
1000	17.84	4.60	54.25	0.31	1.17	0.33	0.43	2.06	1.67	3.75	44.88	9.50	0.34	0.66	43.00	6.58	2.08	3.75	5.58	1.49
2000	13.83	4.85	49.75	0.37	1.37	0.26	0.40	2.03	1.72	3.76	47.25	11.25	0.40	0.84	34.25	5.39	1.49	7.08	8.13	1.16
4000	13.82	4.85	44.00	0.34	1.10	0.41	0.35	1.96	2.02	4.03	47.62	8.00	0.26	0.79	39.50	5.14	1.90	6.02	7.85	1.30
K(kg ha^{-1})																				
0	15.00	4.83	44.25	0.27	0.87	0.32	0.37	2.02	1.47	3.45	43.25	4.50	0.13	0.58	30.00	6.03	2.11	2.61	3.25	1.23
100	17.25	4.70	42.75	0.38	1.22	0.35	0.44	2.08	1.90	4.12	45.50	4.69	0.33	0.80	45.28	7.58	1.60	3.77	5.04	1.39
180	14.25	4.83	49.25	0.36	1.02	0.32	0.33	2.00	1.75	3.72	46.75	8.50	0.28	0.68	38.25	6.86	1.53	4.19	5.85	1.27
240	15.75	4.54	49.36	0.28	1.22	0.27	0.45	2.01	1.47	3.62	40.75	12.54	0.33	0.93	41.86	4.37	1.49	6.90	8.29	1.28
360	15.75	4.83	48.39	0.35	1.52	0.40	0.41	2.06	2.27	4.25	53.50	8.25	0.31	0.74	32.88	6.00	1.70	5.94	7.69	1.44
Average	15.60	4.74	46.80	0.33	1.17	0.33	0.40	2.04	1.77	3.83	45.95	7.70	0.28	0.74	37.65	6.16	1.68	4.68	6.02	1.32
F_G	1.60^{ns}	1.64^{ns}	0.37^{ns}	20.71^{ns}	10.59^{ns}	53.87^{*}	2.44^{*}	1.93^{ns}	8.41^{ns}	7.17^{ns}	6.14^{ns}	25.79^{*}	20.00^{*}	25.64^{ns}	6.63^{ns}	2.95^{ns}	1.80^{ns}	55.43^{ns}	31.20^{ns}	24.92^{*}
F_K	0.79^{ns}	3.55^{ns}	1.49^{ns}	4.20^{ns}	4.89^{ns}	2.26^{ns}	4.80^{ns}	1.16^{ns}	5.52^{*}	4.98^{ns}	3.55^{*}	1.55^{ns}	1.42^{ns}	3.40^{ns}	6.45^{ns}	5.13^{ns}	1.30^{ns}	2.08^{ns}	3.78^{ns}	4.87^{ns}
F_{GxK}	1.37^{ns}	2.37^{ns}	2.06^{ns}	2.56^{*}	3.55^{*}	1.92^{ns}	1.19^{ns}	1.70^{ns}	3.69^{ns}	3.09^{*}	2.92^{ns}	4.14^{ns}	5.98^{ns}	2.20^{ns}	3.93^{ns}	3.76^{ns}	1.32^{ns}	2.57^{*}	3.48^{*}	3.27^{ns}
C.V.%	12.56	2.76	25.93	20.36	14.67	18.12	24.19	6.79	12.42	6.99	7.72	38.31	17.65	15.65	17.04	19.43	57.99	26.92	21.02	18.10

G = gypsum rates; K = K_2O rates; ns = no significant; "*" significant at 5% by F test; C.V. = coeficiente of variation.

The increase in calcium content due to the application of gypsum depends on several factors, including type and soil management. In relation to the increase of this nutrient in response to the application of potassium, it can be related to the displacement of this nutrient from the negative electrical loads of the soil solution after the application of K (ERNANI; BARBER, 1993).

The Mg contents in the 0.0-0.20 (Figure 1-D) and 0.20-0.40 m (Figure 2-C), reduced with the increase of gypsum application, corroborating with the effects reported Quaggio, Dechen and Raij (1982), Silva et al. (1997), Caires et al. (1998, 1999, 2003, 2004, 2006), Soratto and Crusciol (2008), Rampim et al. (2011), Nava et al. (2012) and Ramos et al. (2013) about the use of agricultural gypsum in soil.

According to Zambrosi, Alleoni and Caires (2007), the reduction in the Mg content in the soil in response to the gypsum application may be related to the increase of Ca ions in solution after dissociation of the gypsum, which the displacement of Mg ions from the exchange sites, forming ionic pairs with the sulfate anion ($MgSO_4^0$), and leached to depths.

At the depth of 0.0-0.20 m the Mg content was reduced with the application of up to 3742.42 kg ha^{-1} of gypsum, with a minimum of 0.17 cmol$_c$ dm^{-3} of Mg content (Figure 1-D). In the depth of 0.20-0.40 m, the application of the maximum rate of gypsum resulted in obtaining the minimum Mg content in this depth, that is, 0.16 cmol$_c$ dm^{-3} (Figure 2-C). According to Alvarez et al. (1999), the levels of Mg verified in the present study are classified as low.

The factors evaluated didn’t influence the Al content in the 0.0-0.20 m (Table 1), different the results reported by Vilela et al. (2010) and Rampim et al. (2011) regarding the use of agricultural gypsum, with an medium content of 0.38 cmol$_c$ dm^{-3} of Al in this depth. One of the main benefits of applying this residue in agriculture is the reduction of the exchangeable Al content in the soil, which is toxic to plants. After dissolution of the gypsum in the soil, ionic changes occur between Al^{3+} and Ca^{2+} ions, favoring the displacement of the aluminum to the soil solution, which can bind to the sulfate anion ($SO_2^{4-)}$ and form ionic or complex pairs ($AlSO_4^+$) that will be leach after to depths in the soil (PAVAN; BINGHAM; PRATT, 1984).

The application of gypsum linearly reduced the Al content in the 0.20-0.40 m depth of the soil (Table 2), with a minimum content of 0.36 cmol$_c$ dm^{-3} at 4000 kg ha^{-1} of gypsum rate (Figure 2-D). Souza, Lobato and Rein (1996), Caires et al. (1998), Rampim, Lana and Frandoloso (2013) and Nora et al. (2014) also observed a reduction in the Al content in soil with gypsum application. This reduction indicates the possible action of gypsum in converting toxic aluminum to less toxic compounds to plants ($AlSO_4^0$, $AlSO_4^+$).

Sousa, Miranda and Oliveira (2007) showed the reduction in the levels of aluminum in the soil by the action of gypsum, may still occur due to the formation of the AlF^{2+} ion pair from the presence of fluoride in the agricultural gypsum. The precipitation of aluminum minerals, such as alunite and basaluminite, for example, in response to increasing sulfate concentration in the solution and by the increase of the ionic strength in the soil solution, which causes a decrease in the chemical activity of the aluminum. The aluminum contents verified in the present study are classified as low according to Alvarez et al. (1999), that is, aluminum content in the soil between 0.21 and 0.50 cmol$_c$ dm^{-3}.

