Carbonate-silicate ratio for soil correction and influence on nutrition, biomass production and quality of palisade grass

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ABSTRACT: Silicates can be used as soil correctives, with the advantage of being a source of silicon, a beneficial element to the grasses. However, high concentrations of silicon in the plant would affect the digestibility of the forage. To evaluate the influence of the substitution of the calcium carbonate by calcium silicate on the nutrition, biomass production and the feed quality of the palisade grass [*Urochloa brizantha* (C. Hochstetter ex A. Rich.) R. Webster], three greenhouse experiments were conducted in completely randomized designs with four replications. Experimental units (pots) contained a clayey dystrophic Rhodic Haplustox, a sandy clay loam dystrophic Typic Haplustox and a sandy loam dystrophic Typic Haplustox. Each soil received substitution proportions (0, 25, 50, 75 and 100 %) of the carbonate by calcium silicate. The increase in the proportion of calcium silicate elevated the concentrations and accumulations of Si, Ca, Mg, and B, reduced Zn and did not alter P in the shoot of plants. The effects of the treatments on the other nutrients were influenced by the soil type. Inclusion of calcium silicate also increased the relative nutritional value and the digestibility and ingestion of the forage, while the concentration and accumulation of crude protein and the neutral detergent and acid detergent fibers decreased. Biomass production and feed quality of the palisade grass were generally higher with the 50 % calcium silicate treatment.
Keywords: *Urochloa brizantha*, pasture, lime, silicon, feed value

Introduction

The Brazilian savannah (cerrado) includes approximately 200 million hectares, 25 % of which are pastures, the majority being *Urochloa* spp. Between 70 to 80 % of these pastures are at some level of degradation and low productivity (Reis et al., 2010) due to soil limitations such as aluminum toxicity, phosphorus deficiency, and low pH.

Lime application has been the main method for acidity correction because of its low cost, ease of application and increase of plant availability of Ca and Mg. However, another alternative method used for the acidity correction is the application of silicates, silicon (Si) being also a source for several crops.

Authors have shown beneficial effects of Si in several vegetable species, especially grasses. Benefits include increased availability of P and micronutrients in the soil (Marschner, 1995), resistance to pests and diseases (Rodrigues et al., 2004) and tolerance to excess of Fe^{2+} and Al^{3+} ions (Mengel and Kirkby, 2001), tolerance to salinity (Matoh et al., 1986) and a more erect disposition of leaves, which increases the photosynthetic rate (Ávila et al., 2010; Yoshida et al., 1962). However, the excess uptake of Si by grasses may provide a higher mechanical resistance to degradation (Melo et al., 2003); reducing their ruminal digestibility (Jones and Handreck, 1967).

For these reasons, the objective of this study was to evaluate the effect of the substitution of calcium carbonate by calcium silicate on the nutrition, biomass production and feed quality of palisade grass cultivated in soils with different texture and mineralogical composition.

Materials and Methods

Three greenhouse experiments were conducted in Lavras, state of Minas Gerais - Brazil, with three types of soil, each comprising a specific experiment. In order to include a wide variation soils with varying physical, chemical and mineralogical attributes were used: sandy loam dystrophic Typic Haplustox (LVAd-1), a sandy clay loam dystrophic Typic Haplustox (LVAd-2), and clayey dystrophic Rhodic Haplustox (LVd) (Embrapa, 2006). They were collected from the 0-20 cm layer, under natural vegetation, after the removal of the organic remains present on the surface. Later, after sieving through 4-mm mesh sieve, soil subsamples were characterized chemically, physically and mineralogically (Table 1).

Treatments were distributed in a completely randomized design with four replications and included five substitution levels (0, 25, 50, 75 and 100 %) of $CaCO_3$ and $MgCO_3$ by $CaSiO_3$ and $MgSiO_3$, and an untreated control. The salts (pa grade) were expressed in $CaCO_3$ equivalent (Alcarde and Rodella, 1996). In all of the treatments a 4:1 stoichiometric ratio of Ca:Mg was maintained and supplied in amounts sufficient to elevate the base saturation of each soil to 60 % (Van Raij et al., 1996) (Table 2).

After the application of the treatments and 30 days of incubation, each experimental unit received application of

Table 1 – Chemical, physical and mineralogical attributes of the soil samples (0-20 cm depth), prior to treatments.

Soil	Chemical(1)															
	pH	P	K	Zn	Cu	Mn	Fe	EP	Ca	Mg	Al	H+Al	T	m	V	MPAC
		mg dm^{-3}						mg L^{-1}	$mmol_c$ dm^{-3} of soil					%		mg kg^{-1}
LVAd-1	5.2	2.0	74	2.4	0.9	7.3	86	24.4	5	2	6	40	49	40	18.4	396
LVAd-2	4.9	2.3	52	5.5	1.3	8.2	176	17.4	8	2	8	63	74	41	15.3	776
LVd	4.7	1.4	31	2.0	1.8	6.8	95	8.3	4	1	0	110	116	62	5.3	1275

Soil	Physical(2)			
	Sand	Silt	Clay	OM
	g kg^{-1}			
LVAd-1	690	80	230	19
LVAd-2	520	80	400	26
LVd	250	60	690	41

Soil	Mineralogical(3)										
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	Fe_d	Fe_o	Ct	Gb	Ki	Kr
	g kg^{-1} of clay										
LVAd-1	95.1	97.4	36.2	6.2	0.0	10.8	0.1	752.0	63.0	0.98	0.71
LVAd-2	137.6	203.9	53.9	11.2	0.4	44.5	5.8	535.6	202.3	0.67	0.53
LVd	129.8	319.1	171.8	22.0	0.9	101.6	9.2	292.7	358.8	0.41	0.26

