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Surface Reapplication of Lime and Gypsum on Maize Cultivated Sole and Intercropped with *Urochloa*

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ABSTRACT
The aim of this experiment was to study the lime and gypsum reapplied on surface and their impacts on maize crop under the sole and intercropped systems. The experiment is being developed in a dystrophic Oxisol, since 2011, and arranged in a randomized blocks design, in split-split plots, with four replications. As treatments in the plots, the maize was installed in two cropping systems: sole and intercropped with *Urochloa*. For the subplots, we used four doses of lime (0, 2000, 4000, and 6000 kg ha^{-1}) and four doses of gypsum (0, 1500, 3000, and 4500 kg ha^{-1}) distributed at random in the sub-subplots. The combination of intermediate doses of lime and gypsum resulted in higher foliar Ca content. The grain yield increased with the combination of lime and gypsum. The maize when cultivated in intercropped system is more productive, with a point of maximum for dolomitic lime of 3031 kg ha^{-1}.

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Cropping systems; lime and gypsum application; mineral nutrition

Introduction

Soil acidity is one of the factors that mostly limit the development and reduce the productive potential of crops in the large producing regions of Brazil, the Cerrado. Soils of tropical regions present high weathering, which results in problems of acidity, low cation exchange capacity (CEC), and base saturation, in addition to presenting high contents of toxic elements, such as exchangeable aluminum (Al^{3+}) and manganese (Mn^{2+}) (Bottega et al. 2013). Nutrient limitation causes physiological disorders in plants, severely affecting their productive yield. In this regard, the correction of soil acidity is fundamental to increase its productive capacity (Costa et al. 2015; Soratto, Crusciol, and Mello 2010).

Another problem associated with the surface application and low lime mobility in the soil is the correction in the subsurface, which limits the root development and, consequently, water and nutrients absorption by plants (Carvalho et al. 2013); that is, agriculture is still carried out on a small layer of soil. Thus, the crop is susceptible to dry spell, which could compromise the entire productivity or even occur dosage of lime beyond ideal on the surface that denotes problems with cationic micronutrient deficiency (Silveira and Campos 2017).

In this context, the application of agricultural gypsum, a by-product of phosphoric acid production, basically composed of calcium sulfate, is an alternative in the supply of Ca in depth and to reduce the contents of Al^{3+}, limiting its toxic effect on root development (Silva et al. 2015). Gypsum, therefore, has been used as a complementary input to lime, mainly because lime presents low soil

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mobility (Caires, Joris, and Churka 2011). This input is used because it presents higher solubility, moving through the soil profile by means of percolation with water (Carvalho et al. 2013). On the other hand, the method and application of gypsum dose along with lime to provide greater benefits for the system is still questionable, mainly in the areas of Cerrado.

Based on the above, the objective of this experiment was to study the effect of surface reapplication of lime and/or gypsum on maize cultivated sole and intercropped, in clayey soil under no-tillage system.

Material and methods

The experiment is being developed since 2011 in an experimental area which belongs to the Universidade Estadual Paulista (UNESP), Faculty of Engineering, Ilha Solteira, SP, located in the municipality of Selvíria, MS, situated 20°20′53” South latitude and 51°24′02” West longitude of Greenwich, with an altitude of 335 m, approximately. The climate in this region is of the type Aw, defined as tropical wet with the rainy season in the summer and dry in the winter, with temperature and annual average precipitation of 25 °C and 1313 mm (average of the last 15 years), respectively (Portugal, Peres, and Rodrigues 2015). The climatic data relating to the period of conduction of the experiment are shown in Figure 1.

Before the installation of the no-tillage system, in the area that has water supplementation by a center pivot, winter beans were grown by conventional tillage (one plowing and two harrowing) soon after soil correction with dolomitic lime in order to increase the base saturation to 60%. After the bean crop cycle, in the experimental area, it was cultivated with soybean. In the agricultural years of 2009–2010 and 2010–2011 maize/soybean and maize/soybean were cultivated, respectively. In the agricultural years of 2011–2012, 2012–2013, 2013–2014, 2014–2015, and 2015–2016, the following

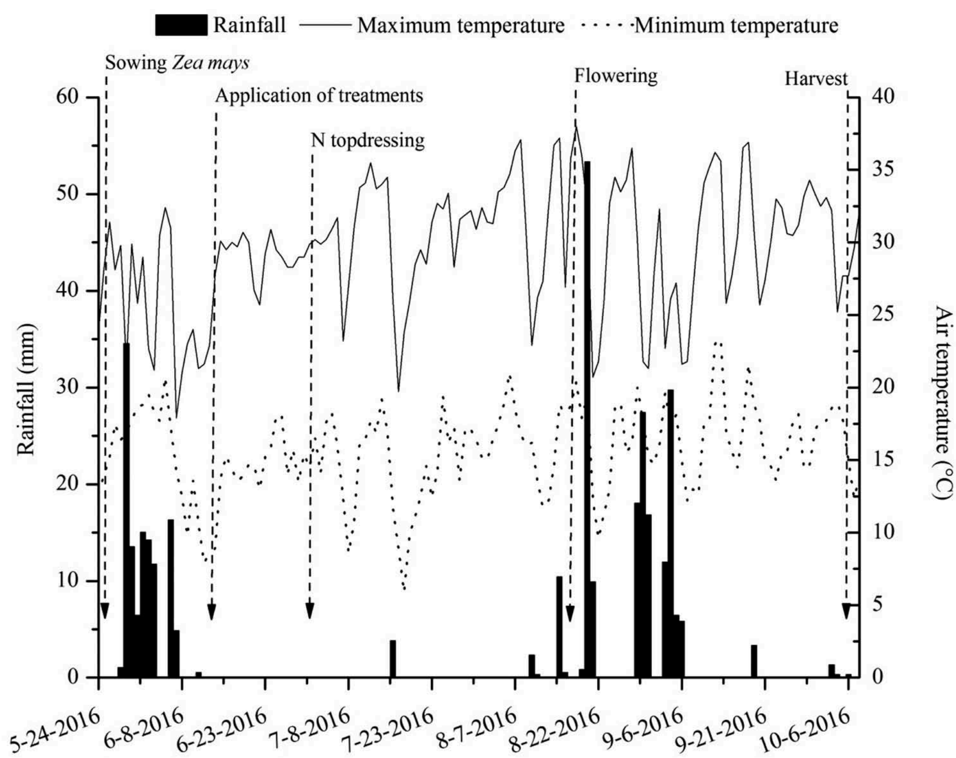

Figure 1. Data of rainfall, maximum and minimum temperatures of the air referring to the period of the experiment conduction.

crops were cultivated in autumn–winter and spring–summer period: maize (application of lime and gypsum doses)/soybean, bean/maize, maize/soybean, bean (reapplication of lime and gypsum doses)/ maize, and maize/soybean, respectively.