The potential acidity (H + Al) in the 0.0-0.20 m (Table 1), linearly reduced with the application of gypsum, highlighting the positive effect of the use of this residue five months after application in the soil. In Figure 1-E, it was verified minimum content (2.08 cmol$_c$ dm^{-3} of H + Al) and it is considered low (1.01 to 2.50 cmol$_c$ dm^{-3}), according to Alvarez et al. (1999). The potential acidity in 0.20-0.40 m (Table 2), wasn’t influenced by the evaluated factors, obtaining the medium value of 2.04 cmol$_c$ dm^{-3} of H + Al, value considered low for the soil.

The values of base sum (SB) in the 0.0-0.20 m weren’t influenced by the factors evaluated (Table 1), with the average content of 1.99 cmol$_c$ dm^{-3}. In the 0.20-0.40 m, the sum of bases (BSUM) was influenced only by the application of K_2O (Table 2). In Figure 2-E, there were increases of 0.000588 cmol$_c$ dm^{-3} in the value of this attribute for each kilogram of K_2O added to the soil, which resulted in the maximum value of 1.88 cmol$_c$ dm^{-3} for BSUM (in the depth 0.20-0.40 m, this value verified with the application of 360 kg ha^{-1} K_2O.

This increase in the sum of bases in response to the potassium application is related to the better availability of this cation in the 0.20-0.40 m, which can be attributed in part to the potassium percolation (Figure 1-B) occurring in the depth 0.0-0.20 m. Alvarez et al. (1999), the BSUM values verified in the present study are classified as medium.

The cation exchange capacity (CEC) calculated at the 0.0-0.20 m, linearly reduced with application of the maximum gypsum rate (Table 1), corroborating Souza et al. (2012). However, Foloni et al. (2008) reported an increase in soil CEC in the 0.0-0.20 m as answer of the increasing rates of gypsum in dystroferric Red Argisol. The reduction of the calculated CEC observed in this study can be attributed to the leaching of cations in 0.0-0.20 m depth which after reacting with the sulfate anion released in the dissociation of the gypsum, formed stable compounds, which, in turn, are not absorbed by the plants and are later carried to depths in the soil profile. The maximum (4.49 $cmol_c$ dm^{-3}) and minimum (4.12 $cmol_c$ dm^{-3}) CEC calculated from the soil in the depth 0.0-0.20 m (Figure 1-F) was verified with 0.0 and 4000 kg ha^{-1} rates of gypsum, respectively.

In the 0.20-0.40 m, there was a significant interaction between the gypsum and potassium rates for the CEC in the soil (Table 2), which responded in adjustment quadratic to the application of the treatments. In Figure 2-F, it was observed that there was a reduction in the CEC of the soil with the increase of the rates of gypsum, evidencing the possible drag of cations to the deeper. With the application of the 0.0 and 360 kg ha^{-1} rates of gypsum and K_2O, respectively, the highest CEC value calculated at the depth of 0.20-0.40 m, 4.03 $cmol_c$ dm^{-3} was verified.

The values of base saturation (V%) in the 0.0-0.20 m weren't influenced as a answer of the application of gypsum and K_2O rates (Table 1), with an medium value of 45.15%. Refer to V% 0.0-0.20 m, this value, classified as medium according Alvarez et al. (1999). Similar to that observed for the sum of bases in the 0-0.20 m depth (Table 1), with application of gypsum and K_2O, there should be a higher concentration of calcium and potassium in this depth, which would possibly influence the V% values. However, only a significant response was observed for this attribute in the 0.20-0.40 m (Table 2) as a response of K_2O application, reinforcing the possible percolation of calcium and potassium in depth.

The maximum value verified for V% in the 0.20-0.40 m was 47.56% (Figure 2-G), saturation classified as medium (ALVAREZ et al., 1999). This increase is justified by the direct addition of K to the soil, which after being applied superficially and incorporated by harrowing, moved to the deeper the leaching process as a response from soil texture medium, by the action of gypsum or for the precipitations that occurred during the cultivation of maize.

The application of gypsum resulted in increased S contents at depths of 0.0-0.20 and 0.20-0.40 m from the soil (Tables 1 and 2). This result is due to the presence of S in the agricultural gypsum (150 g kg^{-1}).

At Figure 3-A shows a linear increase in the S content in the 0.0-0.20 m depth with application of up to 4000 kg ha^{-1} of gypsum, which resulted in the maximum S content, 17.26 mg dm^{-3} of S in the 0-0.20 m profile of the soil, which is considered high for Raij et al. (1997). Pauletti et al. (2014) observed an increase in S content in the 0.0-0.20 m of a Red-Yellow oxysoil, in response to the increasing application of agricultural gypsum (0; 1.5; 3.0; 6.0; and 12000 kg ha^{-1}).

At the depth of 0.20-0.40 m, the S contents increased with the application of up to 3620.45 kg ha^{-1} of gypsum rate (Figure 4-A).

The application of gypsum influenced the levels of B in the 0-0.20 and 0.20-0.40 m depths (Tables 1 and 2). In the 0.0-0.20 m, there was a quadratic adjustment of the application of this residue to the B content, with a maximum content of 0.25 mg dm^{-3} of B, with application of 951.61 kg ha^{-1} of gypsum rate (Figure 3-B).

Thus, as verified in the depth of 0.0-0.20 m, there was a quadratic adjustment of the rates of gypsum for the B content in the depth of 0.20-0.40 m, which resulted in increases in the contents of this nutrient with application of up to 2175 kg ha^{-1} of gypsum rate, resulting in the maximum content of B in this depth, that is, 0.31 mg dm^{-3} (Figure 4-B).

The increase in B content in the 0.20-0.40 m (Figure 4-B) when compared to the content observed in the 0.0-0.20 m (Figure 3-B), can be attributed to the leaching of B of the surface depth by the action of the gypsum, since the soil of the experimental area presented low clay content, which in a way, provides the percolation of nutrients to the depths of the soil, which resulted in B levels considered to be low according to Alvarez et al. (1999), 0.16 to 0.35 mg dm^{-3} of B.

The Cu levels in the 0.0-0.20 and 0.20-0.40 m soil profiles weren't influenced by the factors evaluated (Tables 1 and 2), with mean values of 0.60 and 0.74 mg dm^{-3} in the depths of 0.0-0.20 and 0.20-0.40 m, respectively.

In relation to the Fe content in the 0.0-0.20 m (Table 1), it was reduce linearly with application of up to 4000 kg ha^{-1} of gypsum, resulting in a minimum content of 36.42 mg dm^{-3} of this nutrient in depth (Figure 3-C).

