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Effect of lime, steel mill slag and phosphorus (P) in absorption of silicon and production of Tanzania grass (*Panicum maximum*)

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Abstract

Many pasture areas have Al toxicity, P deficiency and low pH as limiting factors; thus, slag from steel mill can improve Tanzania grass phosphate nutrition by the beneficial effects of the interaction of Si and P. The objectives of this work were to evaluate the “availability” of P and Si in the soil, growth, P and Si accumulation and dry matter production in Tanzania grass plants. The experiment was carried out in a green house in a low-P soil amended with slag and lime and fertilized with P during three cutting seasons at Jaboticabal - São Paulo, Brazil. The experimental design was a randomized block arranged in a 2×5 factorial with three replicates. Treatments consisted of lime and steel mill slag applications. The other sources of variation were five rates of P [0, 100, 200, 300 and 600 mg dm^{-3} pot^{-1} as triple superphosphate (45% of P_2O_5 soluble in citric acid at 2%)]. The experimental units were 3 dm^3 pots. There were increases in the variables plant growth and forage production with increases in available P, suggesting the use of slag as a soil amendment. Slag as soil corrective improved soil chemical attributes by pH correction and by increases in the base saturation index, reflecting in yield gains and in P and Si accumulation in the forage *Panicum maximum*. However, it did not increase the available Si in the soil, due to the low rates supplied, and did not differ from the traditional source regarding the availability of P in the soil.

Keywords: acidity corrective, P-resin, triple superphosphate.
Abbreviations: P_phosphorous; Al_ aluminium; Si_silicon; P-resin_determination of available P by the resin method; O.M._organic matter; SB_sum of bases exchangeable, CEC_cation exchange capacity; V_base saturation; RPTN_relative power of total neutralization; NP_neutralizing power; Int_ interaction.

Introduction

In Brazil Tanzania grass (*Panicum maximum* cv. Tanzania) stands out among other forage crops due to its high ability to withstand drought spells and by its remarkable adaptability to soil types and climates (Lima, 2009), besides having high yield potential (33 t ha^{-1} of total leaf dry matter) and good nutritional value, reaching 8 to 12% of crude protein in leaves and stems (Brâncio et al., 2003; Santos and Costa, 2006).
However, some areas in the Brazilian Cerrado biome where grasses are grown are highly degraded, yielding only 70 to 80% of their productive potential (Reis et al., 2010) due to limiting factors such as aluminum toxicity and phosphorous deficiency. Liming has been the principal method for correcting soil acidity due to its low cost, easy to apply, besides increasing Ca^{2+} and Mg^{2+} availability. Another alternative method is Ca and Mg silicates application (Souza et al., 2011), since besides raising pH, it also provide the $H_3SiO_4^-$ silicate anion, which competes with the phosphate anion for the same adsorption site, saturating the site where phosphorous would possibly be adsorbed (Pulz et al., 2008).

Although not considered a nutrient for plants, silicon benefits crops, particularly grass species, accumulators of this element (Miyake, 1992; Epstein, 1999). As an example, reduction in transpiration (Datnoff et al., 2001) and high photosynthetic rate due to improvements in leaf architecture (Deren, 2001).
In a given grass cultivar, the nutritional value varies by age, plant part, soil fertility and fertilization, among others (Van Soest, 1994). Therefore, adequate fertilizer management is of capital importance, especially phosphorous (P), which in tropical soils the mineral fraction is composed of kaolinite type clays, Fe and Al oxyhydroxides, mainly (Novais and Smyth, 1999). Thus, P is the most limiting element for the development and yield of crops (Santos et al., 2002). Many authors reported Si beneficial effects in some species, especially in grasses (Gutierrez et al., 2011; Castro and Crusciol, 2013). Some other authors also reported increases in P and in micronutrients availability (Marschner, 1995), resistance to pests and diseases (Pozza et al., 2004) and tolerance to Fe^{2+} and Al^{3+} ions (Mengel and Kirby, 2001).

Nonetheless, the highest efficiency of slag on lime to increase the available soil P reported in the literature is due more to the effect of the silicate present in the slag, which promotes competition for the adsorption sites than to the effect of pH itself. In this sense Smyth and Sanchez (1980), working on an Oxisol observed reductions of 18 and 24% in P retention after lime and calcium silicate applications, respectively. However, Baldeón (1995) observed that the effect of silicate on the P available increase is due to pH increase, primarily. Fageria and Baligar (2008) reported linear P increase in Brazilian Oxisols as pH increased from 5.3 to 6.9. In addition, Edmeades and Perrott (2004) observed that liming reduced P adsorption and enhanced P mineralization from organic matter. Assuming that silicate applications can result in increased soil phosphorus availability for crops, because the silicate anion occupies the sites of absorption of the phosphate anion (Pulz et al., 2008), the hypothesis proposed in this research is to demonstrate that slag improves phosphorus nutrition in Tanzania grass through the beneficial effects of the interaction Si x P . Therefore, the objectives of this study were to evaluate the availability of P and Si "available" in soils, P and Si accumulation in plants, growth and dry matter production of Tanzania grass grown in a greenhouse for three cutting seasons in a soil with low P content amended with steel slag and limestone and fertilized with different rates of P.

Results and Discussion

Soil chemical properties

At the end of the experimental period (90 days after germination), P rates affected the levels of P-resin and Si "available" (Table 1). Even though not significant, the unfolding of the interaction was performed to check the performance of each soil corrective type on the parameters evaluated.

P in the soil

P-resin level in the soil increased linearly with lime, resulting in an increase of 22,600% at the rate of 600 mg dm^{-3} of P. Similar result was obtained with slag, increasing P-resin level in 8,293% at the highest rate (Fig 1A). In this sense, Castro and Crusciol (2013), found that the application of slag (4,100 kg ha^{-1} or 2,050 mg dm^{-3}) increased soil P levels after six months of reaction, due to Si and P competition for the same adsorption sites of the soil colloids, which would have provided more P available to plants (Pulz et al., 2008). After 12 months, the authors found that P levels increased in the uppermost soil layer with the two materials used (lime and slag), but only slag differed from the control at soil depth 0.05–0.20 m. In the 18th month, both correctives increased P levels down to 0.10 m.