This experiment is the continuation of a study started in the agricultural year of 2011–2012, maintaining the same treatments of lime and gypsum application, at no-tillage with crop rotation/ succession. In the 2016–2017 crop season, lime and gypsum doses were reapplied on the autumn–winter crop. According to the current nomenclature, the soil of the experimental area is classified as a clayey dystrophic Oxisol (LVd) (Embrapa 2013). Before the installation of the experiment in the field, soil sampling was carried out on the layer 0–0.20 m for chemical analysis, whose results were as follows: P (resin): 8 mg dm^{-3}, organic matter (OM): 24 g dm^{-3}, pH (calcium chloride; $CaCl_2$): 4.7, K: 1.5 $mmol_c$ dm^{-3}, calcium (Ca): 12 $mmol_c$ dm^{-3}, magnesium (Mg): 9 $mmol_c$ dm^{-3}, H+Al: 34 $mmol_c$ dm^{-3}, SB: 22.5 $mmol_c$ dm^{-3}, CEC: 56.5 $mmol_c$ dm^{-3}, and V%: 39.8. In the analysis of soil texture in the layers of 0–0.20 and 0.20–0.40 m, the results were as follows: 484 and 525 g kg^{-1} for clay content, 100 and 101 g kg^{-1} for silt content, and 416 and 374 g kg^{-1} for the sand content, respectively.

The experimental delineation used was the random blocks design in sub-subplots, with four replications. The plots were 14 m wide and 40 m long, comprising a total area of 560 m^2. As treatments in the plots, the maize was installed in two cropping systems: sole and intercropped with *Urochloa*. For the subplots, we used four lime doses (0, 2000, 4000, and 6000 kg ha^{-1}) and four gypsum doses (0, 1500, 3000, and 4500 kg ha^{-1}) distributed simultaneously at random in the sub-subplots. In this regard, each sub-subplot was 10 m long by 3.5 m wide, totaling an area of 35 m^2 each. A sampling of lime and gypsum was carried out prior to calculations, where the water content in these inputs was determined for the correct application of the quantity, considering both inputs with 0% of water content. The physical and chemical characteristics of the inputs used are RPTN: 85%, Ca: 30%, Mg: 7.2% for lime, and Ca: 22% and S: 17% for gypsum.

Maize sowing was carried out on 24 May 2016. The triple hybrid DKB 350 PRO was used, at a row spacing of 0.45 m, with an expected population of 65,000 plants per hectare (3.25 seeds m^{-1}) considering a germination of 90%. Sowing fertilization was based on the analysis of soil previously removed from the experimental area, consisting of 250 kg ha^{-1} of formulation 08–28-16 (Raij et al., 1997). The sowing of *Urochloa brizantha* cv. Marandu used in intercropped occurred simultaneously to maize, with the use of the third sowing box specifically for this purpose. Thus, broadcast seeding was applied and incorporated by the movement of the soil in the sowing line, carried out by the planter. Seeds were used at the rate of 12 kg ha^{-1}, taking into account a crop value of 34%.

Maize and *Urochloa brizantha* cv. Marandu emergence occurred at 6 and 9 days after sowing (DAS), respectively. On 14 June 2016, 15 days after emergence (DAE), lime and/or gypsum doses were reapplied on the surface of the already installed crop, thus, not occurring the risk of contamination of the plots by lime and gypsum by tractor wheel at the moment of sowing. Top dressing was carried out on the occasion of the fourth expanded leaf (stage V_4 of the crop) on 1 July 2016, that is, 32 DAE. Nitrogen fertilization was 150 kg ha^{-1}, using urea as a source of nitrogen (45% of N). The fertilization was carried out manually and after fertilizer application, a center pivot irrigation was performed, applying water depth to approximately 10 mm, to reduce losses by volatilization. Phytosanitary management was performed according to the crop needs. The maize harvest was done on 8 October 2016 (137 DAE).

In the flowering stage of maize, leaf samples were collected to determine the nutrient concentration, which was performed according to the method proposed by Ambrosano et al. (1997). All of the samples were dried in a forced air oven at 65 °C for 72 h. The plants were weighed and the leaves ground (to pass a 40-mesh stainless steel screen) and analyzed to determine the nutrient concentration according to the methods described by Malavolta, Vitti, and Oliveira (1997). All of the macronutrients [phosphorus (P), K, Ca, Mg, and sulfur (S)], except nitrogen (N), were extracted by nitroperchloric digestion. Nitrogen was extracted using a sulfuric acid (H_2SO_4) extract solution and determined by the Kjeldahl distillation method. From the digested solution, P and S were determined by colorimetry and turbidimetry methods, respectively, and, K, Ca, and Mg were determined by atomic absorption spectrophotometry.

The results were submitted to the Shapiro–Wilk normality test, followed by the analysis of individual variance ANOVA by F test ($p \leq 0.05$), and when a significant difference was verified, the averages were compared by the Tukey test ($p \leq 0.05$) for the qualitative factor (systems) and polynomial regression analysis ($p \leq 0.05$) for the quantitative factors (lime and gypsum doses). The analysis was performed using AGROESTAT software.

Results and discussion

Foliar macronutrients

With regard to foliar N content, the significant effect of causal factors studied in an isolated manner was noted (Table 1). In relation to the effect of the system, it was verified that the maize cultivated intercropped provided higher foliar N content in relation to the sole, presenting 32.00 and 31.29 g kg^{-1}, respectively; however, both the contents were within the range considered of sufficiency for the maize crop (27.5–32.5 g kg^{-1}) (Malavolta, Vitti, and Oliveira 1997). Intercropped system provided greater N content in relation to the sole system since *Urochloa*, in general (especially for *U. humidicola*), presents an inhibitor compound of biological nitrification (Subbarao et al. 2009). These researchers have managed to isolate, from the roots of *U. humidicola*, the inhibitor compound of dominant nitrification, which is responsible for 60–90% of the suppressive activity of *U. humidicola* in nitrification. This compound was named “Brachialactone,” and it acts on the suppression of Nitrosomonas activity (Jones 2013). Due to the inhibitory action of this compound, even at the lower expression in *Urochloa brizantha* cv. Marandu, side dressing nitrogen fertilization could have been greater utilization, reducing losses and ensuring a higher supply of this element to the maize crop. Due to the reduction of nitrification, nitrogen in the form of NH_4^+ is predominant in the soil, which

Table 1. F values and foliar content averages for N (nitrogen), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) of maize second crop according to the treatments. Selvíria - MS, Brazil, 2016.

