Yield and mineral nutrition of soybean, maize, and Congo signal grass as affected by limestone and slag

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Abstract – The objective of this work was to evaluate the efficiency of superficial application of limestone and slag, and their effects on soil chemical attributes and on yield and mineral nutrition of soybean, maize, and Congo signal grass (*Urochloa ruziziensis*). The experiment was carried out in a Rhodic Hapludox under no tillage system. The treatments consisted of the use of limestone or slag (silicates of calcium and magnesium) to correct soil acidity, and of a control treatment without the use of soil correctives. Rates were calculated in order to raise soil base saturation up to 70%. Soybean was sown in November 2006 and maize in December 2007. Congo signal grass was sown right after the harvests of soybean and maize, and it was cropped during the off-seasons. Soil chemical attributes were evaluated at 6, 12, and 18 months after the application of the corrective materials. Slag is an efficient source for soil acidity correction, being able to raise the exchangeable base levels in the soil profile faster than lime. Both limestone and slag increase dry matter yield of Congo signal grass, and grain yield of soybean and maize. Slag is more effective in improving maize grain yield.

Index terms: no tillage, silicon, soil chemical attributes, superficial liming, subsuperficial acidity, yield components.

Produtividade e nutrição mineral de soja, milho e capim-ruziziensis influenciados por calcário e escória de siderurgia

Resumo – O objetivo deste trabalho foi avaliar a eficiência da aplicação superficial de calcário e escória de siderurgia e seus efeitos nos atributos químicos do solo e na produtividade e nutrição de soja, milho e capim-ruziziensis (*Urochloa ruziziensis*). O experimento foi conduzido em Latossolo Vermelho distroférrico, sob sistema de semeadura direta. Os tratamentos consistiram do uso de calcário e de escória de siderurgia (silicatos de cálcio e magnésio), para corrigir a acidez do solo, e de uma testemunha sem aplicação de corretivos. As dosagens foram calculadas com o intuito de elevar a saturação por bases a 70%. A soja foi semeada em novembro de 2006 e o milho em dezembro de 2007. O capim-ruziziensis foi semeado logo após as colheitas da soja e do milho e foi cultivado durante as entressafras. Os atributos químicos do solo foram avaliados aos 6, 12 e 18 meses após a aplicação dos corretivos. A escória é uma fonte eficiente para correção da acidez do solo e é capaz de aumentar o nível de bases trocáveis no perfil do solo mais rapidamente do que o calcário. Tanto o calcário como a escória aumentam a produção de matéria seca do capim-ruziziensis e a produção de grãos de soja e milho. A escória é mais eficiente em elevar a produtividade do milho.

Termos para indexação: plantio direto, silício, atributos químicos do solo, calagem superficial, acidez subsuperficial, componentes de produtividade.

Introduction

Cerrado is the main biome in central Brazil, reaching about 205 million hectares, which corresponds to 23% of the country (Fageria & Baligard, 2008). Most part of this area (46%) consists of Oxisols, characterized by low fertility, high aluminum saturation, and high P fixation. However, rainfall, temperature, and topography are generally favorable for agriculture.

Soil acidity affects nutrient availability, deficiency and toxicity of chemical elements (Soratto & Crusciol, 2008), and activity of beneficial microorganisms (Moreira & Siqueira, 2006). Limestone is the most commonly used material for acidity correction in Brazil. Due to its limited mobility in soil, liming has major effects in superficial soil layers, mainly in nonmobilized areas, such as under no tillage system (Soratto & Crusciol, 2008).

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Calcium and magnesium silicates also have neutralizing properties and can be used as liming material even more advantageously (Corrêa et al., 2007). Currently, slag is the main source of calcium and magnesium silicate used in agriculture (Demattê et al., 2011). Because of their similar neutralizing power, particle size, and effective correction capacity (ECC) (Alcarde & Rodella, 2003), slag and limestone have the same recommendation methods. However, calcium silicate is 6.78 times more soluble than limestone (Alcarde & Rodella, 2003), and therefore a good option for superficial application in the no tillage system (Corrêa et al., 2007). Some advantages of silicates include a high reaction rate and mobility in the soil profile (Castro et al., 2013), and the fact that silicon is a beneficial element for plant nutrition, which decreases water losses through evapotranspiration (Ma & Yamaji, 2006) and increases tolerance to pests and diseases (Berni & Prabhu, 2003), toxicity of heavy metals and aluminum (Prabagar et al., 2011), and lodging. Moreover, Si turns plants more erect and improve their photosynthetic efficiency (Pulz et al., 2008). Ma & Yamaji (2006) reported that Si supply may improve crop yield stability as a consequence of the higher tolerance to biotic and abiotic stress.