Increases in the soil P level due to P-soluble applications are reported in the literature (Moreira et al., 2002; Ieiri et al., 2010). Triple superphosphate promotes higher P increases due to its highly solubility in water, supplying higher amounts of phosphorus to the plant in the starting days.

Si in the soil

The available Si content showed decreasing quadratic behavior with lime and slag, and the rates 317 and 363 mg dm^{-3} provided the lowest content of this element in the soil with a reduction of 14 and 16% in the "available" Si, respectively (Fig 1B). The high Si content found at rate P zero indicated absence of absorption of the element once the plants were in a limited growth environment due to the low soil P content (Santos et al., 2002). Brait (2008), observed the same effect. Consequently, plant development improved and Si absorption increased with P rates, reducing the level of the element in the soil, where Si content in the soil showed significant negative correlation with the accumulation of the same in shoots at the three forage cuts (r = -0.61**; r = -0.36*; r = -0.49**). Slag rates did not raise Si and P contents in the soil, probably related to the low amount of silicate applied (217.5 kg ha^{-1} or 108.75 mg dm^{-3} of total Si), provided together with the rate recommended to raise the soil base saturation index. In addition, another factor that may have contributed for the absence of that increase in the Si content in the soil is the low Si-soluble content found in slag (Si-soluble extracted with Na_2CO_3 + NH_4NO_3 = 6.0%). In this sense, Korndörfer et al. (1999) found that calcium silicate at rates 0, 120, 240, 480 and 960 kg ha^{-1} of Si promoted increases in the soluble Si from 10.5 to 22.9 mg dm^{-3} in a Oxisol and from 3.2 to 7.6 mg dm^{-3} in a Quartzipsamment. Barbosa et al. (2003) obtained an increase from 1 to 14 mg dm^{-3} in the available Si content with 1,000 kg ha^{-1} of calcium and magnesium silicate. Gutierrez et al. (2011) found quadratic increase in Si extracted by calcium chloride with rates of P [0 (control), 96, 192, 288, 384 and 480 mg P dm^{-3}] in the presence of 300 mg dm^{-3} of Si.

Moreover, Fonseca et al. (2009), working with steel slag which has low Si concentration but high solubility (Korndörfer et al. 2003; Pereira et al. 2007) found increases in the available Si content in a Oxisol after 90 days of incubation, extending the effect after two cuts in *Brachiaria brizantha*.

Plant growth

There was a significant interaction effect between type of corrective and P rates for leaf area at the second cut (Table 1). Lime promoted a linear increase of 408% in leaf area at the highest rate of P. However, slag promoted a quadratic increase of 545.0 cm^2 in leaf area with 396 mg dm^{-3} P (Fig 2A).

At the third cut, only the effect of P rates in leaf area was observed. However, the unfolding of the interaction was carried out to check the performance of each material. Thus, lime and slag promoted a quadratic increase in leaf area and the rates that promoted larger increases were 476 and 440 mg dm^{-3} P, reaching 633.5 and 582.0 cm^2, respectively (Fig 2B). In this sense, Melo (2005) found larger leaf area in *Brachiaria brizantha* with P rates equal to 130 mg dm^{-3} when associated with Si rates (150 to 450 mg dm^{-3}).

Significant effects of P rates were observed for tiller number at the first and third cuts. However, the unfolding of the interaction was carried out to check the performance of each soil corrective in the variable (Table 1). In the first cut, a linear increase in the number of tillers was observed with lime, reaching 7.7 tillers with 600 mg dm^{-3} P. On the other hand, when slag was used, there was a quadratic adjustment, and the largest number of tillers (6.3) was obtained at the rate of 473 mg dm^{-3} P (Fig 3A).

There was interaction among types of corrective and P levels at the second cut (Table 1). Lime increased tiller number linearly, reaching 9.2 tillers with 600 mg dm^{-3} P, and slag increased tiller number with quadratic adjustment, producing 6.5 tillers at the rate of 470 mg dm^{-3} P (Fig 3B). At the third cut the performance was similar with lime, with linear adjustment of said variable, reaching 9.2 tillers at the

Table 1. Phosphorus and Silicon available in the soil, leaf area (LA), number of tillers (NT) and dry matter production (DM) at the first, second and third cut of *Panicum maximun* cv. Tanzania as a function of acidity corrective type and P rates applied at sowing. Jaboticabal-SP, 2014.

	P-res	Si	LA (cm^2)		NT			DM (g $plant^{-1}$)		
Corrective(C)	mg dm^{-3}	mg dm^{-3}	2nd cut	3dt cut	1st cut	2dt cut	3dt cut	1st cut	2dt cut	3dt cut
Lime	92.7^{a}	6.2^{a}	450.2^{a}	425.5^{a}	4.4^{a}	4.7^{a}	5.5^{a}	2.5^{a}	3.9^{a}	3.7^{a}
Slag	92.2^{a}	6.1^{a}	341.1^{b}	384.0^{a}	4.3^{a}	4.5^{a}	6.1^{a}	2.8^{a}	3.4^{a}	3.6^{a}
F test	0.004^{ns}	0.06^{ns}	5.47^{*}	0.63^{ns}	0.02^{ns}	0.25^{ns}	0.62^{ns}	1.95^{ns}	2.53^{ns}	0.07^{ns}
P rates (R)										
0	5.5	6.9	24.42	74.6	1.0	1.0	1.5	0.0	0.1	0.4
100	38.8	5.7	394.2	473.1	4.5	4.9	5.2	2.8	3.5	4.4
200	69.8	5.9	435.1	360.7	5.4	4.6	6.3	3.4	3.8	3.2
300	116.2	6.0	484.8	552.7	4.0	4.7	7.7	3.3	4.5	4.9
600	232.0	6.3	639.6	562.7	6.8	7.6	8.4	3.6	6.4	5.5
F test	81.27^{**}	8.12^{**}	19.00^{**}	11.91^{**}	26.01^{**}	24.84^{**}	10.52^{**}	13.57^{**}	37.30^{**}	14.09^{**}
Int CxR	0.25^{ns}	0.32^{ns}	4.06^{*}	0.12^{ns}	2.15^{ns}	4.56^{*}	0.29^{ns}	1.41^{ns}	3.21^{*}	0.02^{ns}
CV (%)	25.9	6.7	32.3	35.3	23.7	25.4	34.9	18.6	25.2	35.9