	N	P	K	Ca	Mg	S
TREATMENTS			(g kg^{-1})			
SYSTEM (S)						
Sole crop	31.29 b	2.80	24.86	3.86	3.39	1.66
Intercropped	32.00 a	2.79	24.76	4.81	3.53	1.78
LIME (kg ha^{-1}) (L)						
0	30.47	2.79	24.51	3.96	3.40	1.67
2000	32.11	2.80	24.96	4.47	3.41	1.73
4000	32.10	2.80	25.72	4.99	3.60	1.78
6000	31.91	2.77	24.05	3.93	3.44	1.69
GYPSUM (kg ha^{-1}) (G)						
0	31.32	2.80	24.04	3.88	3.38	1.63
1500	31.67	2.77	26.12	4.61	3.51	1.71
3000	32.28	2.79	25.36	4.60	3.52	1.82
4500	31.33	2.81	23.72	4.26	3.44	1.71
F test						
S	8.78 **	0.36 ns	0.03 ns	2.74 ns	24.38 **	38.23 **
L	11.13 **	0.43 ns	1.53 ns	30.20 **	10.41 **	6.69 **
G	3.65 *	0.84 ns	2.10 ns	14.21 **	5.15 **	16.15 **
S × L	0.47 ns	0.29 ns	1.56 ns	4.50 **	3.14 **	0.87 ns
S × G	0.58 ns	0.32 ns	2.17 ns	1.35 ns	2.68 ns	5.62 **
L × G	1.47 ns	1.91 ns	1.32 ns	5.25 **	2.03 ns	1.49 ns
S × L × G	1.44 ns	0.93 ns	1.88 ns	1.02 ns	1.67 ns	1.86 ns
Overall average	31.64	2.79	24.81	4.33	3.46	1.72
CV. (%)	4.24	3.67	9.29	11.87	4.66	6.25

ns, * and ** is, respectively, not significant, significant at ($P \leq 0.05$) and ($P \leq 0.01$) probability by F test
Averages followed by the same letters in the column do not differ by Tukey’s test at the 5% significance level.

is absorbed by the plants with lower ATP consumption according to the decrease of assimilatory nitrate reduction (Subbarao et al. 2015).

Regarding lime and gypsum, the averages were adjusted to quadratic equations (Figure 2(a,b)). For lime (Figure 2(a)), it was verified that the dose of maximum technical efficiency (DMTE) to the foliar N content occurred around 3947 kg ha^{-1}, which provided maximum N content of 32.31 g kg^{-1}. It is important to emphasize that Mg is the central atom of the chlorophyll, and this compound is formed by four atoms of N; that is, with the release of Mg from the dolomitic lime used, it may have increased the N use, converting into chlorophyll (Wang et al. 2014). In relation to gypsum doses (Figure 2(b)), N content reached 32.06 g kg^{-1} in DMTE of 2402 kg ha^{-1}. The increase in N content coming from gypsum application can be associated with a chemical improvement of soil in subsurface layers, presenting higher N absorption, especially in NO_3^- form (Rosolem, Foloni, and Oliveira 2003). All N obtained (32.31 and 32.06 g kg^{-1} for the lime and gypsum, respectively) are within the range considered ideal for the crop according to the recommendations of Malavolta, Vitti, and Oliveira (1997).

Foliar contents of P and K were not altered by the treatments used, but P was in accordance with the range ideal for the crop (2.5–3.5 g kg^{-1}). In relation to K, the average content obtained (24.81 g kg^{-1}) is above the range considered adequate for maize crop (17.5–22.5 g kg^{-1}), according to Malavolta, Vitti, and Oliveira (1997).

For Ca content, a significant interaction between the factors lime × gypsum doses (Figure 3(a,b)) and systems × lime doses was observed (Figure 3(c)). In the unfolding of lime within each gypsum dose (Figure 3(a)), it was verified that in the absence of gypsum application, the maximum Ca content (4.28 g kg^{-1}) was obtained in lime DMTE of 3490 kg ha^{-1}. In the subsequent dose (1500 kg ha^{-1} of gypsum), lime DMTE of 3307 kg ha^{-1} obtained provided Ca content close to 5.25 g kg^{-1}. In gypsum dose of 3000 kg ha^{-1}, DMTE lime obtained was 3191 kg ha^{-1}, which provided Ca content close to 5.31 g kg^{-1}.

In the unfolding of gypsum within each lime dose (Figure 3(b)), in the absence of lime application, Ca content increased linearly by increasing the gypsum doses (4.53 g kg^{-1}), while the use of 2000, 4000, and 6000 kg ha^{-1} the data were adjusted to quadratic equations with DMTE and maximum Ca content in 2141, 2782, and 1880 kg ha^{-1} of gypsum and 5.03, 5.50, and 4.29 g kg^{-1}, respectively.

In the unfolding of systems within each lime dose (Figure 3(c)), it was observed that for the sole system, the DMTE obtained was 3233 kg ha^{-1} and for intercropped it was 3045 kg ha^{-1}, and it was possible to observe a reduction in dose required to obtain the maximum point of the curve. Foliar Ca contents for sole and intercropped systems in their respective DMTE were 4.16 and 5.47 g kg^{-1},

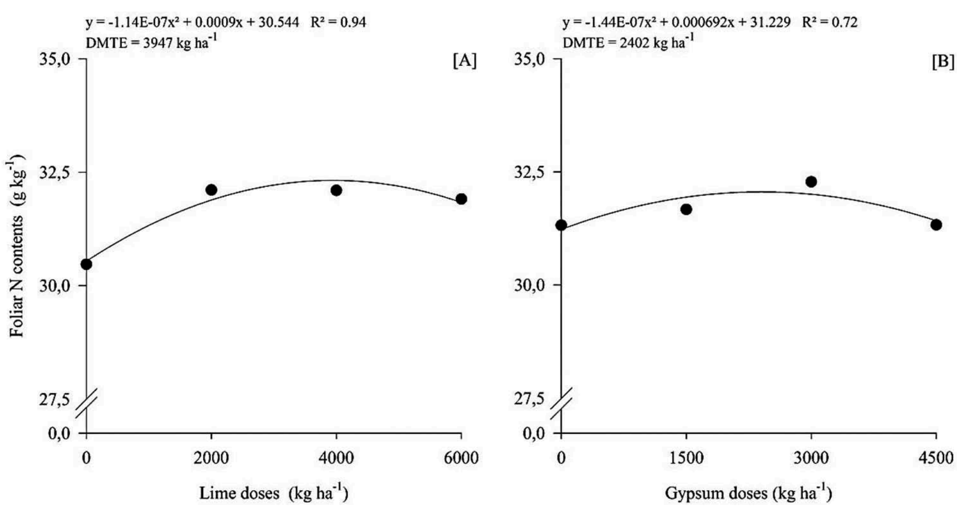

Figure 2. N foliar content according to lime (A) and gypsum (B) doses reapplied on the soil. Selvíria - MS, Brazil, 2016.