(1)pH in water, Ca, Mg, K and Al were determined according to Embrapa (1997); P in the equilibrium solution (EP) according to Alvarez V. et al. (2000); H+Al and level of organic matter (OM) according to Van Raij et al. (1987). T = Cation exchange capacity at pH 7.0; m = Aluminum saturation index; V = Base saturation index and MPAC = maximum P adsorption capacity. (2)The soil granulometry was determined by the pipette method (Day, 1965). (3)SiO_2, Al_2O_3, Fe_2O_3, TiO_2 and P_2O_5 were determined according to Embrapa (1997); Fe_d, according to Mehra and Jackson (1960); Fe_o, according to Schwertmann (1964) and Ct (kaolinite) and Gb (gibbsite) according to Klug and Alexander (1974). Ki = SiO_2 / Al_2O_3 and Kr = SiO_2 / (Al_2O_3 + Fe_2O_3).

Table 2 – Corrective levels to elevate the base saturation of each soil to 60 %, expressed as $CaCO_3$ equivalent: $CaCO_3$ = 1.000; $MgCO_3$ = 1.183; $CaSiO_3$ = 0.879 and $MgSiO_3$ = 1.017.

Soil	Treatment	Corrective				Ca	Mg	Si
		$CaCO_3$	$MgCO_3$	$CaSiO_3$	$MgSiO_3$			
	%$CaSiO_3$	mg dm^{-3}						
LVAd-1	0	815	172	0	0	320	49	0
LVAd-1	25	612	129	232	50	320	49	70
LVAd-1	50	408	86	464	100	320	49	140
LVAd-1	75	204	43	696	150	320	49	210
LVAd-1	100	0	0	928	200	320	49	280
LVAd-2	0	1323	280	0	0	519	79	0
LVAd-2	25	992	210	376	81	519	79	114
LVAd-2	50	662	140	753	163	519	79	227
LVAd-2	75	331	70	1129	244	519	79	341
LVAd-2	100	0	0	1505	325	519	79	455
LVd	0	2538	536	0	0	996	151	0
LVd	25	1904	402	722	156	996	151	218
LVd	50	1269	268	1444	312	996	151	436
LVd	75	635	134	2166	468	996	151	654
LVd	100	0	0	2887	624	996	151	873

fertilizers as basal dressing, made up of: 300 mg dm^{-3} N, 200 mg dm^{-3} P, 300 mg dm^{-3} K, 50 mg dm^{-3} S, 0.5 mg dm^{-3} B, 1.5 mg dm^{-3} Cu, 3.0 mg dm^{-3} Mn, 0.1 mg dm^{-3} Mo, 5.0 mg dm^{-3} Zn and 5.0 mg dm^{-3} Fe; added as solutions of $NH_4H_2PO_4$, K_2SO_4, KNO_3, NH_4NO_3, H_3BO_3, $CuSO_4.5H_2O$, $ZnSO_4.7H_2O$, $FeSO_4.7H_2O$, $MnCl_2.4H_2O$ and $H_2MoO_4.H_2O$ (pa grade). After each cut, fertilization as top dressing was performed, made up of 240, 170 and 60 mg dm^{-3} of N, K and S, respectively, added as solutions of $NH_4H_2PO_4$, K_2SO_4 and KNO_3 (pa grade). During the experimental period, the soil water content was maintained at around 60 % of the total pore volume by periodically weighing the pots and adding deionized water to compensate for weight loss.

Three plants per pot of 'Vitoria' palisade grass [*Urochloa brizantha* (C. Hochstetter ex A. Rich.) R. Webster] were cultivated in 4 dm^3 of soil, which were cut during the pre-flowering developmental phases (90 and 140 days after the seedling emergence). After each cutting, shoots were dried for 72 h at 60-65 °C in a forced draught oven, weighed (to obtain dry matter) and triturated in a Wiley-type mill. Biomass obtained from the two cuts were combined to determine the concentration of crude protein (CP) (Silva, 1998), Si (Gallo and Furlani, 1978) and nutrients (Malavolta et al., 1997). Accumulation of Si and nutrients in plant shoots was measured, from the relationship between biomass production and concentrations of Si and nutrients, and quantification of the neutral detergent fiber (NDF) and acid detergent fiber (ADF) were carried out according to van Soest (1994). From these values, the dry matter ingestion (DMI = 120 / %NDF), the dry matter digestibility [DMD = 88.9 (0.779 × %ADF)] and the relative feed value (RFV = DMD × DMI / 1.29) of the forage were estimated according to *American Forage and Grassland Council* (Ensminger, 1993).

Data were submitted to the variance analysis by the F test ($p \leq 0.05$) using the SISVAR software (Ferreira, 2008). When significant, the effect of the calcium silicate on the variables was verified by polynomial regression analysis.