However, compared to limestone, there are few studies on the superficial application of slag for acidity correction in no tillage system. Field research on slag application indicate that this source can be more efficient for correcting acidity in deeper soil layers than limestone (Castro et al., 2013), aqueous lime, and sewage sludge plus quicklime (Corrêa et al., 2007).

Recommendations usually took into account the full incorporation of liming materials into soil in order to maximize their beneficial effects. However, many studies on no tillage system have shown that the effects of superficial liming on correcting subsuperficial acidity may vary according to product dose, particle size, application method, soil type, climate (especially rainfall), tillage system, and time passed after the application (Soratto & Crusciol, 2008).

The objective of this work was to evaluate the efficiency of superficial application of limestone and slag and their effects on soil chemical attributes and on yield and mineral nutrition of soybean, maize, and Congo signal grass (*Urochloa ruziziensis*) under no tillage system.

Materials and Methods

The experiment was carried out during two seasons (2006/2007 and 2007/2008), at Lageado Experimental Farm, Universidade Estadual Paulista, Botucatu, SP, Brazil. Geographical coordinates are 48º 23' W, 22º 51' S, at 765 m altitude. The soil in the area is a deep acid, clayey Rhodic Hapludox (Food and Agriculture Organization of the United Nations, 2006) with 462, 438 and 100 g kg^{-1} of sand, clay and silt, respectively. According to Köeppen's classification, climate is Cwa, which corresponds to tropical altitude with dry winter (April to November), and a hot, wet summer. The long-term (1956–2006) annual temperatures are 26.1°C maximum, and 15.3°C minimum, with 20.7°C average. Average annual rainfall is 1,358.6 mm (Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura, 2012).

Soil chemical attributes (0.00–0.20 m) were determined according to Raij et al. (2001), with the following results: organic matter, 18.2 g dm^{-3}; pH ($CaCl_2$), 4.2; P (resin), 3.6 mg dm^{-3}; Si (CaCl), 6.2 mg dm^{-3}; and K, Ca, Mg, H+Al, Al^{3+}, and cation exchange capacity of 0.76, 11.6, 5.75, 52.8, 4, and 74.9 mmol$_c$ dm^{-3}, respectively; with 24.2% base saturation.

The treatments consisted of the application of limestone (ECC = 90%, CaO = 36%, and MgO = 12%) and slag (Agrosilício; ECC = 80%, CaO = 34%, MgO = 10%, and SiO_2 = 22%) for soil acidity correction. A control treatment without soil correction was also used. Applied rates were calculated in order to raise the soil base saturation up to 70%. Therefore, in October 2006, 3.8 Mg ha^{-1} limestone and 4.1 Mg ha^{-1} slag were applied over previously desiccated (1,800 g ha^{-1} glyphosate) pearl millet (*Penninsetum americanum*) residues (4.0 Mg ha^{-1}).

Soybean (*Glycine max* L. Merrill), cultivar Embrapa 48, was sown on November 29th, 2006, at 0.45 m row spacing, with 22 seeds per meter. Seeds were previously treated with fungicide (vitavax + thiram: 50 + 50 g a.i. per 100 kg of seeds) and inoculant (*Bradyrhizobium japonicum*). Base fertilization consisted of 250 kg ha^{-1} of 04-20-20 NPK formula (Raij et al., 1997). Full flowering took place 45 days after seedling emergence. At that stage, ten plants were sampled for dry matter evaluation. Also, the 3rd leaf with the petiole from 30 plants per plot was sampled (Raij et al., 1997) for macronutrient and Si diagnosis. Soybean was harvested on April 3rd, 2007, and samples were taken to determine yield components (plant population, number of pods per plant, number of grains per pod, and mass of 100 grains) and grain yield (13% moisture content).