ns; *; **, not significant and significant at the 5 and 1% level, respectively. Means followed by the same letter do not differ by the Tukey test at the 5% level of probability.

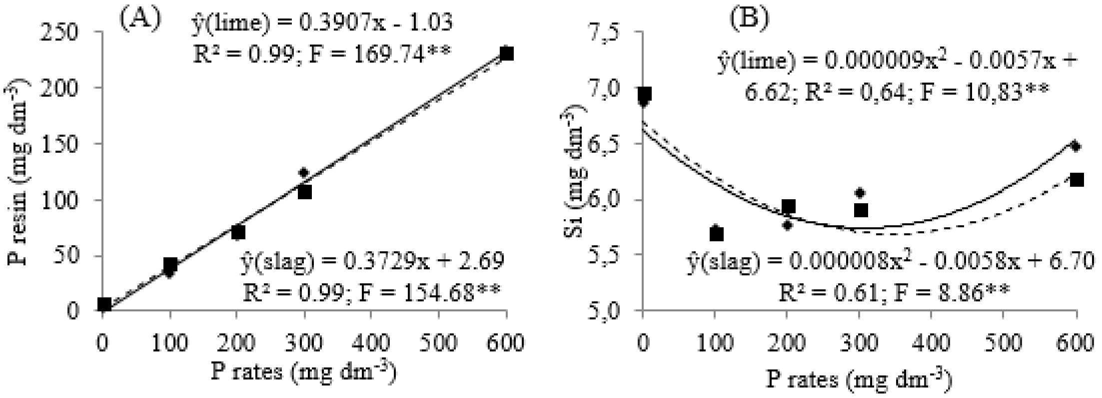

Fig 1. P resin content (A) and "available Si" (B) in an Oxisol 90 days after *Panicum maximum* cv. Tanzania germination, as a function of acidity corrective type and P rates applied at sowing. Jaboticabal-SP, 2014.

highest rate of P, and quadratic adjustment when slag was used, reaching 8.9 tillers at the rate of 420 mg dm^{-3} P (Fig 3C). Werner (1986) highlighted the importance of P for forage, especially in the initial stages of plant development, with great influence in tillering. The same author stated that low availability of P in the soil does not allow good tillering and plants have slow growth. In this sense, several authors observed increases in tillering of *Panicum maximum* (Meirelles et al. 1988; Politi and Prado 2009) and in *Brachiaria brizantha* (Torteli 2006) with increasing doses of P. In addition, Melo (2005) obtained better tillering in Marandu grass, combining high rates of Si (450 mg dm^{-3}) with median rates of P (170 to 250 mg dm^{-3}).

Forage production

P rates significantly affected dry matter production of Tanzania grass plants at the first and third cuts; however, even not being significant, the unfolding of the interaction was performed, and there was significant effect of the interaction type of corrective and P rates at the second cut (Table 1). At the first as at the third cut, there was quadratic adjustment of P rates in the dry matter production. At the first cut the 448 mg dm^{-3} P rate provided maximum dry matter production when lime was used, reaching 4.3 g $plant^{-1}$, but the 450 mg dm^{-3} P rate provided maximum production when slag was applied (4.6 g $plant^{-1}$) (Fig 4A). At the second cut, production of dry matter showed a linear adjustment with P rates with lime applications, and the maximum production obtained with the highest P rate (600 mg dm^{-3}) was 8.1 g $plant^{-1}$. However, there was a quadratic adjustment of dry matter production with P rates when slag was applied as corrective, and the maximum production of 5.4 g $plant^{-1}$ was achieved with 452 mg dm^{-3} P (Fig 4B). At the third cut, the highest dry mass productions of 5.7 and 5.6 g $plant^{-1}$ were achieved with 475 and 480 mg dm^{-3} P when lime and slag were applied, respectively (Fig 4C). Many studies also report increases in forage production with P applications (Patês et al. 2008; Politi and Prado 2009). Melo (2005) also found that the association of 90 mg dm^{-3} P with Si (450 mg dm^{-3}) increased dry matter production by 2.6 times at the first cut of *Brachiaria Brizantha,* compared to the control, a result repeated at the second cut. In general, there were increases in the variables growth and forage production with increases in P availability, not being better than lime. However, when dealing with an alternative source, the results of this study suggest the use of steel mill slag as soil corrective in this forage.

P accumulation

There was significant effect of P rates for nutrient accumulation in shoots at the first and third cuts, and at the second cut, the effect of the interaction corrective type and P rates was observed (Table 2). At the first cut, P rates led to quadratic adjustment in P accumulation in shoots with limestone, and the rate of 737 mg dm^{-3} promoted higher accumulation of P (20.9 mg P $plant^{-1}$). On the other hand slag promoted a linear adjustment in the variable, reaching 20.4 mg P $plant^{-1}$ at the highest rate (600 mg dm^{-3} P) (Fig 5A).

Table 2. P and Si accumulation in shoots at the first, second and third cut of *Panicum maximun* cv. Tanzania as a function of acidity corrective type and P rates applied at sowing. Jaboticabal - SP, 2014.