Results and Discussion

Dry matter production was similar for the first and second cuts and the total of the two cuts (TDM) had similar behavior. In general, the 50 % substitution of $CaCO_3$ by $CaSiO_3$ promoted higher benefits in the production of TDM, which was increased by 2.6, 15.2 and 19.5 % for the LVAd-1, LVAd-2 and LVd soils, respectively, compared to the treatments that only received $CaCO_3$ (Figure 1). Most likely the increase in biomass, particularly for the plants cultivated on LVAd-2 and LVd, was due to the silicon (Si) added to the soil by $CaSiO_3$. Marschner (1995) found Si does not have a defined metabolic role in the plants, however, its action provokes indirect effects, which, when combined can contribute to a higher vegetative production. Silicon accumulation in epidermal cells of the plant shoot promotes a better leaf opening angle, making them more erect, reduces self-shading favoring a better light use and it elevates the photosynthetic rate, culminating in higher biomass production

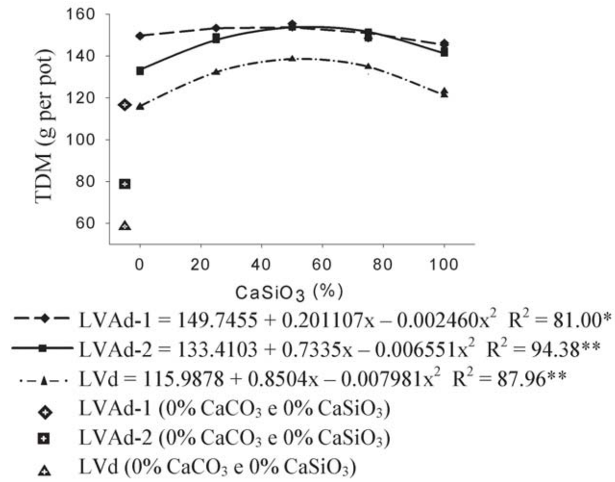

Figure 1 – Production of total dry matter (TDM) for palisade grass shoots cultivated on LVAd-1, LVAd-2 and LVd soils, as a function of substitution proportions of the calcium carbonate by calcium silicate. * and ** = $p \leq 0.05$ and $p \leq 0.01$, respectively.

(Yoshida et al., 1962). Other beneficial effects of Si in grasses have also been noted, such as reduced transpiration (Dayanandam et. al., 1983) and nutrient imbalance (Marschner, 1995; McKeague and Cline, 1963), and increased protection against UV radiation (Tisdale et al., 1993), pest and disease resistance (Rodrigues et al., 2004) and antioxidant enzyme activity (Liang et al., 2003).

In general, the effect of treatments on biomass production was less evident for LVAd-1, probably due its lower clay content (Table 1). Dry matter production by the control (0 % $CaCO_3$ and 0 % $CaSiO_3$) was inferior to the other treatments, which shows the importance of soil correction for palisade grass production.

The concentrations and accumulations of calcium (Ca) and magnesium (Mg) in palisade grass shoots (Figure 2 and Table 3) increased considerably with increasing proportions of $CaSiO_3$ up to an average of 65 %. This behavior can be due to the higher reactivity of the silicates (Lackner, 2002; Ramos et al., 2006). Alcarde and Rodella (2003) found $CaSiO_3$ to be 6.78 times more soluble than $CaCO_3$. These factors could have contributed to increasing the absorption of these nutrients due to higher availability of Ca and Mg to the palisade grass. Kaya et al. (2006) and Mali and Aery (2008) verified increases in the concentrations of Ca in corn (*Zea mays*) and cowpea (*Vigna unguiculata*), respectively, with application of silicates to the soil, in agreement with the results obtained in this work.

The accumulations of Ca and Mg in palisade grass shoots, in the soil without correction (0 % $CaCO_3$ and 0 % $CaSiO_3$), was generally similar to treatments that received only $CaCO_3$. This shows that soil correction with only $CaCO_3$ had little influence on the Ca and Mg absorption by the palisade grass. Concentrations of exchangeable Ca^{2+} and Mg^{2+} in the three soils without correction (Table 1) were in the ranges considered by van Raij et al. (1996) as average