Soon after soybean harvest, Congo signal grass (*Urochloa ruziziensis* – Syn. *Brachiaria ruziziensis*) was sown, in order to maintain the soil covered in the off-season, and to provide plant residues for the no tillage system. A sowing density of 10 kg ha^{-1} (25% of cultural value) was used at 0.45 m row spacing, with 2.5 kg ha^{-1} of viable seeds. No fertilization was carried out, and plants were grown freely until November 21st, 2007, when four 0.5 m^2 squares were used for the evaluation of dry matter yield. Plant material, excluding stalks + sheaths, was used for macronutrient and Si diagnosis. Afterwards, plants were desiccated with glyphosate (1,800 g ha^{-1} a.i.; 200 L ha^{-1} application volume).

Maize (*Zea mays* L.), hybrid 2B570, was sown on December 2nd, 2007, at 0.45 m row spacing with three seeds per meter. Seeds were treated with fungicide (vitavax + thiram: 50 + 50 g a.i. per 100 kg seeds). Base fertilization consisted of 300 kg ha^{-1} of the 08-28-16 NPK formula (Raij et al., 1997). Side dressing fertilization took place on January 10th 2008 and consisted of 90 kg ha^{-1} N, mechanically applied as urea, between rows. Full flowering of maize plants occurred 64 days after the seedling emergence. At that stage, 10 plants per plot were sampled for dry matter evaluation. Also, the central third part of 30 leaves was sampled at ear base (Raij et al., 1997) for macronutrients (N, P, K, Ca, Mg and S) and Si diagnosis. Harvest took place on April 1st, 2008, and samples were taken to determine the yield components (plant population, number of ears per plant, number of grains per ear, and mass of 100 grains) and grain yield (13% moisture content).

Right after the maize harvest, Congo signal grass was once more sown, with the same row spacing and seed rate as its previous cultivation. Plants were grown freely until November 20th, 2008, when samples were taken for dry matter evaluation, and macronutrients and Si diagnosis.

Biomass sampled at full flowering of crops was dried in oven at 65ºC until constant weight. Afterwards, leaves were grounded and chemically evaluated as for macronutrients and Si levels, according to procedures described by Malavolta et al. (1997) and Korndörfer et al. (2004), respectively.

Soil chemical characteristics were evaluated at 6 (April, 2007), 12 (October, 2007) and 18 months (April, 2008) after the application of liming materials, at 0.00–0.05, 0.05–0.10, 0.10–0.20, 0.20–0.40, and 0.40–0.60 m soil depths. Six simple samples were taken at random, in order to form a composite sample, in the useful area of plots, in between rows of the previous crop. The samples were dried, sieved (2 mm sieves) and analyzed according to Raij et al. (2001) and Korndörfer et al. (2004).

A randomized complete bock design was used with 16 replicates. Data were subjected to the analysis of variance, and means were compared by the t test (LSD), at 5% probability.

Results and Discussion

Both limestone and slag were efficient for soil acidity correction (Figure 1). Nevertheless, slag was more effective in deeper soil layers and reacted faster than limestone. These results can be explained by the higher solubility of silicates (Alcarde & Rodella, 2003). As silicate reaction is faster in uppermost soil layers, an alkalinization front is formed in a shorter period of time to correct acidity in deeper layers. Similar results were found for H+Al levels, with slag differing from the control in deeper soil layers, in comparison to limestone. Corrêa et al. (2007) studied the effects of superficial limestone and slag application, and found that pH was increased by slag application down to 0.40 m, after 15 months, whereas liming effects were confined down to 0.10 m.

Organic matter increased after soil correction in the uppermost layer (0–0.05 m), possibly due to a higher production of it by soybean, Congo signal grass, and maize. Moreover, acidity correction may have increased root growth in the uppermost soil layer.

Aluminum levels varied accordingly to pH. Soil acidity enhances Al^{3+} solubilization, which is the primary source of toxicity for plants grown under low pH conditions.

Slag was the only source that increased P levels after six months, in the uppermost soil layer (Figure 1), possibly due to Si and P competition for the same adsorption sites of soil colloids, which would have rendered P more available to plants (Pulz et al., 2008).