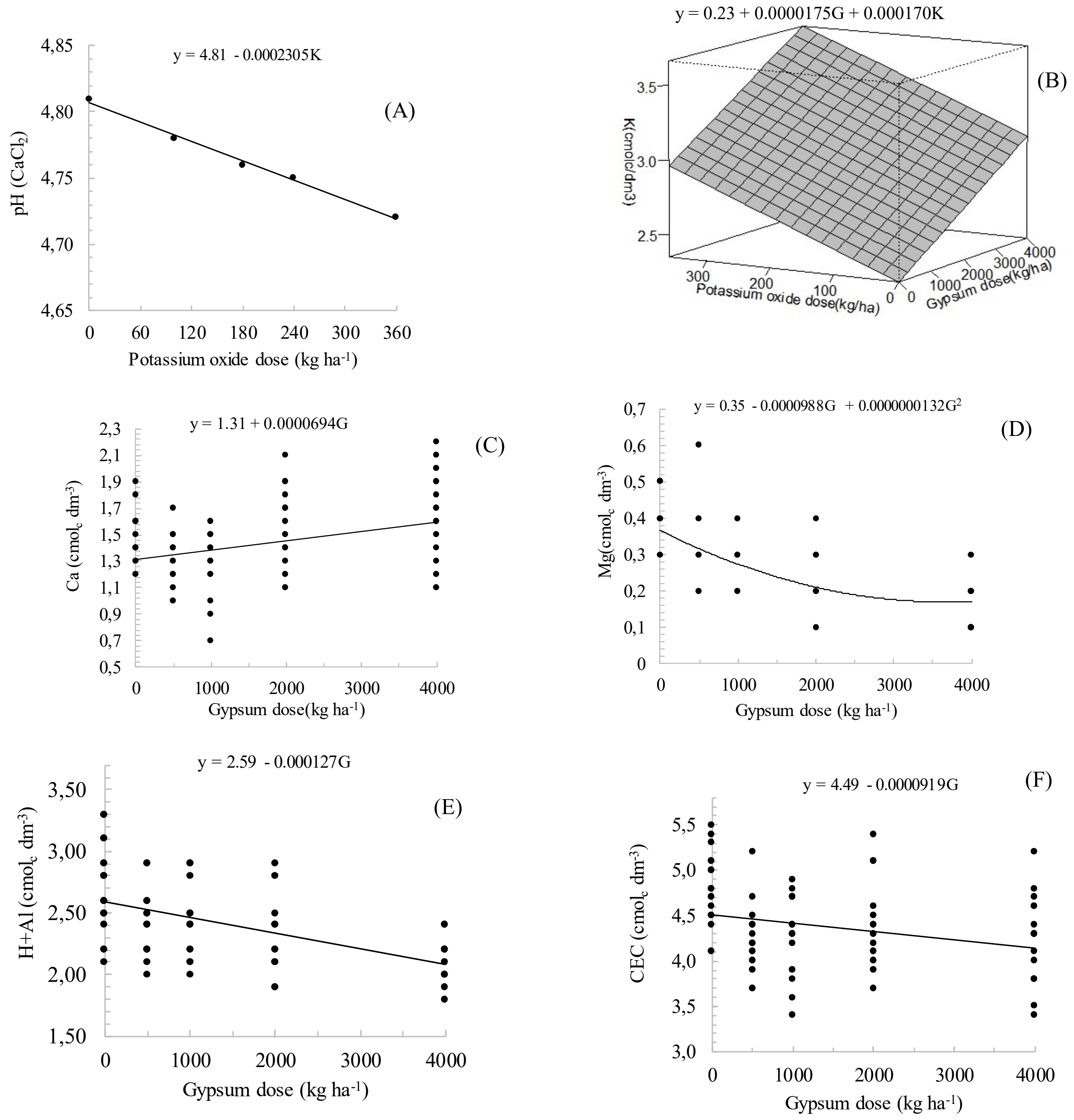

Figure 1. A) pH ($CaCl_2$) in the layer 0.0-0.20 m; B) Potassium (K); C) Calcium (Ca); D) Magnesium (Mg); E) Potential acidity (H+Al); F) Cation Exchange Capacity (CEC), content in the layer 0.0-0.20 m.