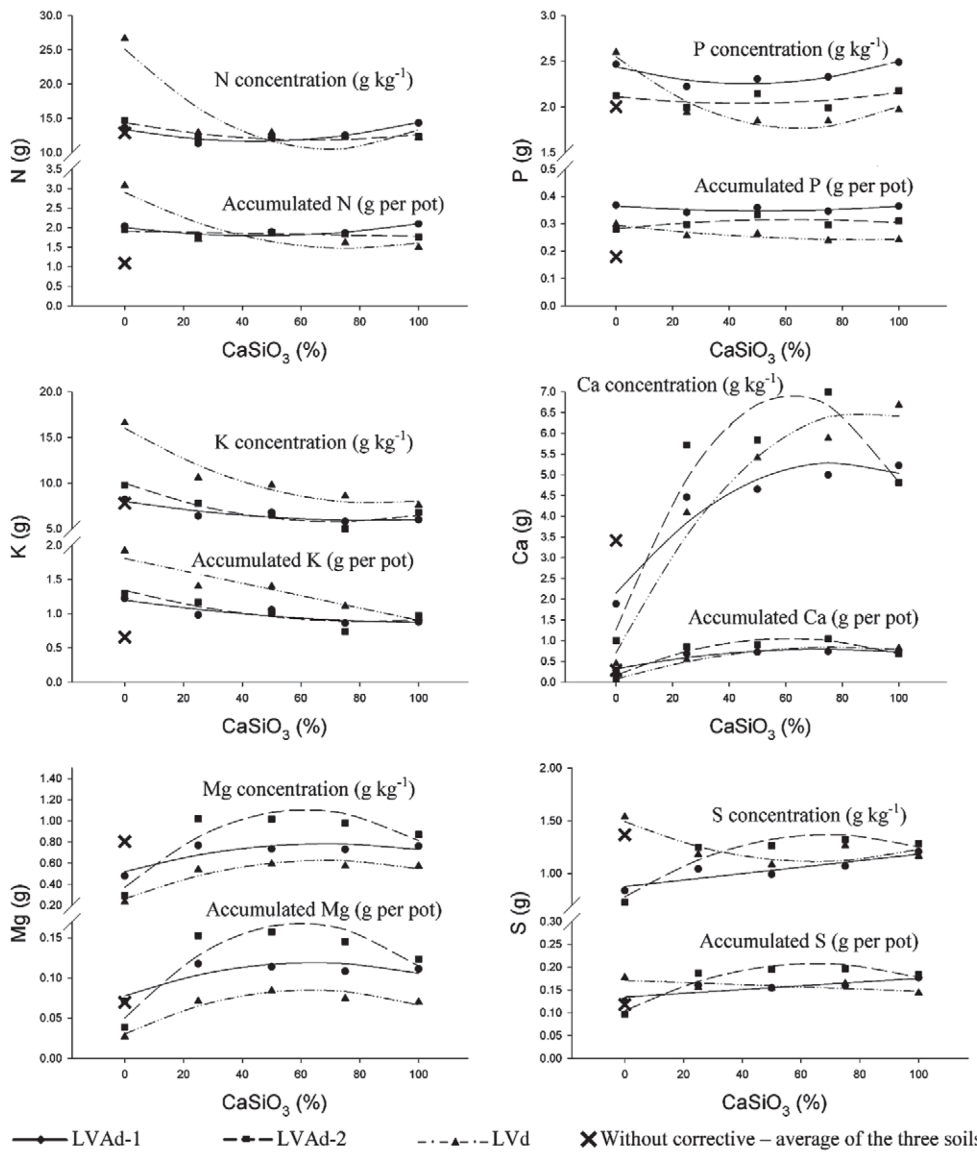

Figure 2 – Concentration and accumulation of macronutrients for palisade grass shoots cultivated on LVAd-1, LVAd-2 and LVd soils, as a function of substitute proportions of the calcium carbonate by calcium silicate.

(4-7 $mmol_c$ of Ca^{+2} dm^{-3}) and low (0-4 $mmol_c$ of Mg^{+2} dm^{-3}), respectively.

The concentration and the accumulation of nitrogen (N), potassium (K) and sulfur (S) in the shoot of the palisade grass (Figure 2 and Table 3), when cultivated in LVd, decreased as the $CaSiO_3$ proportions increased, until an average value of 70 % of $CaSiO_3$, when it tended to stabilize. Calcium silicate at 70 % of the correction for LVd reduced the concentrations of N, K and S to 58, 49 and 25 %, respectively, and their accumulations to 58, 49 and 9 %, respectively. However, for the plants cultivated in LVAd-1 and LVAd-2, the concentrations and accumulations of these nutrients were mostly unaffected. Conversely, S increased in shoots as $CaSiO_3$ increased. LVd has a higher cation exchange capacity (CEC) and levels of organic matter, gibbsite, iron oxides and clay, compared to the other appraised soils (Table 1). This partly explains the differentiated behavior of the plants as to the N, K and S absorption as a function of soil type. For instance, the higher CEC of LVd demanded a higher amount of correctives to elevate the base saturation to 60 %. This resulted in a larger amount of Si being added with $CaSiO_3$. Wallace (1989) reports that for the absorption sites of the plant there is competition among the anions $H_3SiO_4^-$ and NO_3^-. The lower accumulation of K and S observed with increased $CaSiO_3$ proportions can likely be explained by the higher solubility of $CaSiO_3$ compared to $CaCO_3$, which increases soil solution Ca^{2+} and Mg^{2+}, antagonism for the absorption of K^+ (Malavolta et al., 1997), and low solubility SO_4^{2-}. To reiterate, accumulations of N and K in the shoot of the palisade grass were lower when soils did not receive correctives, showing the influence of correctives on N and K absorption by the palisade grass, regardless of soil type.

Table 3 – Regression equations for concentration and accumulation of macronutrients in palisade grass shoots cultivated on LVAd-1, LVAd-2 and LVd soils, as a function of substitute proportions of the calcium carbonate by calcium silicate.