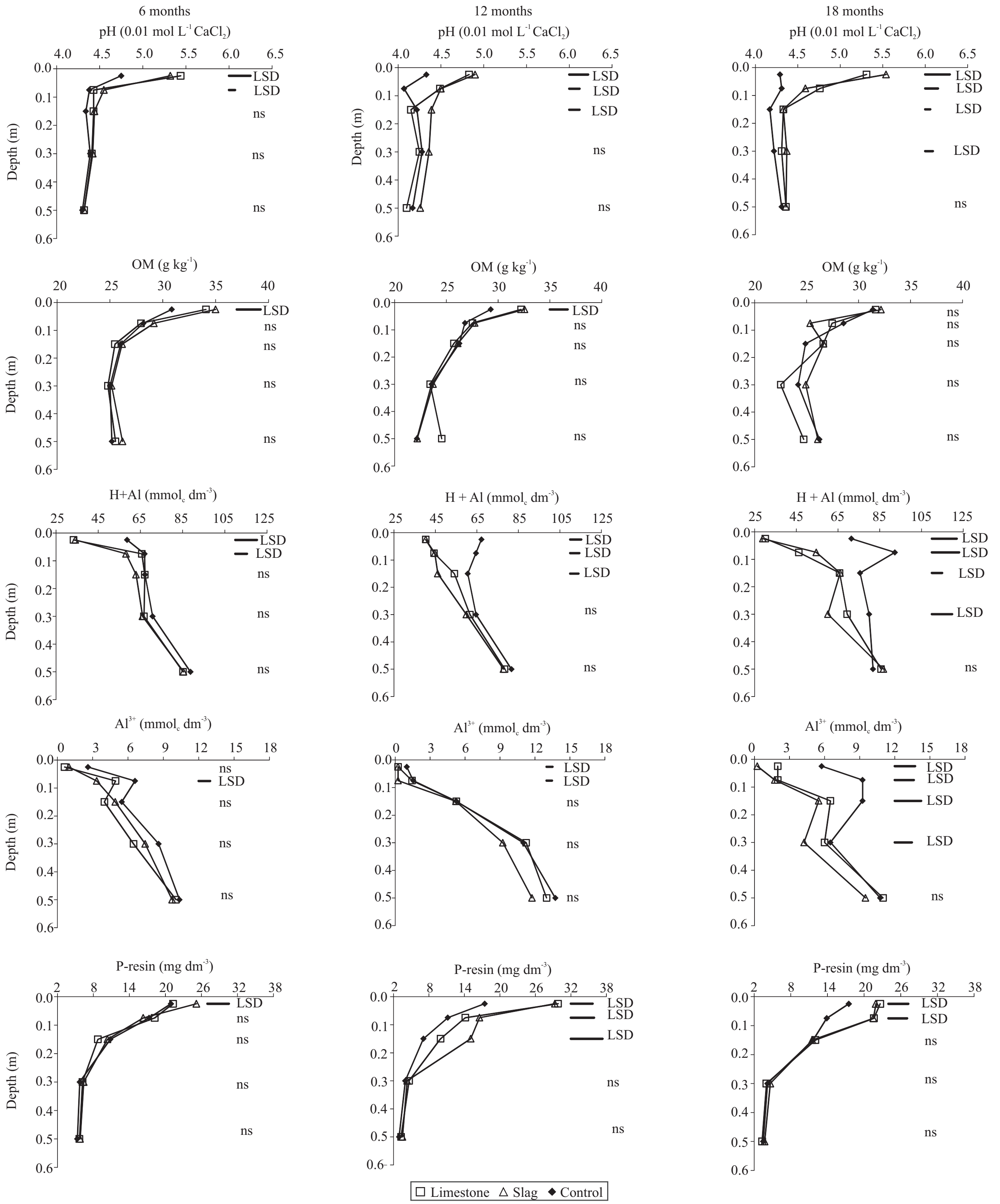

Figure 1. Values of pH, organic matter (OM), H+Al, Al^{3+}, and P in the soil profile after 6, 12 and 18 months from the application of limestone and slag, and in the control treatment. Horizontal bars indicate the least significant difference (LSD). nsNonsignificant.

These adsorption sites are saturated or blocked by the silicate anion, which can improve P fertilization efficiency. After 12 months, P levels increased in the uppermost soil layer with both sources, but only slag differed from the control at 0.05–0.20 m soil depth. In the 18th month, both correctives increased P levels down to 0.10 m.

Fageria & Baligar (2008) reported linear P increase in Brazilian Oxisols, as pH increased from 5.3 to 6.9. Also, Edmeades & Perrott (2004) observed that liming reduced P adsorption and enhanced P mineralization from organic matter.