	P accumulation (mg plant^{-1})			Si accumulation (mg plant^{-1})		
Corrective (C)	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
Lime	9.5^{a}	7.9^{a}	6.8^{a}	26.6^{a}	49.6^{a}	49.3^{a}
Slag	9.4^{a}	5.6^{b}	7.0^{a}	31.2^{a}	41.8^{a}	45.9^{a}
F test	0.02ns	8.68**	0.06ns	3.06ns	3.66ns	0.30ns
P rates (R)						
0	0.0	0.2	0.3	0.0	1.2	4.2
100	5.2	4.1	4.3	33.5	42.7	58.4
200	9.2	5.8	5.0	35.9	48.0	42.1
300	12.6	7.6	9.7	36.6	56.7	63.8
600	20.0	16.3	15.4	38.4	79.8	69.5
F test	95.12**	46.07**	41.78**	31.19**	38.96**	13.85**
Int CxR	2.14ns	6.18**	0.08ns	0.73ns	3.78*	0.05ns
CV (%)	20.2	31.6	31.5	24.7	24.6	36.4

ns; *; **, not significant and significant at 5 and 1% levels of probability, respectively. Means followed by the same letter do not differ by the Tukey test at 5% probability.

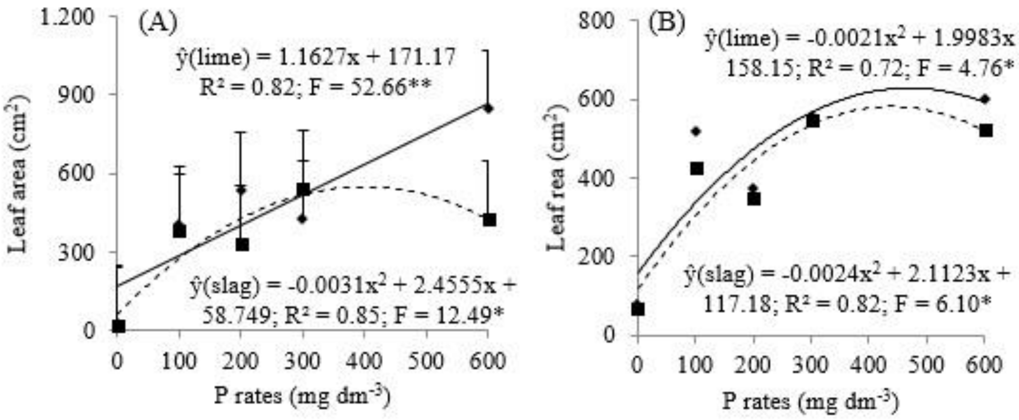

Fig 2. Leaf area of *Panicum maximum* cv. Tanzania at the second (A) and third cut (B) as a function of acidity corrective type and P rates applied at sowing. Jaboticabal-SP, 2014.

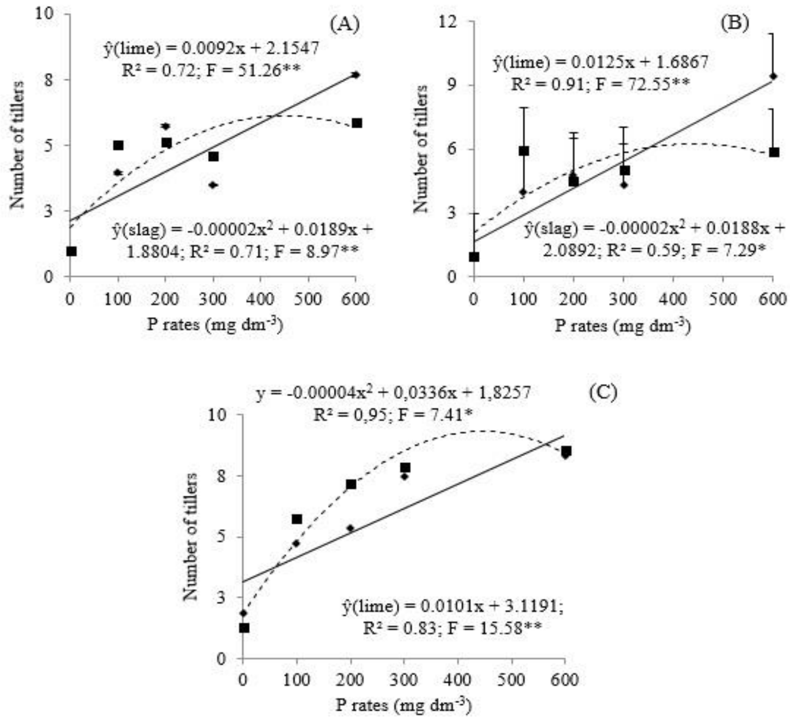

Fig 3. Number of tillers of *Panicum maximum* cv. Tanzania at the first (A), second (B) and third cut (C), as a function of acidity corrective type and P rates applied at sowing. Jaboticabal-SP, 2014.