Factor	Soils	Regression equation for concentration	Regression equation for accumulation
N	LVAd-1	$\hat{y} = 13.3848 - 0.0780x + 0.000884x^2$ $R^2 = 87.28^{**}$	$\hat{y} = 2.0024 - 0.0092x + 0.000102x^2$ $R^2 = 75.52^{*}$
N	LVAd-2	$\hat{y} = 14.3781 - 0.0793x + 0.000617x^2$ $R^2 = 78.34^{*}$	$\hat{y} = 1.9117 - 0.00134x$ $R^2 = 50.62ns$
N	LVd	$\hat{y} = 25.0981 - 0.4196x + 0.003017x^2$ $R^2 = 86.38^{**}$	$\hat{y} = 2.9056 - 0.0374x + 0.000244x^2$ $R^2 = 83.46^{**}$
P	LVAd-1	$\hat{y} = 2.4397 - 0.0080x + 0.000086x^2$ $R^2 = 83.51ns$	$\hat{y} = 0.3649 - 0.0007x + 0.000007x^2$ $R^2 = 47.27ns$
P	LVAd-2	$\hat{y} = 2.1114 - 0.0033x + 0.000037x^2$ $R^2 = 28.64ns$	$\hat{y} = 0.2815 + 0.0011x - 0.000009x^2$ $R^2 = 50.02ns$
P	LVd	$\hat{y} = 2.5477 - 0.0243x + 0.000189x^2$ $R^2 = 94.40^{**}$	$\hat{y} = 0.2948 - 0.0012x + 0.000007x^2$ $R^2 = 85.74ns$
K	LVAd-1	$\hat{y} = 8.0114 - 0.0497x + 0.000297x^2$ $R^2 = 82.13ns$	$\hat{y} = 1.1976 - 0.0061x + 0.000028x^2$ $R^2 = 80.06ns$
K	LVAd-2	$\hat{y} = 2.4397 - 0.0080x + 0.000086x^2$ $R^2 = 91.72^{*}$	$\hat{y} = 1.3389 - 0.0110x + 0.000067x^2$ $R^2 = 79.72^{*}$
K	LVd	$\hat{y} = 16.0114 - 0.1897x + 0.001097x^2$ $R^2 = 93.86^{**}$	$\hat{y} = 1.8058 - 0.009041x$ $R^2 = 91.34^{**}$
Ca	LVAd-1	$\hat{y} = 2.1517 + 0.0807x - 0.000519x^2$ $R^2 = 91.44^{**}$	$\hat{y} = 0.3230 + 0.0130x - 0.000089x^2$ $R^2 = 90.77^{**}$
Ca	LVAd-2	$\hat{y} = 1.2679 + 0.1817x - 0.001461x^2$ $R^2 = 92.54^{**}$	$\hat{y} = 0.1696 + 0.0288x - 0.000237x^2$ $R^2 = 94.23^{**}$
Ca	LVd	$\hat{y} = 0.71196 + 0.1319x - 0.000748x^2$ $R^2 = 97.10^{**}$	$\hat{y} = 0.0783 + 0.0197x - 0.000126x^2$ $R^2 = 97.08^{**}$
Mg	LVAd-1	$\hat{y} = 0.5194 + 0.0077x - 0.000056x^2$ $R^2 = 75.55^{**}$	$\hat{y} = 0.0777 + 0.0013x - 0.000010x^2$ $R^2 = 74.45^{**}$
Mg	LVAd-2	$\hat{y} = 0.3712 + 0.0239x - 0.000195x^2$ $R^2 = 86.44^{**}$	$\hat{y} = 0.0502 + 0.0039x - 0.000033x^2$ $R^2 = 88.53^{**}$
Mg	LVd	$\hat{y} = 0.2619 + 0.0107x - 0.000078x^2$ $R^2 = 91.95^{**}$	$\hat{y} = 0.0304 + 0.0017x - 0.000014x^2$ $R^2 = 92.93^{**}$
S	LVAd-1	$\hat{y} = 0.8760 + 0.003073x$ $R^2 = 82.09^{**}$	$\hat{y} = 0.1344 + 0.000411x$ $R^2 = 74.88^{**}$
S	LVAd-2	$\hat{y} = 0.7782 + 0.0107x - 0.000123x^2$ $R^2 = 90.43^{**}$	$\hat{y} = 0.1042 + 0.0032x - 0.000025x^2$ $R^2 = 92.51^{**}$
S	LVd	$\hat{y} = 1.4918 - 0.0117x + 0.000091x^2$ $R^2 = 72.31^{**}$	$\hat{y} = 0.1709 - 0.000239x$ $R^2 = 55.68^{*}$

* and ** = $p \leq 0.05$ and $p \leq 0.01$, respectively. ns = Not significant ($p > 0.05$).

As for the phosphorus (P), $CaSiO_3$ proportions, up to an average of 64 % $CaSiO_3$, decreased P concentration in palisade grass shoots for the LVd (Figure 2 and Table 3). However, the P accumulation (Figure 2 and Table 3) was not significant ($p > 0.05$) among treatments, showing that a lower P concentration was likely due to the "dilution" effect, which is confirmed by the higher shoot dry matter production observed for the 60 % $CaSiO_3$ treatment (Figure 1). For example, when plant production increases, the "dilution" effect for some nutrients can occur (Crusciol et al., 2008; Marschner, 1995; Miyauchi at al., 2008), which is the reduction of their concentration in the tissue without an alteration in the absorbed quantity. Still, the concentration of P in the plants cultivated on LVAd-1 and LVAd-2 were not different either among treatments. This shows that for P, the substitution of $CaCO_3$ by $CaSiO_3$, in any proportion, does not influence its absorption by palisade grass. Tokura et al. (2007) also verified no effect of silicon doses on P uptake for upland rice (*Oryza sativa* L.) grown on dystroferric Rhodic Acrustox and orthic Ustic Quartzipsamments.

The accumulation of P was much lower in relation to the other plants for palisade grass cultivated in soil without correction. The elevation of the pH promoted by soil correction increases the concentration and activity of the OH^- ion in solution, generating negative charges for the deprotonation of hydroxyls in the exposed clay and organic matter. Thus, the repulsion between orthophosphate ions and the soil mineral particles increases, allowing more P to stay in solution and remain available for plant uptake, especially in soils with high oxide and clay levels. The precipitation of Fe and Al reduces the formation of low solubility P-Fe and P-Al compounds (Novais and Smyth, 1999).