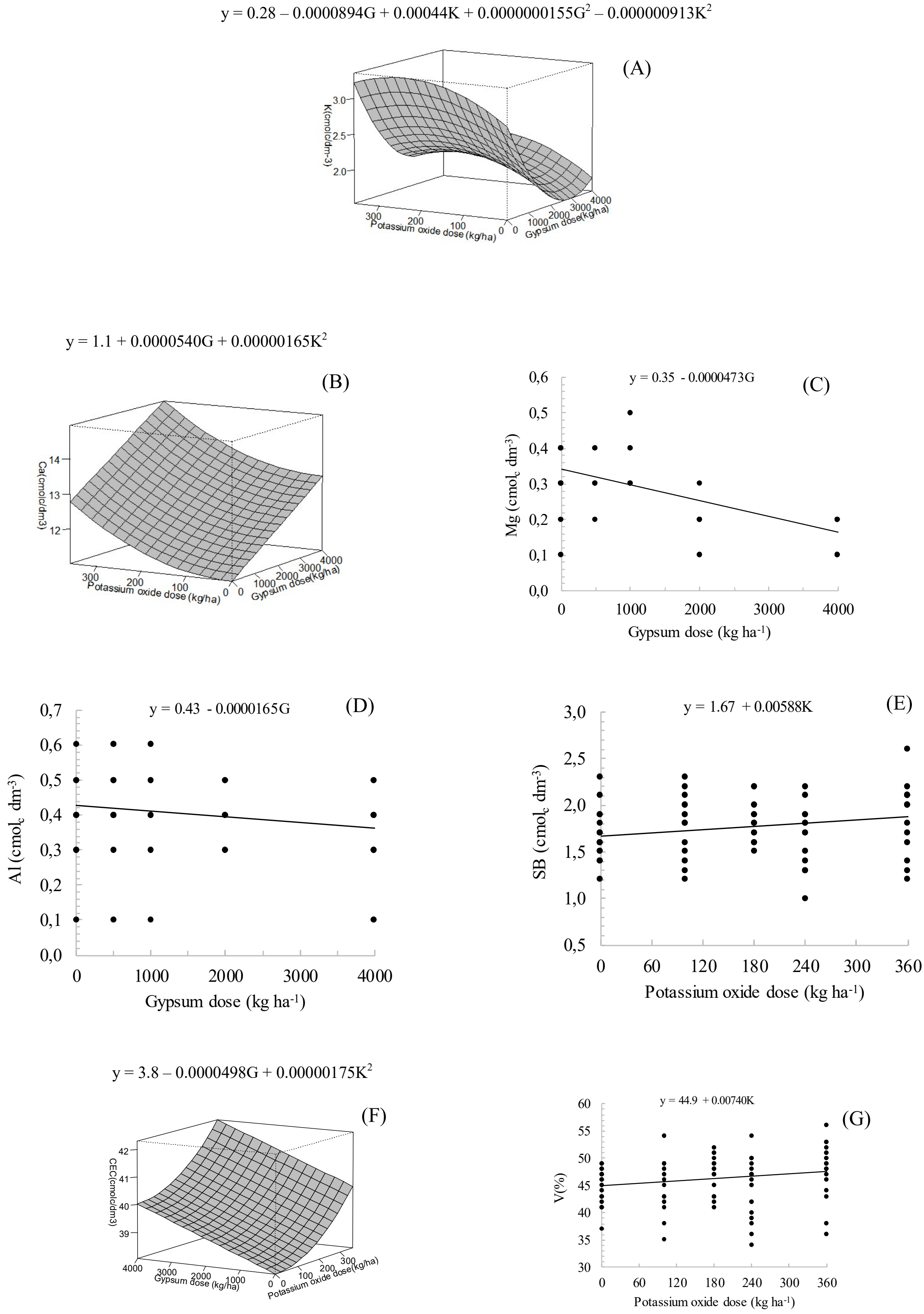

Figure 2. A) Potassium (K); B) Calcium (Ca); C) Magnesium (Mg); D) Aluminum (Al); E) Sum of Bases (SB); F) Cation Exchange Capacity (CEC); G) Base of Saturation, content in the layer 0.20-0.40 m.

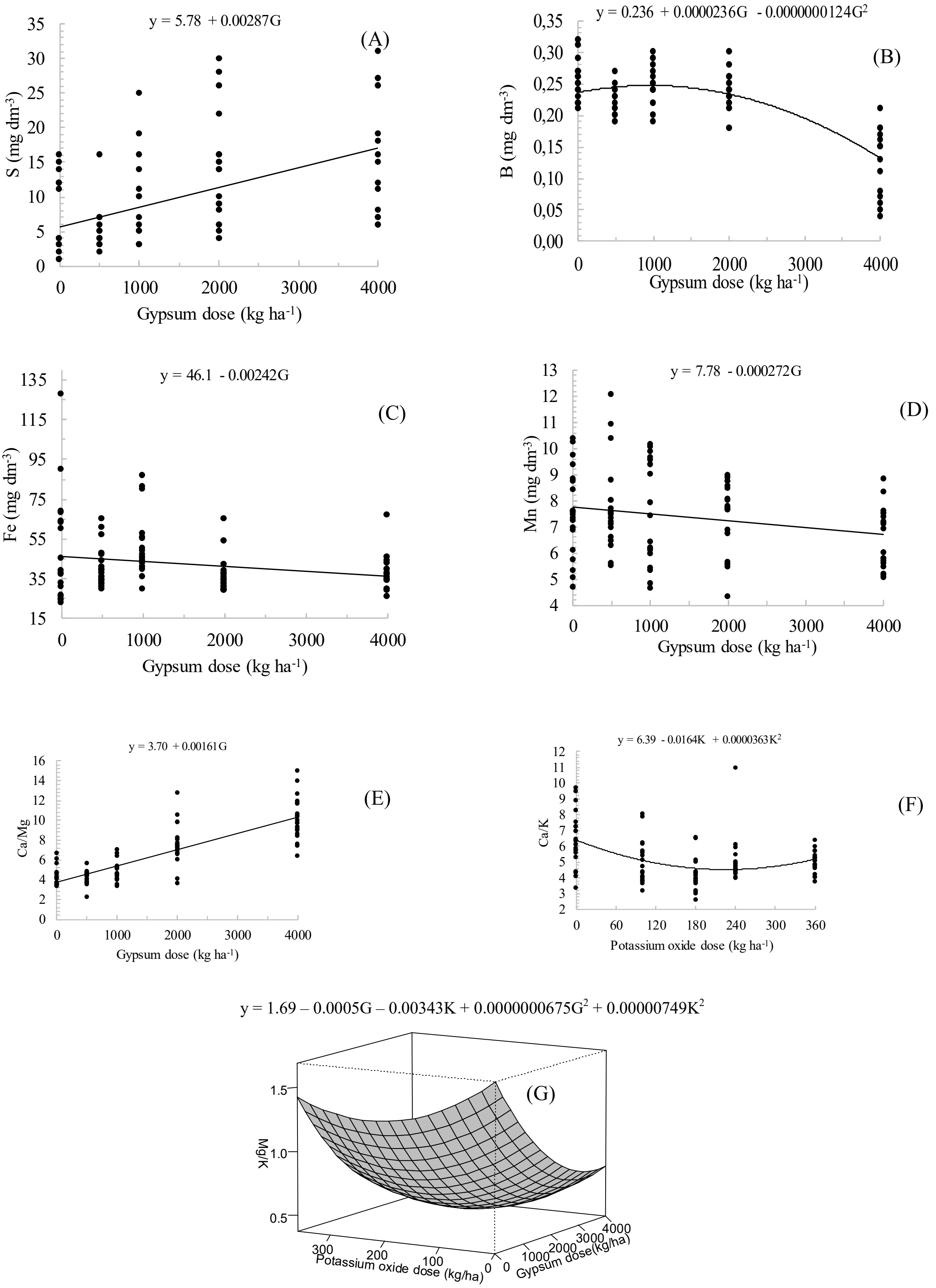

Figure 3. A) Sulfur (S); B) Boron (B); C) Iron (Fe); D) Manganese (Mn); E) Ratio Ca/Mg; F) Ratio Ca/K; G) Ratio Mg/K, content in the layer 0.0-0.20 m

The behavior observed for Fe in the respective depth, due to the application of gypsum, can be attributed to the formation of complexes between the Fe^{2+} and SO_4^{2-} ($FeSO_4^0$) ions present in the soil, which provided the drag of this nutrient to depths of the soil. This soil had a medium texture, unable to retain a considerable number of positive charges. However, the minimum Fe in the present study is classified as adequate, between 31 and 45 mg dm^{-3} (ALVAREZ et al.1999).

The Fe content in the 0.20-0.40 m (Table 2), there was no significant response as a response of the application of gypsum or K in the contents of this attribute, with a mean content of 37.65 mg dm^{-3} of Fe in depth, which is considered medium according to Alvarez et al. (1999).

The manganese content in the 0.0-0.20 m depth of the soil reduced linearly with the increase of the applied gypsum (Table 1), which resulted in the minimum content of 7.00 mg dm^{-3} of Mn.

The effect of gypsum on manganese content in the 0.0-0.20 m (Figure 3-D) may be related to the percolation of this nutrient in the soil after the formation of complexes between manganese (Mn^{2+}) and sulfate (SO_4^{2-})' which added to the medium soil texture associated with rainfall during the crop cycle, should have contributed to the displacement of this nutrient in the soil profile.

At the depth of 0.20-0.40 m (Table 2), the evaluated factors didn’t influence the manganese contents, with a mean content of 6.16 mg dm^{-3} for this nutrient. According to Alvarez et al. (1999), the levels of manganese available in the studied depths are classified as medium, that is, manganese levels in the soil between 6 and 8 mg dm^{-3}.