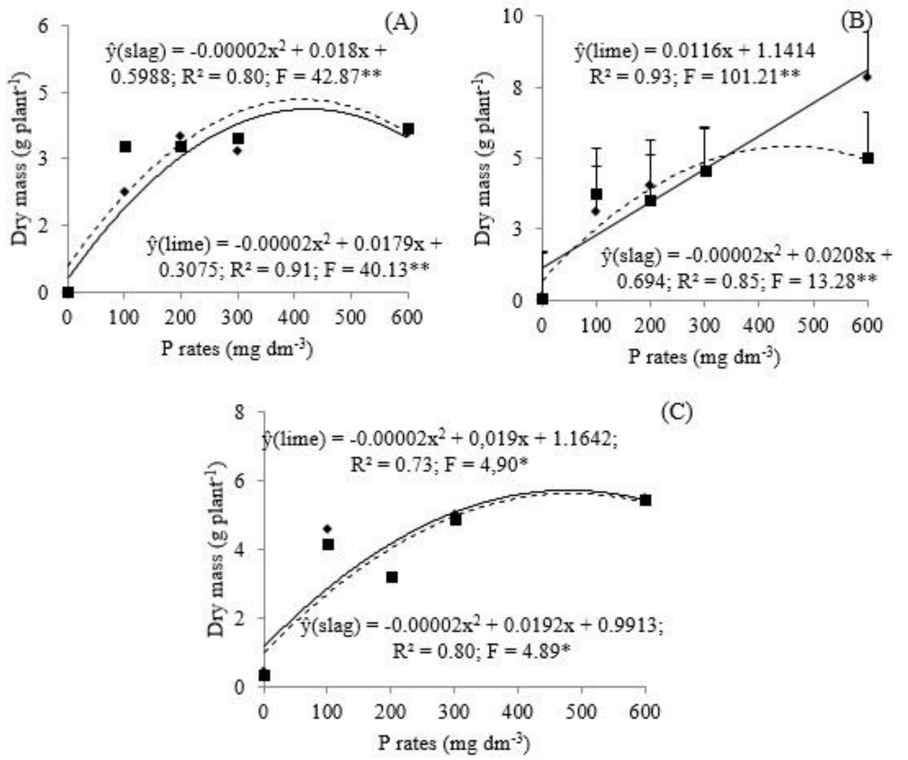

Fig 4. *Panicum maximum* cv. Tanzania dry mass at the first (A), second (B) and third cut (C) as a function of acidity corrective type and P rates applied at sowing. Jaboticabal-SP, 2014.

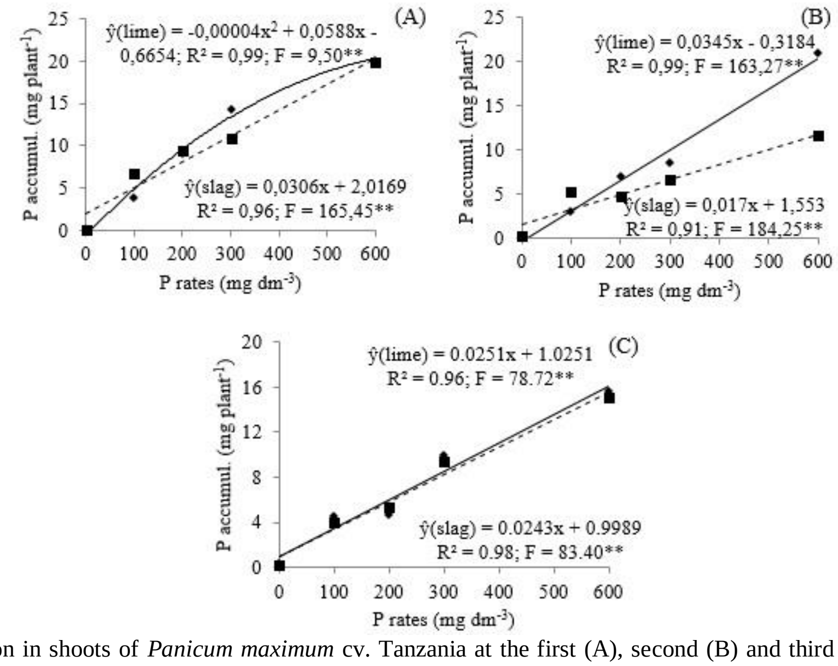

Fig 5. P accumulation in shoots of *Panicum maximum* cv. Tanzania at the first (A), second (B) and third cut (C) as a function of acidity corrective type and P rates applied at sowing. Jaboticabal - SP, 2014.

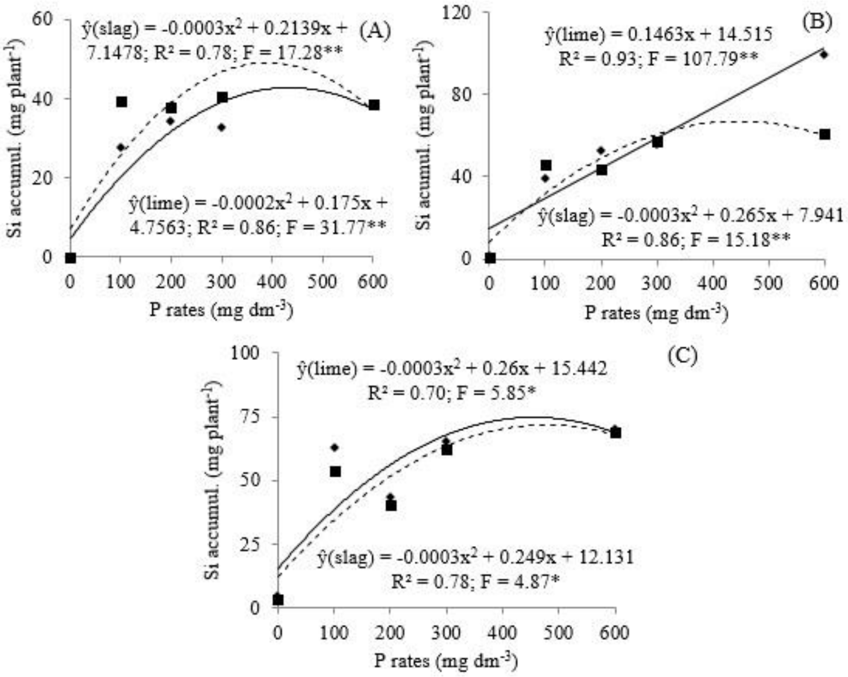

Fig 6. Si accumulation in shoots of *Panicum maximum* cv. Tanzania at the first (A), second (B) and third cut (C), as a function of acidity corrective type and P rates applied at sowing. Jaboticabal - SP, 2014.