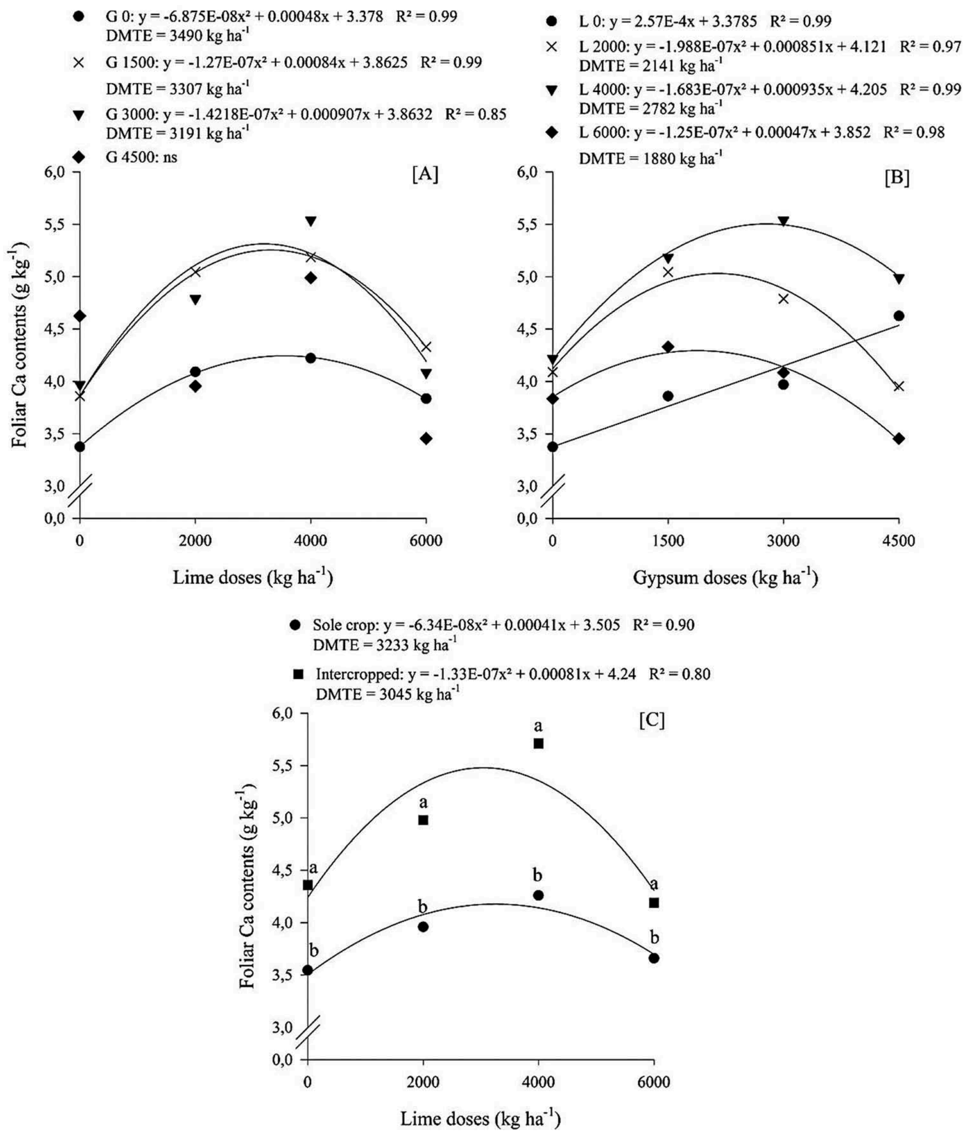

Figure 3. Unfolding of the significant interaction between lime and gypsum doses (A and B) and for systems and lime doses (C) to calcium foliar content. Selvíria - MS, Brazil, 2016.

respectively. It is also noticeable that in all lime doses, intercropped system outperformed sole system. This fact is associated with a greater movement capacity of lime in the soil profile by dragging the soil by the abundant root growth of *Urochloa*, being able to reach greater depths and the element is absorbed by a greater volume of roots (Junior et al. 2013).

Foliar Ca content generally exceeded the recommended range for the crop (2.5–4.0 g kg^{-1}); however, it did not negatively influence its development. It can also be inferred that with the genetic improvement, that is increasingly being studied in order to increase the resistance to biotic and abiotic factors, transgenia, as well as an increase in productivity in more intensive cropping systems, the requirement for nutrients is increased with the passage of time (Bender et al. 2013). Ca is indispensable for the grain pollen germination and pollen tube growth. And it is a cell wall component and also plays an important role in the ionic absorption (Araújo, Santos, and Camacho 2013).

For Mg content, there was a significant effect for gypsum doses (Figure 4(a)) and a significant interaction between systems × lime doses, with the unfolding shown in Figure 4(b).

Despite not presenting MgO in its composition, gypsum provided an increase in foliar Mg content, obtaining DMTE of 2940 kg ha^{-1} and foliar content of 3.52 g kg^{-1}. Although gypsum is associated with greater cation leaching, mainly Ca and Mg in the deeper layers (Caires, Joris, and Churka 2011), in this case, the period elapsed until the foliar collection may have been short, not reflected in a reduction in its absorption. The load of Mg may have occurred from the more superficial layers and taken to a layer a little lower down, coinciding with the most active absorption zones of the roots (Epstein and Bloom 2006). For the unfolding (Figure 4(b)), the systems were adjusted to quadratic equations, and for maize cultivated sole and intercropped, lime DMTE was 3200 and 3933 kg ha^{-1}, respectively, and the maximum Mg contents obtained for these optimum doses were 3.44 and 3.57 g kg^{-1}, respectively. It is also possible to observe that the foliar Mg contents were higher in intercropped associated with the two largest lime doses used. Dragging promoted by the aggressive root system of *Urochloa* may have provided greater displacement of lime on soil profile, ensuring greater absorption of this element by the deepest roots. For this nutrient, the contents found are within the range considered ideal for the crop (2.5–4.0 g kg^{-1}) according to the recommendations of Malavolta, Vitti, and Oliveira (1997). The functions of this element in plants are related mainly to its ability to compose the chlorophyll molecule, and it is an important enzyme activator, controlling numerous physiological processes in plants (Araújo, Santos, and Camacho 2013).

