Nutrient accumulation and biomass production of alfafa after soil amendment with silicates[1]

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ABSTRACT

Studies on the use of silicate correctives in agriculture show that they have great potential to improve soil chemical characteristics, however, little information is available on the reactivity rates of their particle-size fractions. This study investigated whether the reactivity rates obtained experimentally could be considered in the calculation of ECC (effective calcium carbonate) for soil liming, promoting adequate development of alfalfa plants. Six treatments were evaluated in the experiment, consisting of two slag types applied in two rates. The experimental ECC was used to calculate one of the rates and the ECC determined in the laboratory was used to calculate the other. Rates of limestone and wollastonite were based on the ECC determined in laboratory. The rates of each soil acidity corretive were calculated to increase the base saturation to 80%. The treatments were applied to a Rhodic Hapludox and an Alfisol Ferrudalfs. The methods for ECC determination established for lime can be applied to steel slag. The application of slag corrected soil acidity with consequent accumulation of Ca, P, and Si in alfalfa, favoring DM production.

Key words: slag, soil acidity, ECC, *Medicago sativa.*

RESUMO

Acúmulo de nutrientes e produção de biomassa de plantas de alfafa após correção do solo com silicatos

Pesquisas sobre o uso agronômico de corretivos à base de silicatos têm apontado o grande potencial desses insumos, no sentido de promover melhorias químicas do solo. Há poucas informações, porém, sobre as taxas de reatividade de suas frações granulométricas. O objetivo deste estudo foi verificar se a eficiência relativa de reatividade das frações granulométricas, obtidas experimentalmente, poderiam ser consideradas no cálculo do PRNT para prática da calagem, proporcionando adequado desenvolvimento de plantas de alfafa. Utilizaram-se seis tratamentos, que consistiram em duas escórias, aplicadas em duas doses, uma utilizando-se do PRNT medido experimentalmente e, a outra, do PRNT determinado em laboratório; calcário dolomítico e wollastonita, aplicados em uma dose, utilizando-se o PRNT determinado em laboratório. As doses dos corretivos foram calculadas a fim de elevar a saturação por bases a 80 %, considerando o PRNT experimental e de laboratório. Os tratamentos foram aplicados a dois solos: Latossolo Vermelho distrófico e Nitossolo Vermelho eutrófico. Os métodos de determinação de PRNT preconizados para calcários podem ser aplicados para escórias de siderurgia. A aplicação das escórias proporcionou ação corretiva do solo, com consequente maior acúmulo de Ca, P, e Si nas plantas de alfafa, favorecendo sua produção de matéria seca.

Palavras-chave: escória de aciaria, acidez, PRNT, *Medicago sativa L.*.

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INTRODUCTION

Correcting soil acidity is essential for crop productivity, mainly in Brazil, where more than 70% of the agricultural soils are acidic. Limestone is the most used corrective in soil acidity neutralization. However, studies on the use of silicate correctives, such as steel slag, in agriculture show that they have high potential to provide soil chemical improvements, mainly by increasing pH and base saturation (Brassioli *et al*., 2009; Corrêa *et al*., 2009).

Under field conditions, slag corrected soil acidity more efficiently than limestone (Corrêa *et al*., 2007). However, it could be a result of lower effective calcium carbonate (ECC) of some slag types compared with limestone; therefore, greater amounts of silicates are required to raise base saturation to the adequate level for the crop.

Slag is classified as soil acidity corrective and the same legislation for limestone is applied for its commercialization, i.e., the relative efficiency of reactivity (RER) for silicate particle-size fractions are based on the same rates determined for carbonate materials, which are 0 for particles retained in sieve #10, fractions > 2.00 mm; 20% for retention in sieve #20, fractions from 2.00 to 0.84 mm; 60% for retention in sieve #50, fractions from 0.84 to 0.30 mm; and 100% for fractions < 0.30 mm sieved through #50. Although the corrective capacity of slag and limestone are similar, when carbonate RER is used to calculate the dose of steel slag, errors may occur because these materials have distinct compositions. Moreover, SiO_3 anion solubility is six or seven times higher than that of carbonate (CO_3^{2-}) (Alcarde, 1992).

Thus, the RER values used for limestone become inappropriate to evaluate the RER of silicates, resulting in the underestimation of the hydrogen neutralization capacity and, consequently, the overestimation of the silicate amount necessary for soil acidity correction.