No significant differences were observed in the zinc content at depths of 0-0.20 and 0.20-0.40 m (Tables 1 and 2), with mean values of 2.27 and 1.68 mg dm^{-3} respectively, levels considered adequate according to Alvarez et al (1999).

The Ca/Mg ratio in the 0.0-0.20 m depth increased linearly as a response of the applied gypsum (Table 1), corroborating in parts with the results reported by Caires et al. (1999), which also observed an increase in the Ca/Mg ratio in the 0.0-0.05 and 0.05-0.10 m depths after application of gypsum. This increase in the Ca/Mg ratio is attributed to the increase of calcium in the respective depth (Figure 1-C) after the dissolution of the gypsum, since the gypsum used in the present study had 18% calcium in its composition. In Figure 3-E, the maximum Ca/Mg ratio (10.14) in the 0.0-0.20 m depth was verified with the maximum gypsum rate (4000 kg ha^{-1}).

At the depth of 0.20-0.40 m there was a significant interaction between the factors evaluated for the Ca / Mg ratio (Table 2), which increased linearly in response to the increase of gypsum and K_2O applied to the soil (Figure 4-C). Caires et al. (1999), Saldanha et al. (2007) also observed an increase in the Ca / Mg ratio in the 0.20-0.40 m depth of the soil in studies with gypsum application. This increase in the Ca / Mg ratio with the application of gypsum is attributed to the direct addition of calcium in the depth of 0.20-0.40 m (Figure 2-B) of the soil after the solubilization of this residue, which resulted in an increase in the concentration of calcium ions in Magnesium, allowing the increase in this ratio. The maximum Ca/Mg ratio (9.11) in the 0.20-0.40 m depth was verified with the maximum rates of gypsum and potassium, respectively (Figure 4-C).

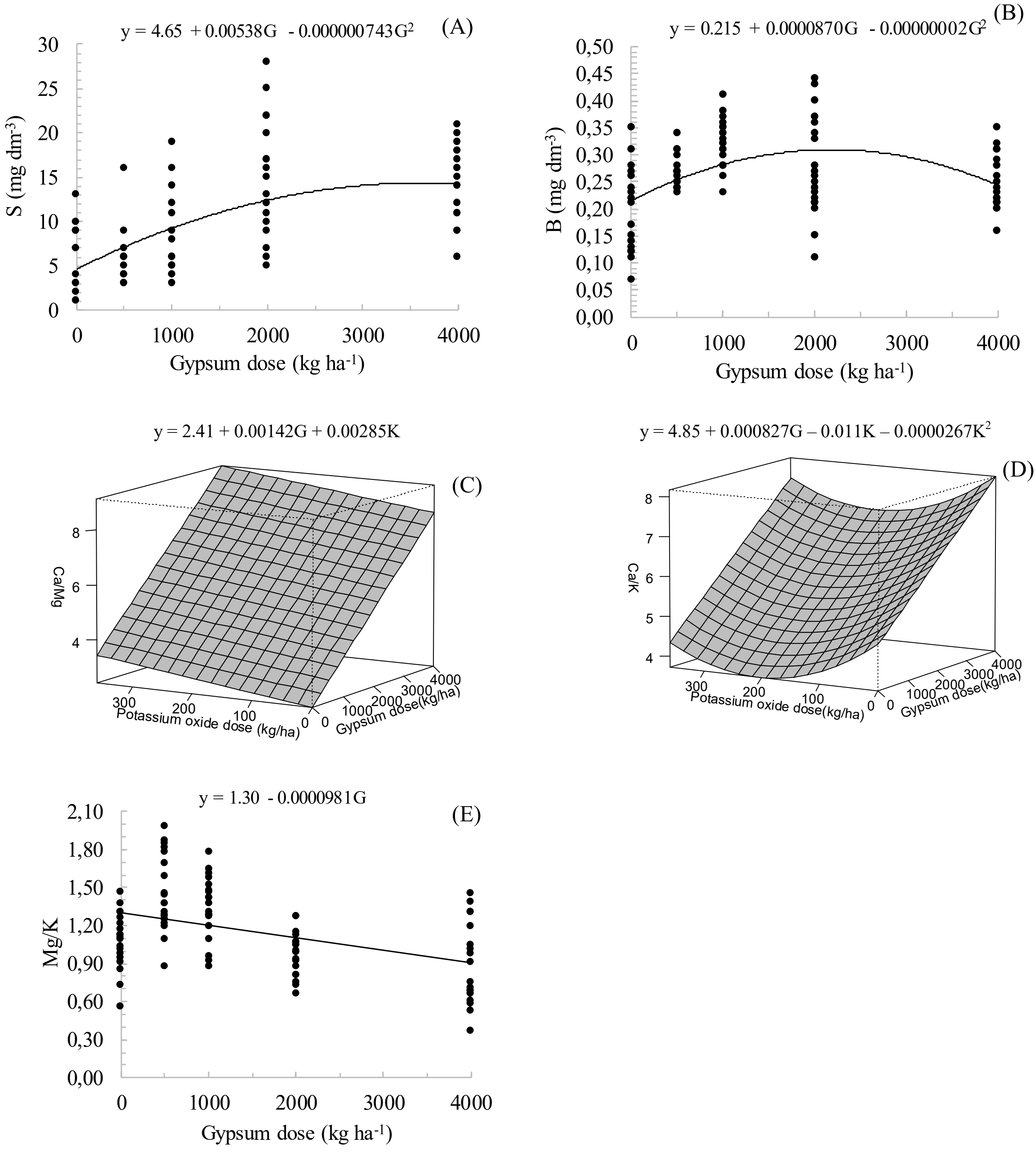

Figure 4. A) Sulfur (S); B) Boron (B); C) Ratio Ca/Mg; D) Ratio Ca/K; E) Ratio Mg/K, content in the layer 0.20-0.40 m.

For the Ca/K ratio in the 0.0-0.20 m depth, only the influence of the K_2O application on its values was verified (Table 1). Figure 3-F shows a reduction in Ca/K ratio with application of up to 225.90 kg ha^{-1} of K_2O, when the lowest Ca/K ratio (4.54) was observed, which can be attributed to the higher concentration of K^+ ions (Figure 1-B) in the 0.0-0.20 m depth of soil compared to calcium (Figure 1-C).

In the 0.20-0.40 m, a significant interaction between the gypsum and potassium rates was observed for the Ca/K ratio (Table 2). In Figure 4-D, there is an increase in this relation Ca/k with the high rates of gypsum, it is attributed to the higher concentration of calcium ions, carried from the 0.0-0.20 m to the 0.20-0.40 m.

However, it is observed in Figure 3-H that the application of increasing rates of potassium, reduced the contents of this relation with application of up to 206 kg ha^{-1} of K_2O, increasing with rates higher than 206 kg ha^{-1} K_2O. As a response of the application of 4000 and 206 kg ha^{-1} of gypsum and

K_2O, respectively, the lowest Ca/K ratio was observed in the depth of 0.20-0.40 m or 7.02.