Despite numerous studies claim that magnesium leaching can occur, and consequently, reduction in foliar content of this nutrient, in the present experiment, when gypsum is used in conjunction, this effect was not observed, and its concentration in tissues was similar in all treatments. This fact can be related to the soil clayey texture, retaining the greater part of these cations in its CTC, thus, allowing higher gypsum doses (Caires, Joris, and Churka 2011).

In relation to foliar S content, isolated effect of lime doses (Figure 5(a)) and the significant interaction between systems and gypsum doses were verified (Figure 5(b)). Maximum S content obtained in relation to the lime doses was 1.76 g kg^{-1}, obtained in DMTE of 3333 kg h^{-1}. The

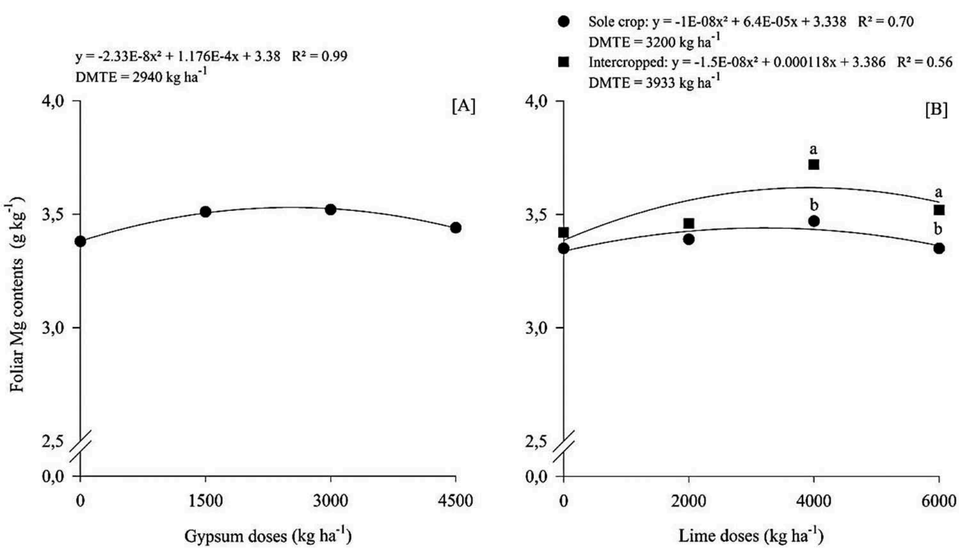

Figure 4. Mg foliar content according to gypsum doses reapplied on soil (A) and unfolding of significant interaction between systems and lime doses (C). Selvíria - MS, Brazil, 2016.

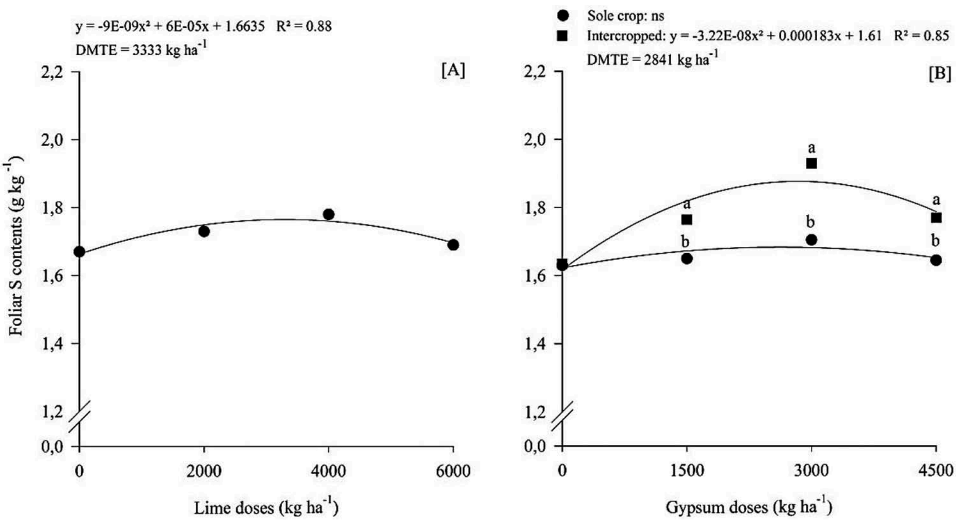

Figure 5. Mg foliar content according to lime doses reapplied on soil (A) and unfolding of significant interaction between systems and gypsum doses (B). Selvíria - MS, Brazil, 2016.

binding energy of SO_4^{-2} to functional groups of soil is smaller in relation to phosphate, being able to be displaced by other anions. Thus, the total quantity of sulfur and the adsorption capacity of SO_4^{-2} are high in soils with higher clay contents, even though its retention can be reduced by lime and phosphate application (Rheinheimer et al. 2005).

In the unfolding of the significant interaction for foliar S content (Figure 5(b)), it was noted a statistically significant only for the intercropped system, in such a way that associated with DMTE of 2841 kg ha^{-1}, the values of S reached values close to 1.87 g kg^{-1}. In general, maize cultivated in intercropped with *Urochloa* provided higher foliar S content compared to sole when gypsum was used. Gypsum alone presents relatively high solubility in water, facilitating the percolation of this input through the layers of soil, and combined with the fact of *Urochloa* by means of its root system potentiates this effect; the plants can benefit even more on the absorption of this element.

In addition to improving the root exploration by neutralization of exchangeable aluminum, ypsum releases calcium and sulfur. These elements can be absorbed by plants in the soil, fact of utmost importance, since Cerrado soils have low concentrations of these elements in natural conditions (Amaral et al. 2017). S content is within the reference range of sufficiency (1.5–2.0 g kg^{-1}).

Quantities of nutrients absorbed and exported are not constant within each crop, varying according to cultivar, climatic conditions, type of management implemented, and technology employed, as well as the level of soil fertility (Resende et al. 2012). The predefined standards of maize nutritional requirement, and many other crops in Brazil and several other countries, are outdated, since these types of research were conducted more than two decades ago and still remain as standards in several official recommendation tables (Von Pinho et al. 2009). On the other hand, it is noticeable that these requirements have increased as higher productivity indices were acquired and increasingly early-maturing cultivars were placed in the market (Bender et al. 2013).