Prado *et al.* (2004) evaluated the steel slag reactivity and observed that the fraction retained in ABNT 5-10 sieves was inefficient to modify the soil pH. For the intermediate sieves ABNT 10-20 and 20-50, the RER was proportional to the current values prescribed in the Brazilian legislation for limestone. However, the industrial process generates several types of slag with different recrystallization points because of the amount of Ca, Mg and cooling time (Pereira *et al*., 2010). These characteristics can be related to the solubility of the slag compounds when added to the soil and, consequently, influence the material reactivity.

To obtain more information on the reactivity of steel slag, this study investigated whether the reactivity rates obtained experimentally could be considered in the ECC calculation for soil liming, promoting adequate development of alfalfa plants.

MATERIALS AND METHODS

Reactivity of two types of slag from distinct origins (slag 1, from steel and slag 2, from stainless steel) was compared with limestone and an additional treatment with wollastonite, which is a calcium silicate considered as an international standard.

Initially, an experiment was carried out for three months to determine relative efficiency of reactivity (RER) of each particle-size (ABNT # 5-10, 10-20, 20-50 and <50 sieves) of the sources. The RER value was used to calculate the reactivity rate (RR) for each corrective source (Deus *et al.*, 2014). Afterwards, the ECC was calculated, hereby denominated Experimental *ECC*, by the following equation:

$$ECC = \left(\frac{NP \times RR}{100}\right)$$

being: NP = neutralization power
RR = reactivity rate

The NP was determined by the acid base titration method (Alcarde, 2009). The laboratory ECC was determined following the official methodology for limestone (Alcarde, 2009).

This study was carried out in a greenhouse, using four soil acidity correctives: steel slag (slag 1) provided by Mannesmann®; stainless steel slag (slag 2) provided by Recmix®, limestone and wollastonite. The rates of each soil acidity corrective were calculated to increase the base saturation (BS) to 80%, as recommended for alfalfa (Raij *et al*., 1996). To calculate the rates of slag, the experimental and laboratory ECC were used. Limestone and wollastonite had similar experimental and laboratory values of ECC (Table 1); thus, only the laboratory ECC was used. The amount of corrective material applied per pot was calculated based on the volume of 1 ha at 0-20 cm depth, considering the capacity of 12 L per pot.

The treatments were applied to two soils (Table 2), a Rhodic Hapludox and an Alfisol Ferrudalfs (Soil Taxonomy, 2010). The experiment was arranged in a randomized block design with four replications. Fertilization was the same in both soils with 150 mg kg^{-1} of P using monoammonium phosphate (MAP) as source and 120 mg kg^{-1} of K using potassium chloride as source. The micronutrients Zn, B, Cu and Fe were provided by using 1g of silicate oxides (FTE BR12) per pot. N was supplied by MAP and seeds were inoculated with aerobic bacteria of the species *Rhizobium melilotti* for symbiotic N fixation.

Soil moisture was kept at approximately 70% of the field capacity by weekly weighing. The treatments were incubated for 30 days; then, the soil from each pot was collected for fertility analyses (Raij *et al.*, 2001) and Si determination (Korndorfer *et al*., 2004). Alfalfa was sown

Table 1. Chemical characterization of soil acidity correctives used in this study

Correctives	CaO	MgO	Si(1)	NP*	RR*	ECC*	RR	ECC
					laboratory		experimental	
		%		%ECaCO$_3$			%	
Steel Slag	36.4	14.4	14.2	71	73.3	52	116.7	82.9
Stainless Slag	47.0	10.5	13.6	87	72.3	63	116.6	101.4
Wollastonite	43.0	2.9	16.0	60	100.0	59	103.0	61.8
Limestone	47.8	14.5	9.7	105	92.5	97	99.7	104.7

(1)Si= total silicon, determined by the methodology of Korndorfer et al., 2004.(*)Methods used according to the Brazilian legislation for limestone (ALCARDE, 2009). NP - Neutralization Power; RR – reactivity rate; ECC – effective calcium carbonate.