The ratio Mg/K in the 0.0-0.20 m there was a significant interaction between the factors evaluated for the values of this relation (Table 1). The Figure 3-G shows a reduction in the Mg/K ratio with application of up to 3703.70 and 228.97 kg ha^{-1} of gypsum and K_2O rates, respectively.

The reduction in the Mg/K ratio in response to the application of increasing rates of gypsum and potassium is attributed to the higher availability of potassium (Figure 1-B) and calcium (Figure 1-C) compared to magnesium in the 0.0-0.20 m (Figure 1-D). The maximum and minimum values for the Mg/K ratio in the 0.0-0.20 m depth were 1.69 and 0.37 at the 3703.70 and 228.97 kg ha^{-1} rates of gypsum and K_2O, respectively.

At the depth of 0.20-0.40 m, the Mg/K ratio was influenced only by the application of gypsum (Table 2), showing in Figure 4-E, linear reduction in the contents of this relation with the increase of the application of this residue, which is justified by the increase of the concentration of calcium ions in this depth, resulting from the addition of gypsum, resulting in the displacement of magnesium and potassium in depth. The maximum and minimum Mg/K ratio observed in the 0.20-0.40 m depth with application of the 0 and 4000 kg ha^{-1} rates of gypsum were 1.30 and 0.91.

Grains productivity

Gypsum and K rates did not influence the biometric and productive characteristics evaluated for grain corn (Table 3). Mean values of 188.79 and 163.32 g, respectively, were verified for the corn ears with and without husk dry mass. For the dry mass of the cob and grain for ears, average values of 26.61 and 136.69 g, respectively, were observed (Table 3). Valderrama et al. (2011) working with different sources of N, P and K applied in the cultivation in dystrophic Red Oxysoil, also didn't verify significant effects of the application of K rates (0, 40, 80 and 120 kg ha^{-1} K_2O) on the productivity of grains yield, reporting a mean yield of 9110 kg ha^{-1}.

Table 3. Biometric and productivity characteristics of corn as response at different K and gypsum rates.

G	MDH	MDWH	CDM	MGE	PG
(kg ha^{-1})	-----------------------------------	g	-------------------------------------		------ kg ha^{-1} ------
0	182.20	157.48	25.48	131.89	7913.53
500	194.25	168.32	31.65	136.66	8199.80
1000	181.51	157.95	24.49	133.46	8007.52
2000	193.39	167.01	24.62	142.39	8543.32
4000	192.57	165.83	26.78	139.06	8343.32
K (kg ha^{-1})					
0	180.74	154.26	24.06	130.10	7805.93
100	191.01	166.38	26.14	140.25	8414.91
180	188.87	163.24	28.04	135.20	8111.90
240	187.98	163.39	25.54	137.85	8270.71
360	195.32	169.31	29.25	140.07	8404.05
Average	188.79	163.32	26.61	136.69	8201.50
F_G	1.56^{ns}	1.28^{ns}	3.10^{ns}	1.06^{ns}	1.06^{ns}
F_K	1.09^{ns}	1.51^{ns}	1.47^{ns}	1.05^{ns}	1.06^{ns}
F_{GxK}	1.05^{ns}	1.15^{ns}	1.25^{ns}	0.98^{ns}	0.98^{ns}
C.V.%	12.05	12.56	28.31	13.42	13.42

G = Gypsum rates; K = K_2O rates; ns = not significant by F test; C.V. = coeficiente of variation; MDH= maize with husk; MDWH = maize without husk; CDM = cob dry mass; MGE = grain mass per ear; PG = grains productivity.

According to Brunetto et al. (2005), numerous crops have shown little response to potassium fertilization, when K contents in the cultived depth are greater than 0.15-0.20 $mmol_c$ dm^{-3}. In the present study the initial K^+ content in the soil before the installation of the experiment was 0.16 $cmol_c$ dm^{-3}, considered medium for the development of the crop.

Pavinato et al. (2008) evaluated corn grain yield as a response of different rates of N and K (0, 40, 80 and 120 kg ha^{-1} K_2O) in Dystrophic Red Oxysoil, that potassium fertilization didn't influence the productivity of corn, attributing this response to the high initial content of K in the depths 0.0 to 0.10 m, 0.51 and 0.43 cmolc dm^{-3} of K, respectively, corroborating with the present study.

CONCLUSIONS

The application of gypsum, even at the highest rate, didn't exchange the K contents in the soil.

There was a linear reduction of the Mg content in the soil due to the increase of the gypsum rates.

The agricultural gypsum reduced the content of Al and K in the subsurface depth of the soil.

The production and yield components of corn weren't influenced by the gypsum and potassium rates.

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RESUMO: A calagem é uma prática comum na agricultura. Esta prática visa reduzir a acidez do solo, além de fornecer cálcio e magnésio. Contudo, devido ao fato de o calcário apresentar baixa solubilidade no solo, os produtos de sua reação ficam retidos na camada onde o produto foi aplicado, a qual geralmente é na camada superficial do solo. Para se aumentar a concentração de nutrientes em camadas mais profundas, o gesso agrícola - um subproduto da produção de ácido fosfórico, rico em cálcio e enxofre tem sido usado. Neste contexto, o objetivo deste trabalho foi avaliar a influência da aplicação de diferentes doses de gesso em associação a doses de potássio, nos atributos químicos do solo e na produtividade de grãos de milho. O estudo foi conduzido no Instituto Federal de Educação, Ciência e Tecnologia do Triângulo Mineiro (IFTM), Campus Uberaba, localizado no município de Uberaba-MG, Brasil. O experimento foi instalado em esquema fatorial 5x5, sendo cinco doses de gesso (0, 500, 1000, 2000 e 4000 kg ha^{-1}) e cinco doses de K_2O (0, 100, 180, 240 e 360 kg ha^{-1}) no delineamento em blocos completos casualizados, com quatro repetições. Os atributos químicos do solo foram avaliados nas camadas de 0,0 a 0,20 m e de 0,20 a 0,40 m, além das características biométricas e produtivas da cultura do milho. A aplicação de gesso resultou no aumento de cálcio e enxofre em ambas as profundidades; reduziu os níveis de pH, manganês, acidez potencial (H + Al) na camada de 0,0-0,20m; e, aumentou os níveis de saturação por bases e soma de bases na camada de 0,20-0,40 m. A produção de milho não foi influenciada pelos fatores avaliados.

PALAVRAS-CHAVES: Gesso. Interação gesso e potássio. *Zea mays.*

REFERENCES

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v. 22, n. 6, p. 711 – 728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

ALVAREZ V, V. H.; NOVAIS, R. F.; BARROS, N. F.; CANTARUTTI, R. B.; LOPES, A. S. Interpretação dos resultados das análises de solos. In: RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ V, V. H. (Ed.). Recomendações para o uso de corretivos e fertilizantes em Minas Gerais, 5ª aproximação. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais, 1999. p. 25-32.