Concentrations and accumulations of the cationic micronutrients in the shoot of the palisade grass (Figure 3 and Table 4) tended to reduce with the elevation of the $CaSiO_3$ proportions, particularly for Zn. Besides the direct effect of silicate, the increased absorption of Ca^{2+} and Mg^{2+} by palisade grass with increased proportions of $CaSiO_3$ could have been one of the causes of lower Zn^{2+} absorption, as Malavolta et al. (1997) found competitive inhibition among those nutrients for plant absorption sites. Concentration and accumulation of Cu were decreased only for plants cultivated on LVd. Malavolta et al. (1997) also mentioned Ca^{2+} can impede the exaggerated absorption of Cu^{2+}. The effects of the treatments on the concentrations and accumulations of Mn and Fe were also influenced by the soil type. Decreased accumulations of these nutrients in the shoot of the plants were significant only for those cultivated on LVAd-1. Silicon can increase the paerenchyma quantity and diameter in the grasses elevating the oxidant power of the roots, therefore reducing the availability of Mn^{2+} and Fe^{2+} (Korndörfer et al., 1999; Marschner, 1995).

Boron concentration and accumulation (Figure 3 and Table 4) increased as $CaSiO_3$ proportions were elevated in the three soils, until an average value of 57 % $CaSiO_3$, thereafter decreasing in plants cultivated on LVd and LVAd-1 soils. In comparison, the $CaSiO_3$ proportion of 57 % in the correction of LVAd-1, LVAd-2 and LVd promoted increases of 71, 30 and 53 % in the B concentration, respectively, and 74, 34 and 85 % in the accumulation, respectively, in shoots. Marschner (1995) mentioned H_4SiO_4 and H_3BO_3, which are

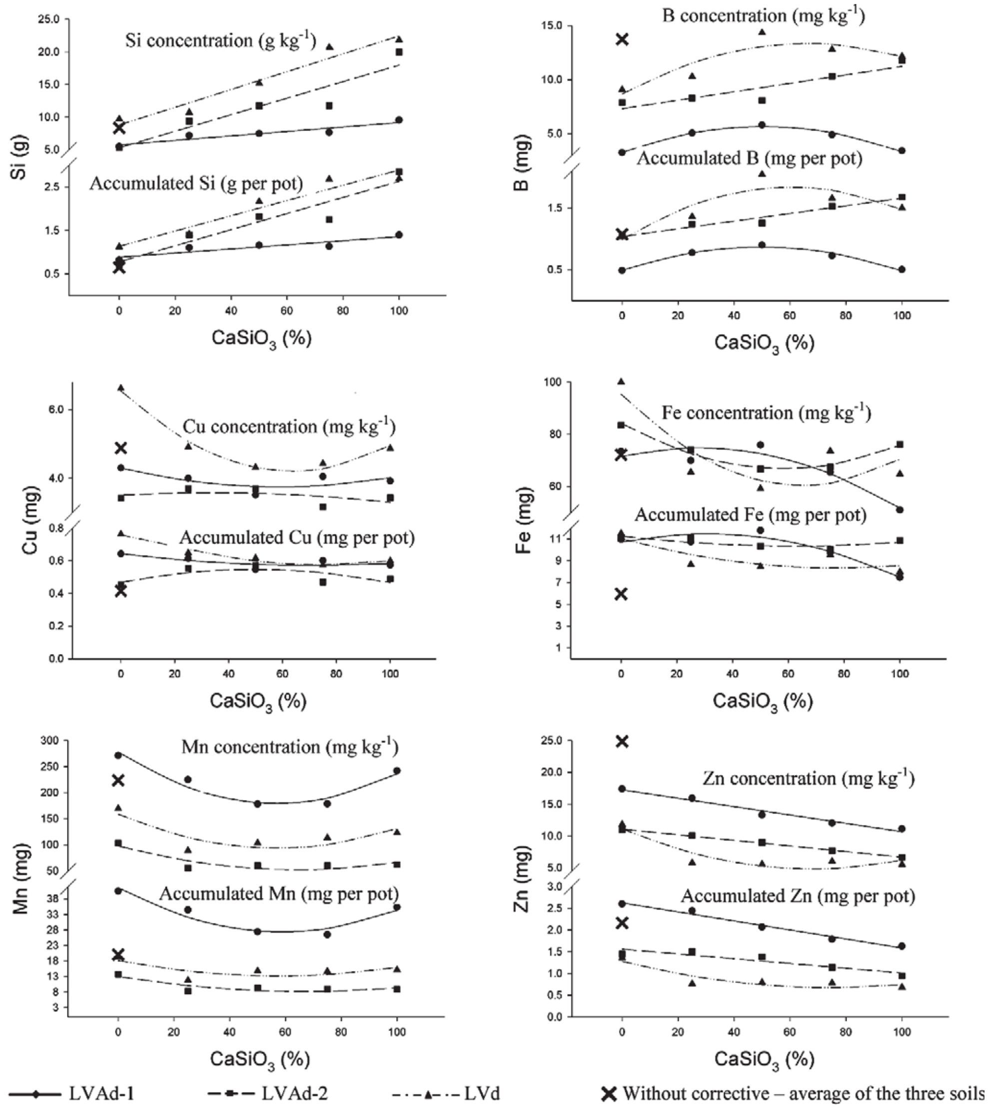

Figure 3 – Concentration and accumulation of micronutrients and Si for palisade grass shoots cultivated on LVAd-1, LVAd-2 and LVd soils, as a function of substitute proportions of the calcium carbonate by calcium silicate.

the main forms of Si and B absorbed by plants, present some similarities as to their behavior in soil solution and plant tissue; both acids are very weak in aqueous solutions and, in the plant, they concentrate in the cell wall, interacting with pectins and polyphenols.

Silicon concentration and accumulation (Figure 3 and Table 4) increased linearly with the elevation of the $CaSiO_3$ proportions in the three soils. Plants cultivated on LVd and LVAd-2 had a higher rate of increase in Si content with increased $CaSiO_3$, compared to those cultivated on LVAd-1. The range of Si concentration was between 5 to 23 g kg^{-1} of Si, which is equal to 1.1-4.9 % of SiO_2, a range considered appropriate by Marschner (1995) for grasses grown on non-flooded soil.