At the second cut, the correctives promoted a linear increase in P accumulation in shoots, reaching the highest level (20.4 and 11.8 mg P plant^{-1}) at the highest rate (600 mg dm^{-3} P) with limestone and slag, respectively (Fig 5B). At the third cut similar behavior was observed, reaching the maximum accumulation of P (16.1 and 15.6 mg P plant^{-1}) at the highest rate (600 mg dm^{-3} P) with limestone and slag, respectively (Fig 5C). Other studies with forage have shown accumulation of P in shoots similar to this work with quadratic behavior at the first cut as a function of P rates (25; 50; 75; 100 and 200 mg dm^{-3}) (Santos et al. 2002). Politi and Prado (2009) found linear increases in P concentrations in *Panicum maximum* cv. Tanzania as a function of P rates (0; 137; 274; 411 and 548 mg dm^{-3}) at three consecutive cuts. However, Melo (2005) found that low rates of P (10 mg dm^{-3}) associated with Si (450 mg dm^{-3}) promoted higher accumulation of P compared to low rates of Si (150 mg dm^{-3}).

Si accumulation

There was significant effect of P rates in Si accumulation in shoots at the first and third cuts. However, there was a significant effect of the interaction type of corrective and P levels in said variable at the second cut (Table 2). At the first cut, Si accumulation showed quadratic adjustment with increasing P rates for type of corrective, reaching 42.8 and 49.0 mg of Si plant^{-1} at rates 435 and 392 mg P dm^{-3} associated with lime and slag, respectively (Fig 6A). Si accumulation showed linear adjustment with P rates when lime was used at the second cut, reaching 102.3 mg Si plant^{-1} at the highest P rate (600 mg dm^{-3}). On the other hand, when slag was used, Si accumulation showed quadratic adjustment with P with maximum level equal to 66.9 mg Si plant^{-1} at the 445 mg dm^{-3} P rate (Fig 6B). The third cut presented Si accumulation with quadratic behavior with P rates in the two corrective used, reaching maximums of 74.7 and 71.7 mg Si plant^{-1} at rates 456 and 479 mg dm^{-3} P, with lime and slag, respectively (Fig 6C).

Melo (2005) observed higher Si accumulation in B. *brizantha* at rates 90 to 250 mg dm^{-3} P associated with Si (450 mg dm^{-3}). In a study regarding Si accumulation by forages B. *decumbens* and B. *brizantha*, Melo et al. (2003) observed increasing Si accumulation in three cuts, and B. *decumbens* accumulated more Si (112.0 mg pot^{-1}) than B. *brizantha* (105 mg pot^{-1}), on the average, in response to silicon fertilization (0 to 1,452 kg ha^{-1} Si).

Materials and Methods

Location and soil classification

The experiment was carried out in a greenhouse at Faculdade de Ciências Agrárias e Veterinárias (FCAV/UNESP), Jaboticabal, São Paulo, Brazil. The soil used was classified as Oxisol (Soil Survey Staff, 2010) collected from the 0 to 20 cm depth layer in 20 random sites in a grazing pasture in the county of Jaboticabal.

Chemical properties of soil and correctives

The analyses presented the following chemical attributes: pH ($CaCl_2$) = 4.9; P (resin) = 4 mg dm^{-3}; O.M. (organic matter) = 10 g dm^{-3}; K, Ca, Mg, H+Al, SB (sum of exchangeable bases), CEC (cation exchange capacity) (mmol$_c$ dm^{-3}) = 0.3, 9, 7, 22, 16.3, 38.3, respectively; V (base saturation) (%) = 42.6, determined according to methodology by Raij et al. (2001). Liming [RPTN (Relative power of total neutralization) = 70%, CaO = 24%, MgO = 17%, NP (Neutralizing power) = 85%] and steel mill slag applications (RPTN = 72.3%, CaO = 42.1%, MgO = 12.4%, Si-total extracted with fluoridric acid = 15%, Si-soluble extracted with Na_2CO_3 + NH_4NO_3 = 6.0%, Cd = 2.4 mg kg^{-1}, Cr = 2,3 g kg^{-1}, Ni = 163.8 mg kg^{-1}, Pb = 27.3 mg kg^{-1}) were performed to raise soil base saturation to 70%, as indicated by Werner et al. (1997). Soil correctives were homogenized and incubated into the soil for 90 days, keeping moisture at

60% of the soil water holding capacity. After that, soil samples were drawn from treatments with lime and slag. Soil analyses showed the following attributes: pH ($CaCl_2$) = 5.3 and 5.3; P (resin) = 5 and 4 mg dm^{-3}; O.M. = 13.0 and 62.0, respectively (Raij et al. 2001). and 14 g dm^{-3}; K = 0.1 and 0.1 $mmol_c$ dm^{-3}; Ca = 14 and 19 $mmol_c$ dm^{-3}; Mg = 13 and 14 $mmol_c$ dm^{-3}; H+Al = 18 and 20 $mmol_c$ dm^{-3}; SB = 27.1 and 33.1 $mmol_c$ dm^{-3}; CEC = 45.1 and 53.1 $mmol_c$ dm^{-3}; and V (%) = 60.

Experimental design and fertilization

The experimental design was a randomized block arranged in a 2x5 factorial with three replicates. Treatments were rates of lime and steel mill slag. The other source of variation were five rates of P (0, 100, 200, 300 and 600 mg dm^{-3}) as triple superphosphate (45% P_2O_5 soluble in citric acid at 2%). The experimental units were 3 dm^3 plastic pots.

N and K fertilizations were performed as Malavolta (1981), using 200 mg dm^{-3} of N as urea (45% N) and 150 mg dm^{-3} of K as potassium chloride (60 % K_2O) to supply the exact amount in all treatments. The other nutrients were applied following recommendations proposed by Mesquita et al. (2004): 1.5, 0.8, 4, 5, and 0.15 mg dm^{-3} of Cu, B, Fe, Zn, and Mo, respectively, using $CuSO_4.5H_2O$, H_3BO_3, $Fe_2(SO_4)_2.4H_2O$, $ZnSO_4.7H_2O$, and $NaMoO_4.2H_2O$ as sources. At this stage, fertilizers were incorporated into the soil.