AZEVEDO, W. R.; FAQUIN, V.; FERNANDES, L. A.; OLIVEIRA JUNIOR, A. C. Disponibilidade de fósforo para o arroz inundado sob efeito residual de calcário, gesso e esterco de curral aplicados na cultura do feijão. Revista Brasileira de Ciência do Solo, Viçosa, v. 28, n. 6, p. 995-1004. 2004. https://doi.org/10.1590/S0100-06832004000600008

BORKERT, C. M.; PAVAN, M. A.; LANTMANN, Á. F. Considerações sobre o uso de gesso na agricultura. Londrina: EMBRAPA, 1987, n. 40, 5 p.

BRUNETTO, G.; GATIBONI, L. C.; SANTOS, D. R.; SAGGIN, A.; KAMINSKI, J. Nível crítico e resposta das culturas ao potássio em um argissolo sob sistema plantio direto. Revista Brasileira de Ciência do Solo, Viçosa, v. 29, n. 4, p. 561-571. 2005. https://doi.org/10.1590/S0100-06832005000400009

CAIRES, E. F.; CHUEIRI, W. A.; MADRUGA, E. F.; FIGUEIREDO, A. Alterações de características químicas do solo e resposta da soja ao calcário e gesso aplicados na superfície em sistema de cultivo sem preparo do solo. Revista Brasileira de Ciência do Solo, Viçosa, v. 22, p. 27-34. 1998. https://doi.org/10.1590/S0100-06831998000100004

CAIRES, E. F.; FONSECA, A. F.; MENDES, J.; CHUEIRI, W. A.; MADRUGA, E. F. Produção de milho, trigo e soja em função das alterações das características químicas do solo pela aplicação de calcário e gesso na superfície, em sistema de plantio direto. Revista Brasileira de Ciência do Solo, Viçosa, v. 23, p. 315-327. 1999. https://doi.org/10.1590/S0100-06831999000200016

CAIRES, E. F.; BLUM, J.; BARTH, G.; GARBUIO, F. J.; KUSMAN, M. T. Alterações químicas do solo e resposta da soja ao calcário e gesso aplicados na implantação do sistema plantio direto. Revista Brasileira de Ciência do Solo, Viçosa, v. 27, n. 2, p. 275-286. 2003. https://doi.org/10.1590/S0100-06832003000200008

CAIRES, E. F.; KUSMAN, M. T.; BARTH, G.; GARBUIO, F. J.; PADILHA, J. M. Alterações químicas do solo e resposta do milho à calagem e aplicação de gesso. Revista Brasileira de Ciência do Solo, Viçosa, v. 28, p. 125-136. 2004. https://doi.org/10.1590/S0100-06832004000100013

CAIRES, E. F.; GARBUIO, F. J.; ALLEONI, L. R. F.; CAMBRI, M. A. Calagem superficial e cobertura de aveia preta antecedendo os cultivos de milho e soja em sistema plantio direto. Revista Brasileira de Ciência do Solo, Viçosa, v. 30, n. 1, p. 87-98. 2006. https://doi.org/10.1590/S0100-06832006000100010

CASTRO, A. M. C.; RUPPENTHAL, V.; RANDO, E. M.; MARCHIONE, M. S.; GOMES, C. J. A. Calcário e gesso no desenvolvimento do milho cultivado em um Latossolo Vermelho Amarelo distrófico. Revista Cultivando o Saber, Cascavél, v. 6, n. 1, p. 8-16. 2013.

CRUSCIOL, C. A. C.; FOLTRAN, R.; ROSSATO, O. B.; MCCRAY, J. M.; ROSSETTO, R. Effects of surface application of calcium magnesium silicate and gypsum on soil fertility and sugarcane yield. Revista Brasileira de Ciência do Solo, Viçosa, v. 38, n. 6, p. 1843-1854. 2014. https://doi.org/10.1590/S0100-06832014000600019

DEMATTÊ, J. L. I. Ação do Gesso e do Calcário na relação do Cálcio:Magnésio do solo e na produtividade da cana-de-açúcar. Informações agronômicas. International Plant Nutrition Institute, Piracicaba, n. 136, p. 11-16. 2011.

ERNANI, P. R.; BARBER. S. A. Composição da solução do solo e lixiviação de cátions afetadas pela aplicação de cloreto e sulfato de cálcio em um solo ácido**.** Revista Brasileira de Ciência do Solo, Viçosa, v. 10, n. 1, p. 41-46. 1993. https://doi.org/10.1590/S0103-90162001000400026

ERNANI, P. R.; RIBEIRO, M. S.; BAYER, C. Modificações químicas em solos ácidos ocasionadas pelo método de aplicação de corretivos da acidez e de gesso agrícola. Scientia Agricola, Piracicaba, v. 58, n. 4, p. 825-831. 2001.

FOLONI, J. S. S.; TIRITAN, C. S.; CALONEGO, J. C.; JUNIOR, J. A. Aplicação de fosfato natural e reciclagem de fósforo por milheto, braquiária, milho e soja. Revista Brasileira de Ciência do Solo, Viçosa, v. 32, n. 3, p. 1147-1155. 2008. https://doi.org/10.1590/S0100-06832008000300023

JAMES, G.; WITTEN, D.; HASTIE, T.; TIBSHIRANI, R. 2013. An Introduction to Statistical Learning: with aplications in R. Springer, New York: Springer, 2013. 401 p. https://doi.org/10.1007/978-1-4614-7138-7

MARTINEZ, H. E. P.; CARVALHO, J. G.; SOUZA, R. B. Diagnose foliar. In: RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ V., V. H. (Eds.). Recomendações para o uso de corretivos e fertilizantes em Minas Gerais. 5ª Aproximação. Viçosa: UFV, p. 143-168. 1999.

NAVA, G.; ERNANI, P. R.; SÁ, A. A.; PEREIRA, A. J. Soil Composition and nutritional status of apple as affected by long-term application of gypsum. Revista Brasileira de Ciência do Solo, Viçosa, v. 36, p. 215-222. 2012. https://doi.org/10.1590/S0100-06832012000100022

NORA, D. D.; AMADO, T. J.; BORTOLOTTO, R. F.; FERREIRA, A. O.; KELLER, C.; KUNZ, J. Alterações químicas do solo e produtividade do milho com aplicação de gesso combinado com calcário. Magistra, Cruz das Almas, v. 26, n. 1, p. 1-10. 2014.