Concentration and accumulation of Si in the soil without correction were similar to those of plants that received only $CaCO_3$ (0 % $CaSiO_3$ treatment), regardlees of the soil type. As a result, it is explicit that the additional Si absorbed by palisade grass in treatments that received $CaSiO_3$ originated from this source. These results corroborate those of Melo et al. (2003) who also verified increases in concentration and accumulation of Si in the palisade grass shoots with the application of this element to the soil.

The substitution of the $CaCO_3$ by $CaSiO_3$ promoted decreased crude protein (CP) concentration in palisade grass shoots for plants cultivated on the LVd. The highest $CaSiO_3$ proportion also provided reduced NDF and ADF, consequently, resulting in an increase of the estimated values of dry matter digestibility (DMD), dry matter ingestion (DMI) and relative feed value (RFV) of the forage (Figure 4). According to Ensminger (1993) DMD and DMI values of forage are correlated with the concentrations of ADF and NDF, respectively.

Thus, the increased concentration and accumulation of Si (Figures 2 and 3) did not result in reduction of forage feed quality. To the contrary, an increase in RFV was observed

Table 4 – Regression equations for concentration and accumulation of micronutrients and Si in palisade grass shoots cultivated on LVAd-1, LVAd-2 and LVd soils, as a function of substitute proportions of the calcium carbonate by calcium silicate.

Factor	Soils	Regression equation for concentration	Regression equation for accumulation
Si	LVAd-1	$\hat{y} = 5.7469 + 0.034235$ $R^2 = 88.17^{**}$	$\hat{y} = 0.8853 + 0.0047x$ $R^2 = 83.00^{*}$
Si	LVAd-2	$\hat{y} = 5.3067 + 0.126664$ $R^2 = 87.64^{**}$	$\hat{y} = 0.7781 + 0.0185x$ $R^2 = 88.99^{**}$
Si	LVd	$\hat{y} = 8.7785 + 0.136692x$ $R^2 = 94.80^{**}$	$\hat{y} = 1.1360 + 0.0176x$ $R^2 = 93.17^{**}$
B	LVAd-1	$\hat{y} = 3.2883 + 0.0944x - 0.000937x^2$ $R^2 = 98.62^{**}$	$\hat{y} = 0.4935 + 0.0150x - 0.000151x^2$ $R^2 = 97.25^{**}$
B	LVAd-2	$\hat{y} = 7.32427 + 0.039041x$ $R^2 = 82.53^{**}$	$\hat{y} = 0.0388 + 0.0062x$ $R^2 = 95.30^{**}$
B	LVd	$\hat{y} = 8.6814 + 0.1406x - 0.001059x^2$ $R^2 = 79.38^{**}$	$\hat{y} = 0.9917 + 0.0279x - 0.000231x^2$ $R^2 = 96.79^{**}$
Cu	LVAd-1	$\hat{y} = 4.2037 - 0.0185x + 0.000157x^2$ $R^2 = 56.02^{ns}$	$\hat{y} = 0.6431 - 0.0020x + 0.000014x^2$ $R^2 = 61.01^{ns}$
Cu	LVAd-2	$\hat{y} = 3.5069 + 0.0041x - 0.000062x^2$ $R^2 = 23.82^{ns}$	$\hat{y} = 0.4691 + 0.0032x - 0.000032x^2$ $R^2 = 51.67^{ns}$
Cu	LVd	$\hat{y} = 6.5403 - 0.0723x + 0.000571x^2$ $R^2 = 98.18^{**}$	$\hat{y} = 0.7600 - 0.0047x + 0.000031x^2$ $R^2 = 97.92^{*}$
Fe	LVAd-1	$\hat{y} = 71.5174 + 0.2407x - 0.004383x^2$ $R^2 = 90.02^{ns}$	$\hat{y} = 10.7065 + 0.0506x - 0.000826x^2$ $R^2 = 91.28^{*}$
Fe	LVAd-2	$\hat{y} = 84.2069 - 0.5941x + 0.005090x2$ $R^2 = 97.90^{ns}$	$\hat{y} = 11.2636 - 0.0295x + 0.000236x^2$ $R^2 = 57.33^{ns}$
Fe	LVd	$\hat{y} = 95.3400 - 1.0723x + 0.008232x^2$ $R^2 = 72.80^{*}$	$\hat{y} = 11.0183 - 0.0692x + 0.000444x^2$ $R^2 = 62.83^{ns}$
Mn	LVAd-1	$\hat{y} = 278.0420 - 3.4624x + 0.030440x^2$ $R^2 = 93.71^{**}$	$\hat{y} = 41.6557 - 0.4835x + 0.004105x^2$ $R^2 = 91.49^{**}$
Mn	LVAd-2	$\hat{y} = 97.8774 - 1.4099x + 0.010945x^2$ $R^2 = 80.44^{ns}$	$\hat{y} = 13.0046 - 0.1427x + 0.001061x^2$ $R^2 = 74.42^{ns}$
Mn	LVd	$\hat{y} = 158.7883 - 2.2849x + 0.020091x^2$ $R^2 = 71.75^{*}$	$\hat{y} = 18.1686 - 0.1720x + 0.001496x^2$ $R^2 = 51.46^{ns}$
Zn	LVAd-1	$\hat{y} = 17.2540 - 0.065800x$ $R^2 = 96.90^{**}$	$\hat{y} = 2.6259 - 0.010392x$ $R^2 = 98.02^{**}$
Zn	LVAd-2	$\hat{y} = 11.0620 - 0.04400x$ $R^2 = 99.62^{**}$	$\hat{y} = 1.5587 - 0.005481x$ $R^2 = 84.88^{**}$
Zn	LVd	$\hat{y} = 11.1003 - 0.1841x + 0.001347x^2$ $R^2 = 84.00^{**}$	$\hat{y} = 1.2780 - 0.01618x + 0.000108x^2$ $R^2 = 81.09^{*}$