Reproductive components of maize

Significant influence of treatments used was verified for all components of maize production and productivity (Table 2). In relation to the number of rows per ear, the cropping system of maize provided significant values, and maize intercropped with *Urochloa* promoted higher values than sole. It was also verified that the lime doses also influenced significantly by adjusting to a quadratic

Table 2. F values and averages for the number of rows per ear (NRE), number of grains per row (NGR), number of grains per ear (NGE), weight of 100 grains (W100G), and grain yield (PROD) of maize second crop according to the treatments. Selvíria - MS, Brazil, 2016.

TREATMENTS	NRE	NGR	NGE	W100G (g)	PROD (kg ha^{-1})
SYSTEM (S)					
Sole crop	14.97 b	27.54 b	411	26.39	7936
Intercropped	15.23 a	28.65 a	438	27.40	9896
LIME (kg ha^{-1}) (L)					
0	14.62	27.36	405	26.66	8160
2000	15.29	28.00	424	27.51	9221
4000	15.28	29.08	447	27.55	10183
6000	15.23	27.93	423	25.85	8099
GYPSUM (kg ha^{-1}) (G)					
0	15.02	27.45	414	26.13	8006
1500	15.08	28.49	430	27.60	9497
3000	15.36	28.44	437	27.04	9382
4500	14.95	27.99	418	26.80	8778
F test					
S	5.19 *	24.74 **	37.28 **	3.47 ^{ns}	106.07 **
L	8.09 **	8.85 **	15.01 **	2.27 ^{ns}	27.03 **
G	2.46 ^{ns}	4.46 **	5.63 **	1.27 ^{ns}	12.90 **
S × L	1.36 ^{ns}	2.41 ^{ns}	4.65 **	0.34 ^{ns}	4.29 **
S × G	0.24 ^{ns}	2.91 ^{ns}	0.41 ^{ns}	0.91 ^{ns}	1.31 ^{ns}
L × G	0.91 ^{ns}	1.89 *	1.20 ^{ns}	0.44 ^{ns}	4.40 **
S × L × G	1.22 ^{ns}	1.49 ^{ns}	1.32 ^{ns}	0.95 ^{ns}	0.99 ^{ns}
Overall average	15.11	28.10	425	26.90	8916
CV. (%)	4.25	4.51	5.90	11.31	12.07

^{ns}, * and ** is, respectively, not significant, significant at (P ≤ 0.05) and (P ≤ 0.01) probability by F test
Averages followed by the same letters in the column do not differ by Tukey's test at the 5% significance level.

equation, with DMTE of 4011 kg ha^{-1}, obtaining approximately an average of 15.37 rows per ear (Figure 6). Intercropped system promoted higher utilization of N and cations absorption essential to the development of the crop, and these factors may have contributed in an effective way in the ear differentiation, providing greater average of rows per ear.

With regard to the number of grains per row, it was noted that the system influenced in an isolated manner for this character and also a significant interaction between the causal factors silicate × gypsum doses was verified (Figure 7). The number of grains per row was superior on maize cultivated intercropped than sole. This fact is associated with the possible greater utilization of N applied in top-dressing, once the *Urochloa* releases to the soil the substance Brachialactone, inhibiting the nitrification and consequently, increasing the efficiency of the use of this important nutrient, which interferes in the plant growth and photosynthetic rate (Jones 2013).

In the unfolding of lime within each gypsum dose (Figure 7(a)), for the absence of gypsum application, an increasing linear adjustment was observed for the number of grains per row with increment in lime doses, presenting an average of 28.35 grains. However, at gypsum dose of 4500 kg ha^{-1} associated with lime DMTE (3200 kg ha^{-1}), the average value of 31.4 grains per row was obtained.

In the unfolding of gypsum doses within each lime dose (Figure 7(b)), the best combination of input doses used was 4000 kg ha^{-1} of lime associated with gypsum DMTE (3849 kg ha^{-1}), presenting approximately 30 grains of maize per row of the ear. The increase in the number of grains in maize may be related to higher supply of Ca from lime and gypsum, which is an essential element in the grain pollen germination and, consequently, in the formation of the pollen tube (Araújo, Santos, and Camacho 2013). This element also participates in the formation of spindle fibers in cell division. This fact is indispensable in the reproductive phase of crops (Silva et al. 2015).

In relation to the number of grains per ear, in the unfolding (Figure 8(a)), it was observed that, regardless of the lime dose used, in maize associated with intercropping with *Urochloa brizantha* cv. Marandu, the results were higher compared to maize cultivated sole. Regarding the unfolding of

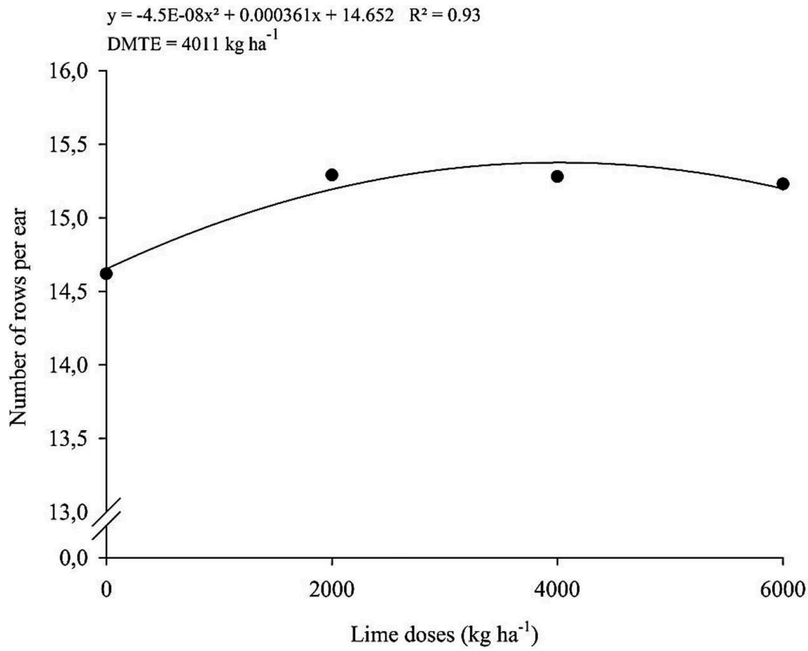

Figure 6. Number of rows per ear of maize according to lime doses reapplied on the soil. Selvíria - MS, Brazil, 2016.