PAULETTI, V.; PIERRI, L.; RANZAN, T.; BARTH, G.; MOTTA, A. C. V. Efeitos em longo prazo da aplicação de gesso e calcário no sistema de plantio direto. Revista Brasileira de Ciência do Solo, Viçosa, v. 38, n. 2, p. 495-505. 2014. https://doi.org/10.1590/S0100-06832014000200014

PAVAN, M. A.; BINGHAM, F. T.; PRATT, P. F. Redistribution of exchangeable calcium, magnesium, and aluminum following lime and gypsum applications to a Brazilian Oxisol. Soil Science Society of America Journal, Madison, v. 48, n. 1, p. 33-38. 1984. https://doi.org/10.2136/sssaj1984.03615995004800010006x

PAVINATO, P. S.; CERETTA, C. A.; GIROTTO, E.; LOPES MOREIRA, I. C. Nitrogênio e potássio em milho irrigado: análise técnica e econômica da fertilização. Ciência Rural, Santa Maria, v. 38, n.2, p. 358-364. 2008. https://doi.org/10.1590/S0103-84782008000200010

QUAGGIO, J. A.; DECHEN, A. R.; RAIJ, B. V. Efeitos da aplicação de calcário e gesso sobre a produção de amendoim e a lixiviação de bases no solo. Revista Brasileira de Ciência do Solo, v. 6, n. 3, p. 189-194. 1982.

R Development Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2014.

RAIJ, B.; CANTARELLA, H.; QUAGGIO, J. A.; FURLANI, Â. M. C. Recomendações de Adubação e Calagem para o Estado de São Paulo. 2 ed. rev. ampl. Campinas: Instituto Agronômico e Fundação IAC, (Boletim Técnico, 100). 1997. 88 p.

RAIJ, B.; ANDRADE, J. C.; CANTARELLA, H.; QUAGGIO, J. A. Análise química para avaliação da fertilidade de solos tropicais. Campinas: Instituto Agronômico, 2001. 285p.

RAIJ, B. Gesso na agricultura. Campinas: Instituto Agronômico, 2008. 233 p.

RAMOS, B. Z.; TOLEDO, J. P. V. F.; LIMA, J. M. SERAFIM, M. E.; BASTOS, A. R. R GUIMARÃES, P. T. G.; COSCIONE, A. R. Doses de Gesso em cafeeiro: influência nos teores de cálcio, magnésio, potássio e pH na solução de um Latossolo Vermelho distrófico. Revista Brasileira de Ciência do Solo, Viçosa, v. 37, p. 1018-1026. 2013. https://doi.org/10.1590/S0100-06832013000400019

RAMPIM, L.; LANA, M. C.; FRANDOLOSO, J. F.; FONTANIVA, S. Atributos químicos de solo e resposta do trigo e da soja ao gesso em sistema semeadura direta. Revista Brasileira de Ciência do Solo, Viçosa, v. 35, p. 1687-1698. 2011. https://doi.org/10.1590/S0100-06832011000500023

RAMPIM, L.; LANA, M. C.; FRANDOLOSO, J. F. Fósforo e enxofre disponível, alumínio trocável e fósforo remanescente em latossolo vermelho submetido ao gesso cultivado com trigo e soja. Semina: Ciências Agrárias, Londrina, v. 34, n. 4, p. 1623-1638. 2013. https://doi.org/10.5433/1679-0359.2013v34n4p1623

ROCHA, A. T.; OLIVEIRA, A. C.; RODRIGUES, A. N.; LIRA JÚNIOR, M. A.; FREIRE, F. J. Emprego do gesso do Araripe na melhoria do ambiente radicular da cana-de-açúcar. Revista Brasileira de Ciências Agrárias, Pernambuco, v. 3, p. 307-312. 2008. https://doi.org/10.5039/agraria.v3i4a282

SALDANHA, E. C. M.; ROCHA, A. T.; OLIVEIRA, E. C. A.; NASCIMENTO, C. W. A.; FREIRE, F. J. Uso do gesso mineral em Latossolo cultivado com cana-de-açúcar. Revista Caatinga, Mossoró, v. 20, n. 1, p. 36-39. 2007.

SILVA, N. M. A.; RAIJ, B. V.; CARVALHO, L. H. D.; BATAGLIA, O. C.; KONDO, J. I. Efeitos do calcário e do gesso nas características químicas do solo e na cultura do algodão. Bragantia, Campinas, v. 56, n. 2, p. 389-401. 1997. https://doi.org/10.1590/S0006-87051997000200018

SORATTO, R. P.; CRUSCIOL, C. A. Atributos químicos do solo decorrentes da aplicação em superfície de calcário e gesso em sistema plantio direto recém-implantado. Revista Brasileira de Ciência do Solo, Viçosa, v. 32, p. 675-688. 2008. https://doi.org/10.1590/S0100-06832008000200022

SOUSA, D. M. G.; MIRANDA, L. N. de; OLIVEIRA, S. A. de. Acidez do solo e sua correção. In: NOVAIS, R. F.; ALVAREZ V., V. H.; BARROS, N. F.; FONTES, R. L. F.; CANTARUTTI, R. B.; NEVES, J. C. L. (Ed.). Fertilidade do Solo. Viçosa: Sociedade Brasileira de Ciência do Solo, 2007. p. 205-274.

SOUZA, D. M. G.; LOBATO, E.; REIN, T. A. Uso do gesso agrícola nos solos dos cerrados. Planaltina: EMBRAPA-CPAC, 1996. 20 p. (Circular técnica, 32).

SOUZA, F. R.; JUNIOR, E. J. R.; FIETZ, C. R.; BERGAMIN, A. C.; ROSA, Y. B. C. J.; ZEVIANI, W. M. Efeito do gesso nas propriedades químicas do solo sob dois sistemas de manejo. Semina: Ciências Agrárias, Londrina, v. 33, n. 5, p. 1717-1732. 2012. https://doi.org/10.5433/1679-0359.2012v33n5p1717

VALDERRAMA, M.; BUZETTI, S.; BENETT, C. G.; ANDREOTTI, M.; FILHO, M. C. M. T. Fontes e doses de NPK em milho irrigado sob plantio direto. Pesquisa Agropecuária Tropical, Goiânia, v. 41, n. 2, p. 254-263. 2011. https://doi.org/10.5216/pat.v41i2.8390

VILELA, L. C.; SANTOS, A. C.; BARRETO, P. M.; BRITO, S. S.; SILVA, J. E. C.; OLIVEIRA, L. B. T. Propriedades químicas de Latossolo Vermelho em função da aplicação de gessagem e calagem**.** Revista Acadêmica: ciências agrárias e ambientais, Curitiba, v. 8, n. 1, p. 19-27. 2010. https://doi.org/10.7213/cienciaanimal.v8i1.10385

VITTI, G. C.; LIMA, E.; CICARONE, F. Cálcio, magnésio e enxofre. In: MANLIO, S. F. (Ed.). Nutrição mineral de plantas. Viçosa: Sociedade Brasileira de Ciência do Solo, 2006. p. 299-325.

ZAMBROSI, F. C. B.; ALLEONI, L. R. F.; CAIRES, E. F. Aplicação de gesso agrícola e especiação iônica da solução de um Latossolo sob sistema plantio direto. Ciência Rural, Santa Maria, v. 37, n. 1, 110-117. 2007. https://doi.org/10.1590/S0103-84782007000100018