Plant materials

Ten seeds of *Panicum maximum* cv. Tanzania were sown directly in the pots and tinning performed ten days after germination, keeping four plants per pot and soil moisture holding capacity kept at 60%.

Soil and leaf analyses

Soil analysis was performed at the end of the experimental period, 90 days after germination to determine P-resin levels (Raij et al., 2001) and Si "available" in the soil, using the method of extraction with calcium chloride 0.01 mol L^{-1} proposed by Korndörfer et al. (2004). After obtaining the extract, samples were allowed to stand for one hour for further Si reading on a spectrophotometer at wavelength 660nm (Kilmer, 1965). At 30, 60 and 90 days after germination cuts were performed to record the number of tillers and for plant growth evaluations (leaf area with the help of a Li-Cor apparatus, L1-3000® model). The material was washed with running water and a neutral detergent solution (1 mL L^{-1}), then washed twice with deionized water, dried in a forced-air oven at 65°C to attain constant weight followed by shoot dry mass determinations. After those procedures, samples were grinded to determine P (Bataglia et al., 1983) and Si (Kraska and Breitenbeck, 2010) levels for subsequent nutrient accumulation calculations. After each cut, 200 mg dm^{-3} of N as urea (Malavolta 1981) was side dressed in all treatments and irrigation turned on to reduce losses via volatilization.

Statistical analysis

Data were subjected to the analysis of variance by the F test ($p<0.05$), to mean comparison (Tukey 5% probability) for the source of qualitative variability (corrective type) and to the polynomial regression analysis for the source of quantitative variability (phosphorus rates), using the statistical program Sisvar® (Ferreira 2003). The coefficients of the components of each model were tested selecting the significant models with greater coefficient of determination. It was also applied a simple linear correlation test among the studied variables, using the statistical program Assistat, version 7.6 beta (Silva and Azevedo, 2006).

Conclusions

Steel mill slag applied as acidity corrective improves soil chemical attributes by correcting pH and increasing the base saturation index, with increments in P and Si accumulation as well as in yield gains of *Panicum maximum* cv. Tanzania. However, it does not increase the content of Si available in the soil due to the low rate applied, and does not differ from the traditional source regarding soil P availability.

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References

Baldeón JRM (1995) Efeito da ação alcalinizante e do silício na eficiência do termofosfato magnesiano em solos ácidos. Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, São Paulo, p 92.

Barbosa DS, Camargo MS, Ramos LA, Resende RH, Arruda DG, Korndorfer GH, Pereira HS and Nolla A (2003). Correção da acidez do solo em profundidade e disponibilidade de silício proporcionados pela aplicação de silicato e calcário em lisímetros. Paper presented at the 2nd Simpósio sobre Silício na Agricultura, Universidade Federal de Lavras, Lavras, 2003.

Bataglia OC, Furlani AMC, Teixeira JPF, Furlani PR, Gallo JR (1983) Métodos de análise química de plantas. IAC, Campinas. 48 p.

Brait MAH (2008) Interação silício e fósforo na adsorção desses elementos em diferentes solos de cerrado. Universidade Federal de Goiás, Jataí, Goiás, p 99.

Brâncio PA, Nascimento Júnior D, Euclides VPB, Fonseca DM, Almeida RG, Macedo MCM, Barbosa RA (2003) Avaliação de três cultivares de *Panicum maximum* Jacq. sob pastejo: composição da dieta, consumo de matéria seca e ganho de peso animal. Rev Bras Zootec. 32(5): 1037-1044.

Castro GSA, Crusciol CAC (2013) Yield and mineral nutrition of soybean, maize, and Congo signal grass as affected by limestone and slag. Pesqui Agropecu Bras. 48(6): 673-681.

Datnoff LE, Snyder GH, Korndörfer GH (2001) Silicon on agriculture. Elsevier, Amsterdam, Holland. 403 p.

Deren C (2001) Plant genotypes, silicon concentration and silicon related responses. In: Datnoff LE, Snyder GH, Korndörfer GH (eds) Silicon on agriculture. Elsevier, Amsterdam, Holland.

Edmeades DC, Perrott KW (2004) The calcium requirements of pastures in New Zealand: a review. New Zeal J Agr Res. 47: 11-21.

Epstein, E (1999) Silicon. Annu Rev Plant Phys. 50: 641-664.

Fageria NK, Baligar VC (2008) Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. Adv Agron. 99: 345-399.

Ferreira DF (2003) Sisvar: sistema de análise de variância versão 4.6. Lavras, UFLA/DEX.

Fonseca IM, Prado RM, Vidal AA, Nogueira TAR (2009) Efeito da escória, calcário e nitrogênio na absorção de silício e na produção do capim-marandu. Bragantia. 68: 221-232.

Gutierrez RS, Inocêncio MF, Novelino JO (2011) Extração de silício em solos fertilizados com fosfato e silicato. Pesq Agropec Trop. 41(1): 1-7.

Ieiri AY, Lana RMQ, Korndorfer GH, Pereira HS (2010) Fontes, doses e modos de aplicação de fósforo na recuperação de pastagens com *Brachiaria*. Cienc Agrotec. 34(5): 1154-1160.

Kilmer VJ (1965) Silicon. Methods of soil analysis. Part 2. Chemical and microbiological properties. Americam Society of Agronomy, Madison. p 959-962.

Korndörfer GH, Pereira HS, Nolla A (2004) Análise de silício: solo, planta e fertilizante. GPSi/ICIAG/UFU, Uberlândia, Brasil. 34 p.

Korndörfer GH, Pereira HS, Camargo MS (2003) Silicatos de cálcio e magnésio na agricultura. GPSi/ICIAG/UFU, Uberlândia, Brasil. 23 p.

Korndörfer GH, Arantes VA, Corrêa GF, Snyder GH (1999) Efeito do silicato de cálcio no teor de silício no solo e na produção de grãos de arroz de sequeiro. Rev Bras Cienc Solo. 23: 623-629.