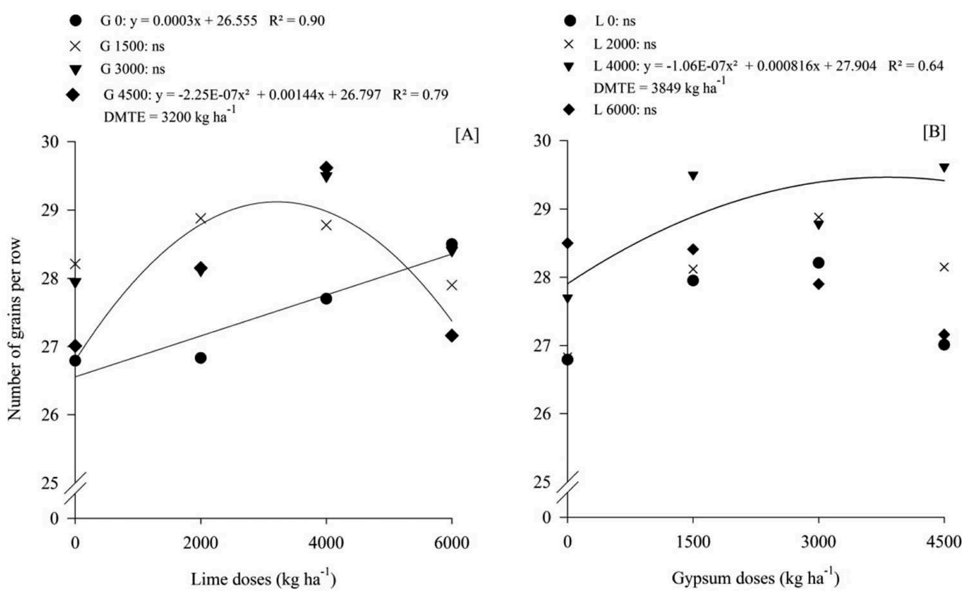

Figure 7. Unfolding of the significant interaction between lime and gypsum doses for the number of grains per row. Selvíria - MS, Brazil, 2016.

systems within each lime dose, only the consortium had significant results, presenting a DMTE of 3791 kg ha^{-1}, in which it obtained an approximate average of 460 grains per ear. Proper nutrition provided by the lime application and the benefits of the consortium benefited the crop development, reflecting the number of rows per ear and grains per row, which directly influence the number of grains per ear.

For the number of grains per ear, it is noted that gypsum doses alone influenced this component (Figure 8(b)) and a significant interaction between systems × lime doses was verified (Figure 8(b)). For the gypsum doses (Figure 8(a)), the averages were adjusted to a quadratic equation, obtaining DMTE of 2350 kg ha^{-1} and a maximum yield of 435 grains per ear. Gypsum has the potential to provide Ca and S, essential elements in the process of germination of the pollen grains, the formation of the pollen tube, and consequently, the formation of grain (Araújo, Santos, and Camacho 2013).

In relation to the weight of 100 grains, there was no significant difference for any of the causal factors studied. This fact may be related to the favorable water supply during the grain filling promoted by supplemental irrigation and, also because it is an intrinsic characteristic of the cultivar, without large fluctuations in values (Argenta and Sangoi 2001). Regarding grain yield, a significant interaction between lime × gypsum doses (Figure 9(a, b)) and systems × lime doses (Figure 9(c)) was verified.

In the unfolding of lime doses within each gypsum dose (Figure 9(a)), with the exception of the highest gypsum dose, others presented significance for the unfolding, and with the absence of gypsum, the averages adjusted to a quadratic equation, obtaining lime DMTE of 3560 kg ha^{-1}, and in this dose, the averages obtained a yield of 8763 kg ha^{-1}. At gypsum dose of 1500 kg ha^{-1}, the combination with lime DMTE of 3184 kg ha^{-1}, the productivity reached values close to 10732 kg ha^{-1}. It was noted that with the increase in gypsum dose, the dose of maximum efficiency of lime was reduced. When gypsum dose of 3000 kg ha^{-1} was used, the optimum dose of lime presented the same previous pattern, reducing even more, since DMTE for lime was 3175 kg ha^{-1}. In this combination of doses, productivity reached approximately 10738 kg ha^{-1}, presenting low difference in relation to the previous combination.

In the unfolding of gypsum doses within each lime dose (Figure 9(b)), in the absence of lime, a linear increase in the average of productivity was observed by increasing of gypsum doses, producing up to 9349 kg ha^{-1}. With the combination of lime dose of 2000 kg ha^{-1}and DMTE of gypsum (2146 kg ha^{-1}), the average obtained for grain yield was close to 10382 kg ha^{-1}. For the lime dose of 4000 kg ha^{-1}, the best combination was obtained in the gypsum dose of 2815 kg ha^{-1}, in a way that at this combination, the productivity average reached 11134 kg ha^{-1}. At the highest lime dose, gypsum DMTE was close to 1885

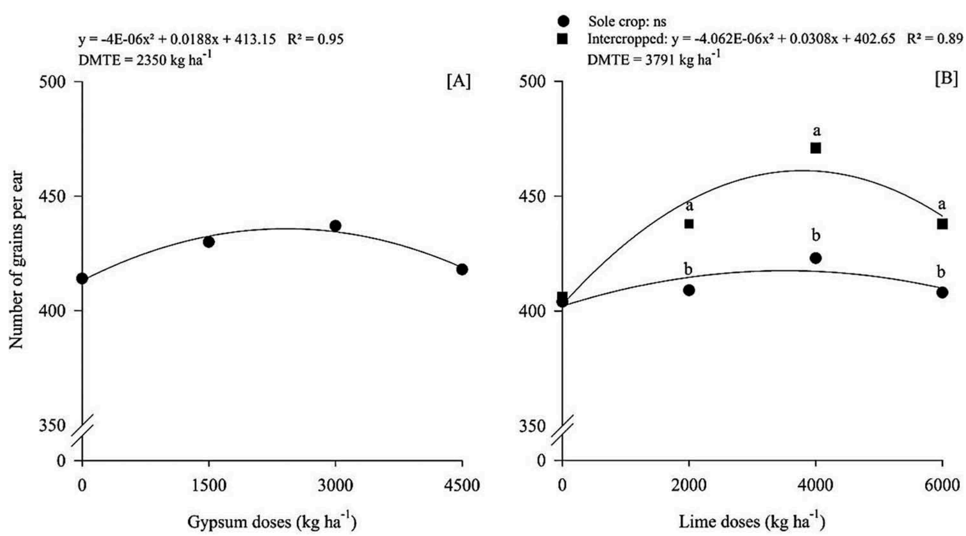

Figure 8. Number of grains per ear of maize according to gypsum doses reapplied on soil (A) and unfolding of significant interaction between systems and lime doses (C). Selvíria - MS, Brazil, 2016.