Potassium levels were not influenced by any source, after 6 or 12 months from the application (Figure 2). However, Ca levels were increased by both sources down to 0.10 m. Additionally, slag effects were more accentuated than the limestone ones, at 0.05–0.10-m soil depth, in the second sampling. In the 18th month, both sources increased Ca levels down to 0.20 m, but only slag effects were found from 0.20 to 0.40 m. Magnesium levels varied accordingly to the Ca ones, and slag was more efficient than limestone in providing it at 0.10–0.20 m soil depth, in the 18th month.

Effects of soil correction on H+Al, Ca, and Mg levels reflected on base saturation and caused significant variations down to 0.10 m in the 6th and 12th months, and down to 0.40 m in the last sampling period. Base saturation was increased by slag application more than by limestone; those effects were observed at 0.05–0.10 and 0.20–0.40 m soil depths, after 12 and 18 months, respectively. These results show the higher solubility of slag and are an evidence of this source potential for fertility management in soils under no tillage. Similar findings were reported by Corrêa et al. (2009). However, Miranda et al. (2005) only observed effects of superficial liming on exchangeable base mobility in the uppermost soil layer of a Typic Hapludox.

Macronutrient levels in leaves (Table 1) were within the range considered appropriate for soybean production (Raij et al., 1997). Correction sources did not influence N, K and S levels, probably because the application of 4-20-20 NPK formula was sufficient to provide them, even in the control treatment.

Superficial liming is known to positively influence Ca and Mg nutrition in soybean and maize cropped under well-established no-till, as limestone dissociation products reach a large area explored by plant roots (Caires et al., 2006).

Slag application allowed higher levels of P and Si in soybean leaves, compared to limestone and the control (Table 1). Phosphorus uptake by crops is related to soil pH (McBride, 1994). Nevertheless, the observed effect of slag application on soil P availability was probably predominant in the increased P levels found in leaves with slag application. Pulz et al. (2008) also observed a higher P availability in soil and in potato leaves after silicate application, in comparison to limestone.

Yield components of soybean were all affected by the treatments (Table 2). Both sources provided increased shoot dry matter yield and grain yield. Dry matter yield was higher with slag application, but it did not significantly differ between sources.

Corrêa et al. (2009) studied superficial limestone and silicate applied as slag, and observed that both sources increased yield components and soybean final yield. According to Caires et al. (2006), organic matter conservation and moisture content in topsoil layers are improved by no tillage system, which favors nutrient uptake by plants even in acid soils. Therefore, beneficial effects of liming can fade under appropriate rainfall conditions and be more accentuated in dry winter regions, where production of plant residues for soil covering is limited.

Soil correction did not influence N, K, Mg, and S levels in the dry matter of Congo signal grass cropped after soybean (Table 1). However, P and Ca levels were increased by the application of both sources. Limestone and the control treatments provided lower Si levels than slag, evidencing the Si supplying capacity of this material. However, the increased Si levels in the slag treatment was not sufficient to increase dry matter of Congo signal grass compared to the limestone treatment. Appropriate supplies of Ca and P were related to increased dry matter production of grass.

Except for the low K (Table 1), macronutrient levels in leaves were within the range considered appropriate for maize (Raij et al., 1997). Treatments did not influence P, K and S levels. However, N, Ca and Mg levels were increased by soil correction, as also noticed in soybean. Oliveira et al. (1997) found similar results.

Soil correction increased Si levels in maize leaves compared to the control, and higher values were found after slag application. Ramos et al. (2006) also observed increased Si levels by liming. The authors explained