Kraska JE, Breitenbeck GA (2010) A simple, robust method for quantifying silicon in plant tissue. Commun Soil Sci Plan. 41(17): 2075-2085.

Lima AF (2009) Avaliação de clones de *Panicum maximum* Jacq. submetidos à suspensão hídrica. Universidade Federal Rural de Pernambuco, Recife, Brasil, p 54.

Malavolta E (1981) Manual de Química Agrícola: Adubos e Adubação. Agronômica Ceres, São Paulo, Brasil. 594 p.

Marschner H (1995) Mineral nutrition of higher plants. Academic Press, London, England. 889 p.

Meirelles NMF, Werner JC, Abramides PLG, Carriel JM, Paulino VT, Colozza MT (1988) Nível crítico de fósforo em capim-colonião cultivado em dois tipos de solo: Latossolo Vermelho-Escuro e Podzólico Vermelho-Amarelo. Bol Ind Animal. 45(1): 215-232.

Melo SP (2005) Silício e fósforo para o estabelecimento do capim-marandu num Latossolo Vermelho-Amarelo. Escola Superior de Agricultura “Luiz de Queiroz”, Piracicaba, São Paulo, p 110.

Melo SP, Korndörfer GH, Korndörfer CM, Lana RMQ, Santana DG (2003) Silicon accumulation and water deficit tolerance in *Brachiaria* grasses. Sci Agric. 60: 755-759.

Mengel K, Kirkby EA (2001) Principles of plant nutrition. Kluwer Academic Publishers, Dordrecht, Holland. 849 p.

Mesquita EE, Pinto JC, Furtini Neto AE, Santos IPA, Tavares VB (2004) Teores críticos de fósforo em três solos para o estabelecimento de capim-Mombaça, capim-Marandú e capim-Andropogon em vasos. Rev Bras Zootec. 33: 290-301.

Miyake Y (1992) The effect of silicon on the grow of the different groups of rice (*Oryza sativa*) plants. Sci Report Fac Agric. 8(1): 101-105.

Moreira A, Malavolta E, Moraes LAC (2002) Eficiência de fontes e doses de fósforo na alfafa e centrosema cultivadas em Latossolo Amarelo. Pesqui Agropecu Bras. 37(10): 1459-1466.

Novais RF, Smyth TJ (1999) Fósforo em solos e planta em condições tropicais. Universidade Federal de Viçosa, Viçosa, Brasil. 399 p.

Patês NMS, Pires AJV, Carvalho GGP, Oliveira AC, Foncêca MP, Veloso CM (2008) Produção e valor nutritivo do capim-tanzânia fertilizado com nitrogênio e fósforo. Rev Bras Zootec. 37(11): 1934-1939.

Pereira HS, Barbosa NC, Carneiro MAC, Korndörfer GH (2007) Avaliação de fontes e extratores de silício no solo. Pesqui Agropecu Bras. 42(2): 239-247.

Politi LS, Prado RM (2009) Fósforo na nutrição e produção de massa seca do capim-tânzania. Rev FZVA. 16(1): 95-104.

Pozza AAA, Alves E, Pozza EA, Carvalho JG, Montanari M, Guimarães PTG, Santos DM (2004) Efeito do silício no controle da cercosporiose em três variedades de cafeeiro. Fitopatol Bras. 29(2): 185-188.

Pulz AL, Crusciol CAC, Lemos LB, Soratto RP (2008) Influência de silicato e calcário na nutrição, produtividade e qualidade de batata sob deficiência hídrica. Rev Bras Cienc Solo. 32: 1651-1659.

Raij B, Cantarella H, Quaggio JA, Furlani AMC (1997) Recomendações de adubação e calagem para o estado de São Paulo. 2nd edn. IAC, Campinas. 285 p.

Reis GL, Lana AMQ, Maurício RM, Lana RMQ, Machado RM, Borges I, Quinzeiro Neto T (2010) Influence of trees on soil nutrient pools in a silvopastoral system in the Brazilian Savannah. Plant Soil. 329: 185-193.

Santos PM, Costa RZM (2006) Manejo de pastagens tropicais. Embrapa Pecuária Sudeste, São Carlos, Brasil. 26 p.

Santos HQ, Fonseca DM, Cantarutti RB, Alvarez VH, Nascimento Júnior D (2002) Níveis críticos de fósforo no solo e na planta para gramíneas forrageiras tropicais, em diferentes idades. Rev Bras Cienc Solo. 26(1): 173-182.

Silva FAS, Azevedo CAV (2006) A new version of the Assistat - Statistical Assistance Software. World Congress on Computers in Agriculture, Orlando, USA, 2006.

Smyth TJ, Sanchez PA (1980) Effects of lime, silicate and phosphorus applications to an oxisol on phosphorus sorption and ion retention. Soil Sci Soc Am J. 44: 500-504.

Soil Survey Staff (2010) Keys to soil Taxonomy. USDA, Washington DC.

Souza RF, Ávila FW, Faquin W, Pozza AAA, Carvalho JG, Evangelista AR (2011) Carbonate-silicate ratio for soil correction and influence on nutrition, biomass production and quality of palisade grass. Sci Agric. 68(5): 526-534.

Torteli GT (2006) Avaliação agronômica de doses e fontes de fósforo para *Urochloa brizantha* (Stapf) webster cv. Marandú. Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal, Brasil, p 42.

Van Soest PJ (1994) Nutritional ecology of the ruminant. Cornell University, New York, USA. 476 p.

Werner JC, Paulino VT, Cantarella H, Quaggio JA, Andrade NO (1997) Forrageiras. In: Raij B van, Cantarella H, Quaggio JA, Furlani AMC (eds) Recomendações de adubação e calagem para o Estado de São Paulo, 2nd edn. IAC, Campinas.

Werner JC (1986) Adubação de pastagens. Instituto de Zootecnia, Nova Odesa, Brasil. 49 p.