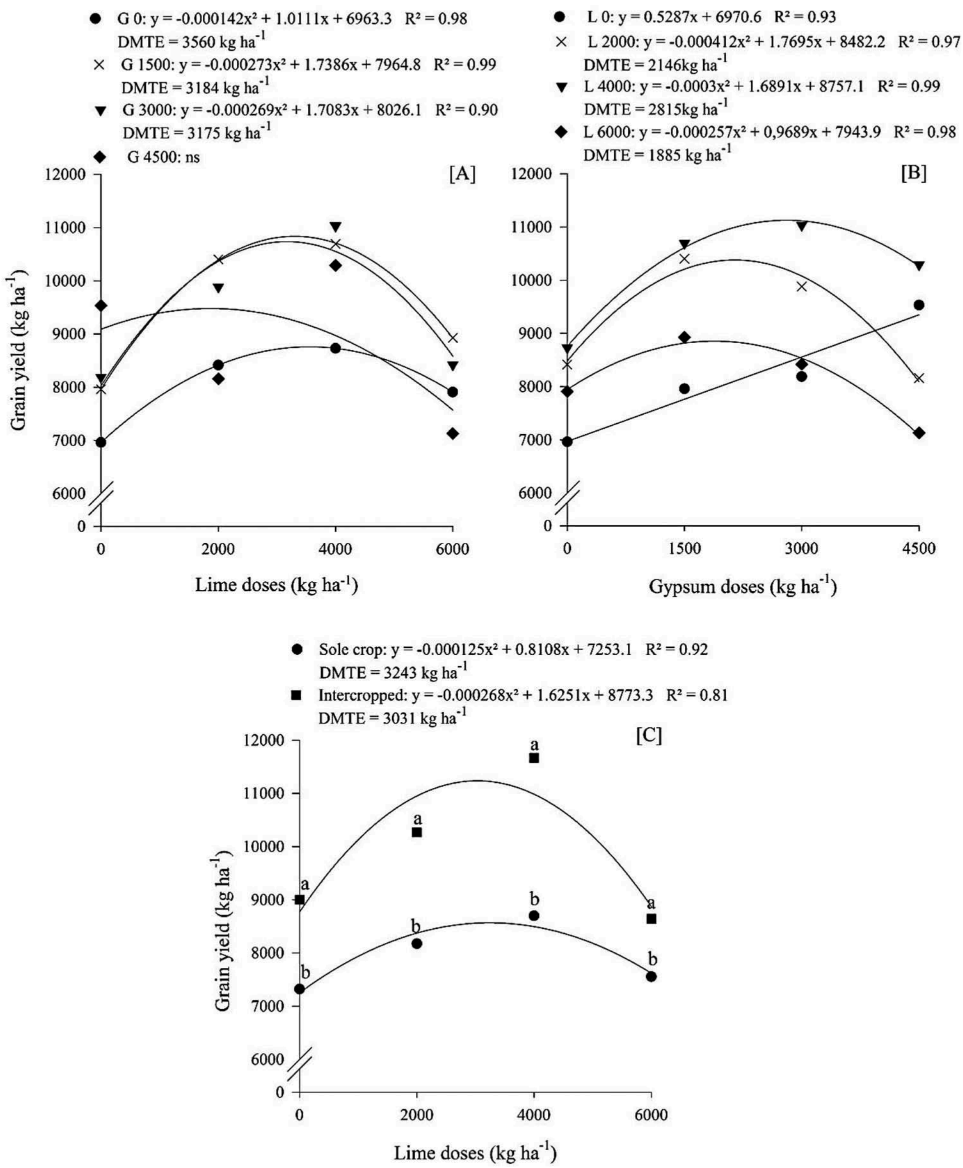

Figure 9. Unfolding of the significant interaction between lime and gypsum doses (A and B) and for systems and lime doses (C) for grain yield. Selvíria - MS, Brazil, 2016.

kg ha^{-1}, the smallest among those presented. This association of doses, the maximum productivity of grains obtained was 8857 kg ha^{-1}.

The increase in productivity obtained by a combination of lime and gypsum is due to the greater availability of nutrients in the soil profile, such as Ca, Mg, and S, and by the possible reduction in the contents of Al^{3+}, providing chemical conditions more favorable to root development, absorption of water, and nutrients (Zandoná et al. 2015).

In relation to the unfolding of systems × lime doses (Figure 9(c)), maize cultivated sole presented higher productivity when associated with lime DMET of 3243 kg ha^{-1}, so that for maize intercropped with *Urochloa* the optimum dose obtained was 3031 kg ha^{-1}. In intercropped, the optimum lime dose was reduced and the productivity was increased. For maize cultivated sole, the maximum grain yield obtained was 8567 kg ha^{-1} and for maize intercropped 11236 kg ha^{-1}, that is, 23.75% increase, in addition to reducing the lime doses to be used. In general, it is also noticeable that the productive capacity of maize cultivated intercropped was greater in relation to sole, regardless of the lime dose to be used.

Maize cultivated intercropped with *Urochloa* provided superior condition to maize cultivated sole, where the utilization of N applied to the system and the availability of Ca and Mg, in addition to the possible greater acidity correction and neutralization of Al^{3+} in the deeper layers of soil, provided a better development of crop, being able to exploit its productive potential.

Conclusions

The combination of intermediate lime (3000–4000 kg ha^{-1}) and gypsum doses (2700–3000 kg ha^{-1}) provides higher foliar Ca content, besides that intercropped system also increases the foliar Ca content in maize when associated with a 3045 kg ha^{-1} lime dose.

Intercropped system when associated with the reapplication of higher lime doses increases the foliar Mg content and when associated with gypsum, promotes an increase in S content.

Grain yield is positively influenced by the reapplication of lime and gypsum, and the combination of the lime dose of 4000 kg ha^{-1} with gypsum doses between 1500 and 3000 kg ha^{-1} provides the highest yield. Maize when intercropped with *Urochloa brizantha* cv. Marandu, associated with lime dose (3031 kg ha^{-1}), promoted better soil conditions and consequently higher maize nutrition, resulting in higher grain yield.

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