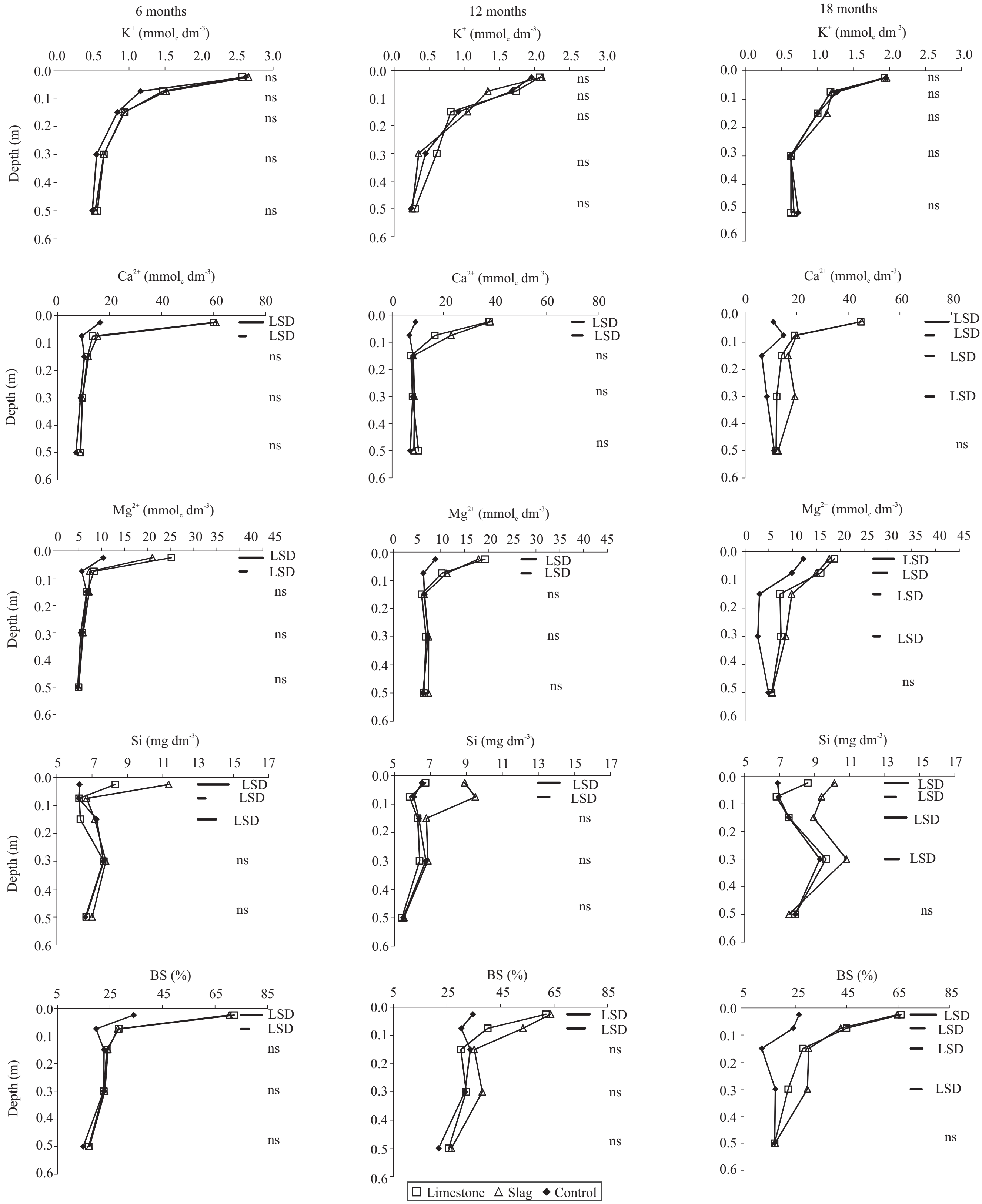

Figure 2. Values of K, Ca, Mg, Si, and base saturation (BS%) in the soil profile after 6, 12, and 18 months from the application of limestone and slag, and in the control treatment. Horizontal bars indicate the least significant difference (LSD).

Table 1. Levels of macronutrients and silicon in the leaves of soybean, maize, and Congo signal grass (*Urochloa ruziziensis*), cropped under no tillage system, according to the superficial application of limestone or slag$^{(1)}$.

Treatment	N	P	K	Ca	Mg	S	Si
	(g kg^{-1})						
Soybean							
Control	43.6	3.0c	16.2	7.4b	3.6b	2.3	2.2c
Limestone	44.9	3.2b	16.8	8.3a	4.2a	2.5	2.6b
Slag	45.0	3.6a	16.1	8.6a	4.3a	2.6	3.8a
Anova	ns	**	ns	**	**	ns	**
LSD	1.61	0.06	1.06	0.39	0.19	0.72	0.12
Congo signal grass in soybean succession							
Control	15.5	2.5b	13.0	5.1b	4.5	0.85	13.6b
Limestone	16.0	3.5a	13.0	6.3a	4.7	0.86	13.9b
Slag	16.9	3.2a	12.7	6.5a	4.7	0.88	15.5a
Anova	ns	**	ns	**	ns	ns	**
LSD	1.56	0.55	1.00	0.59	0.48	0.08	0.04
Maize							
Control	31.3b	2.8	12.5	3.6b	2.9b	2.3	10.3b
Limestone	31.8b	2.6	12.3	4.2a	3.7a	2.3	10.5b
Slag	32.9a	2.6	12.5	4.2a	3.7a	2.3	12.3a
Anova	**	ns	ns	*	**	ns	**
LSD	0.61	0.16	0.56	0.41	0.14	0.06	0.03
Congo signal grass in maize succession							
Control	19.9b	2.7b	19.2	5.5b	4.8	1.0	14.6b
Limestone	20.1b	2.9a	19.5	7.2a	5.0	1.1	14.7b
Slag	23.6a	2.9a	18.9	7.2a	4.9	1.0	15.4a
Anova	**	**	ns	**	ns	ns	**
LSD	0.44	0.10	2.08	0.41	2.22	0.16	0.25