* and ** = $p \leq 0.05$ and $p \leq 0.01$, respectively. ns = Not significant ($p > 0.05$).

with up to 50 % of substitution of the $CaCO_3$ by $CaSiO_3$. These results are corroborated by those of Minson (1990) and van Soest (1994) who did not find negative correlation between Si concentration and forage digestibility. Forage quality is directly related to its nutritional composition, anti-nutritional factors and those which are usually involved in plant protection against the predation and degradation (van Soest, 1994). Garleb et al. (1988) found decreased forage digestibility as the lignin concentration increased.

There is no consensus regarding the effect of Si on forage quality (van Soest, 1994), due to the fact that plants with different Si concentrations also have different composition of other components such as lignin concentration, carbon to nitrogen ratio and differentiated arrangements of cellulose fibrils, which could affect the forage digestibility. Minson (1971) found that Si caused lignin reduction in leaf tissues due to the similar role of both in strengthening cell walls.

The presence of Si in the forage is of great interest because it is considered an essential element for animals being a component of mucopolysaccharides in connective tissues. In herbivores the ingestion of high amounts of phytoliths can cause excessive abrasion in the rumen wall and the dissolved Si can form kidney concretions, causing serious damage to the livestock (Marschner, 1995).

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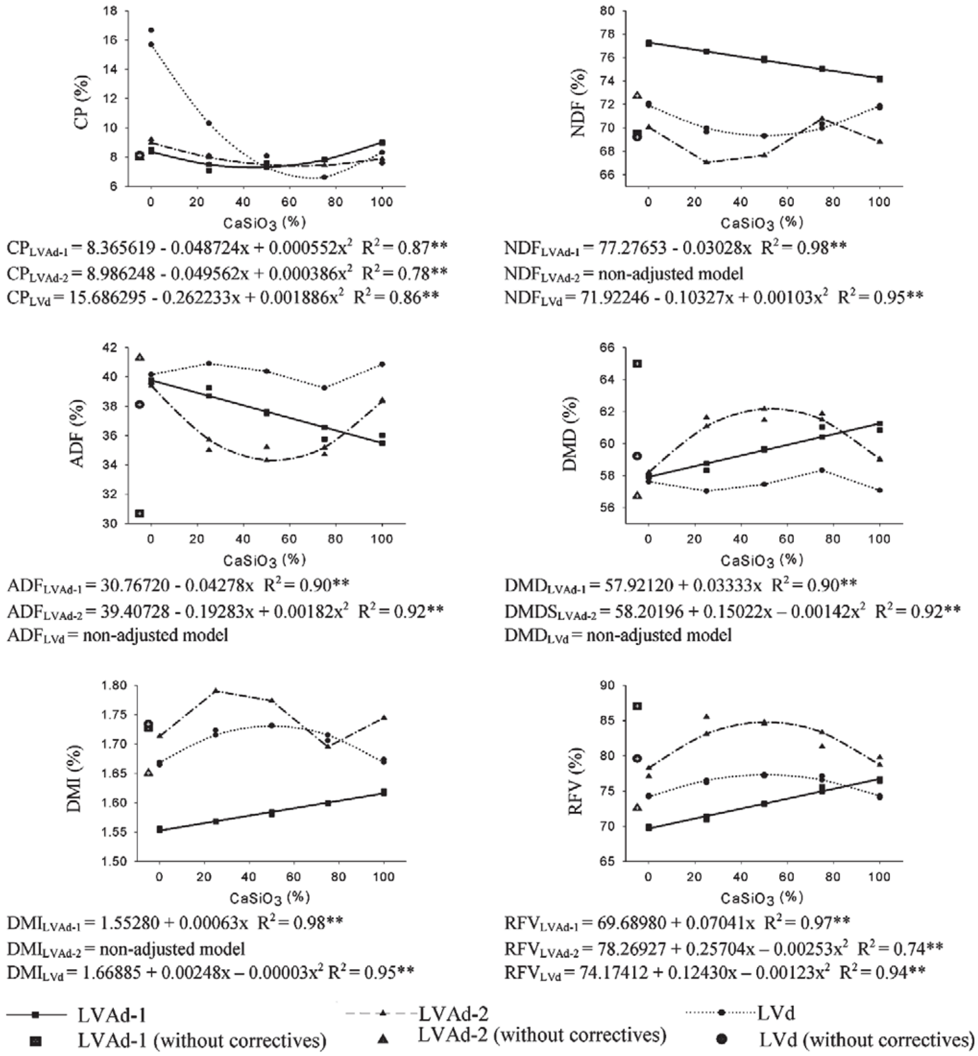

Figure 4 – Concentration of crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF), and dry matter digestibility (DMD), dry matter ingestion (DMI, in % of body weight) and relative feed value (RFV) for palisade grass shoots, as a function of substitute proportions of the calcium carbonate by calcium silicate. ** and ns = $p \leq 0.01$ and not significant ($p > 0.05$), respectively.

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