$^{(1)}$Means followed by equal letters do not differ, by the t test (LSD), at 5% probability. ^{ns}Nonsignificant. * and **Significant by the F test, respectively at 5 and 1% probability.

Table 2. Yield components, dry matter (DM) yield, and grain yield of soybean, maize, and Congo signal grass (*Urochloa ruziziensis*) under no tillage system, according to the superficial application of limestone or slag$^{(1)}$.

Treatment	Yield components						Yield	
	Population (plants ha^{-1})	Pods per plant	Ear index	Grains per pod	Grains per ear	Mass of 100 grains (g)	DM (kg ha^{-1})	Grains (kg ha^{-1})
Soybean								
Control	381,273b	27.2b		1.4b		17.3b	2,639c	2,872b
Limestone	398,226a	32.1a		1.6a		18.8a	3,244b	3,428a
Slag	396,684a	32.0a		1.6a		18.7a	3,694a	3,539a
Anova	**	**		**		**	**	**
LSD	3,081	4.13		0.18		1.04	317.7	156.6
Congo signal grass in soybean succession								
Control	-	-		-		-	4,494b	-
Limestone	-	-		-		-	5,286a	-
Slag	-	-		-		-	5,218a	-
Anova	-	-		-		-	**	-
LSD	-	-		-		-	355	-
Maize								
Control	56,207b		1.1		420c	36.5	15,631b	6,554c
Limestone	60,680a		1.1		434b	37.5	18,202a	8,037b
Slag	61,805a		1.1		468a	38.0	18,049a	8,628a
Anova	**		ns		*	ns	**	**
LSD	1,791		0.12		32.24	2.65	1,341	580
Congo signal grass in maize succession								
Control	-		-		-	-	5,843b	-
Limestone	-		-		-	-	6,872a	-
Slag	-		-		-	-	6,783a	-
Anova	-		-		-	-	**	-
LSD	-		-		-	-	461	-

$^{(1)}$Means followed by equal letters do not differ, by the t test (LSD), at 5% probability. ^{ns}Nonsignificant. *and**Significant by the F test, respectively at 5 and 1% probability.

that pH is extremely important to Si availability to plants.

Soil correction with both sources increased plant population and number of grains per ear, in comparison to the control, which positively influenced grain yield (Table 2). The highest grain yield was observed with the use of slag.

Maize is considered responsive to soil correction (Miranda et al., 2005; Caires et al., 2006), although genotype may affect tolerance to acidity in soil (Miranda et al., 2005). Oliveira et al. (1997) obtained maximum maize yield after applying 6.6 Mg ha^{-1} limestone in Brazilian Cerrado soil.

Congo signal grass cropped after maize showed similar results compared to the first cultivation (Table 2), especially in increased leaf levels of P and Ca, and in shoot dry matter after soil correction. However, in the second cultivation, N and Si levels were also increased by slag application. Elawad et al. (1982) applied 5 Mg ha^{-1} of silicate and observed chlorophyll levels 65% higher in sugarcane. The positive effect of Si on chlorophyll levels can help to explain the higher levels of N with slag application. Fonseca et al. (2009) reported that nitrogen fertilization plus slag increased plant Si contents and dry matter yield of 'Marandu' palisade grass (*Urochloa brizantha*). However, increased levels of N and Si were not sufficient to enhance dry matter production in the slag treatment compared to limestone.

Conclusions

1. Slag corrects soil acidity and increases exchangeable base levels down the soil profile faster than lime.
2. Both limestone and slag increase dry matter yield of Congo signal grass and the yield components and grain yield of soybean and maize.
3. Slag is more effective in improving maize grain yield than limestone.

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