Table 2. Chemical and textural attributes of the soils used in the experiment

Chemical attributes	Rhodic Hapludox	Alfisol Ferrudalfs
P resin (mg dm^{-3})	3	4
Organic matter (g dm^{-3})	30	18
pH (CaCl$_2$)	4.1	4.4
K(mmol$_c$ dm^{-3})	0.4	0.6
Ca (mmol$_c$ dm^{-3})	8	7
Mg (mmol$_c$ dm^{-3})	1	1
H+Al (mmol$_c$ dm^{-3})	69	71
Sum of bases (mmol$_c$ dm^{-3})	9	9
CEC (mmol$_c$ dm^{-3})	79	80
Base saturation (%)	12	11
B (mg dm^{-3})	0.34	0.41
Cu (mg dm^{-3})	0.70	8.6
Fe (mg dm^{-3})	83	36
Mn (mg dm^{-3})	0.7	11.3
Zn (mg dm^{-3})	0.0	0.2
Si (mg Kg^{-1})	4	8
Texture		
Clay (g Kg^{-1})	274	607
Sand (g Kg^{-1})	669	169
Silt (g Kg^{-1})	57	224

after the soil sampling. Twelve alfalfa plants were kept per pot until the end of the experiment. Water loss through evapotranspiration was replaced according to each plant's needs, by *in loco* observation of each pot.

At 60 days after planting, when the plants showed at least 10% of the first flowers, the first cutting was done at 10 cm above the soil. Shoot dry matter (DM) was determined and the plant material was subjected to the chemical analysis as described by Malavolta *et al*. (1997) and silicon by Korndorfer *et al*. (2004).

After the plant cutting, soil samples were collected from each pot for analyses of pH, Ca, Mg and BS% (Raij *et al*., 2001), using a small screw auger in three points of the pot not to damage the plants. At 90 days after planting, the second plant cutting was performed and the whole shoot was collected. The same procedure of the first cutting was used to determine DM and the chemical analysis.

Data were examined by analysis of variance (F test) and when there was a significant difference among the treatments, the means were compared by the t test (LSD) at 5% probability.

Table 3. Chemical analyses of the soils in the treatments after 30 and 90 days of incubation

Treatments*	pH	Ca	Mg	Base	pH	Ca	Mg	Base
	CaCl$_2$	mmol$_c$dm^{-3}		saturation (%)	CaCl$_2$	mmol$_c$dm^{-3}		saturation (%)
Lab slag 1	6.0 a	47 a	10 bc	72 a	5.5 a	30 a	6 bc	54 a
Exp slag 1	5.4 b	35 ab	8 c	58 b	4.9 b	20 ab	4 c	36 b
Lab slag 2	5.8 a	38 ab	13 b	68 a	5.3 a	26 ab	8 b	50 a
Exp slag 2	5.4 b	26 c	9 c	55 b	5.0 b	17 b	5 bc	36 b
Wollastonite	6.0 a	45 a	7 c	71 a	5.4 a	26 ab	3 c	50 a
Limestone	5.8 a	28 c	18 a	67 a	5.5 a	24 ab	15 a	57 a
C.V. %	3.2	22.3	22.9	6.4	3.5	28.2	33.4	18.4
Lab slag 1	6.0 a	49 ab	10 c	69 a	5.4 ab	45 a	10 abc	60 a
Exp slag 1	5.3 c	38 cd	9 c	58 b	4.9 b	29 b	6 cd	43 b
Lab slag 2	5.9 a	44 bc	16 b	72 a	5.6 a	41 a	13 a	65 a
Exp slag 2	5.4 bc	33 d	12 bc	58 b	4.9 b	24 b	8 bcd	41 b
Wollastonite	5.8 ab	54 a	9 c	72 a	5.1 ab	23 b	4 d	40 b
Limestone	5.7 abc	31 d	20 a	63 ab	4.9 b	19 b	12 ab	41b
C.V. %	4.7	12.6	21.1	9.7	7.3	24.5	32.9	23.0

Means followed by the same letter in the column are not significantly different by the t test at 5% probability. * Lab: laboratory ECC; Exp: experimental ECC; slag 1: steel slag; slag 2: stainless steel slag.

RESULTS AND DISCUSSION

Slag reactivity rate (RR) obtained experimentally were higher than the laboratory RR (Table 1). Therefore, the values of experimental ECC were higher than those determined in the laboratory, hence, the slag rate applied by the experimental method was lower. However, in the Alfisol Ferrudalfs, the slags applied using the experimental ECC were similar to limestone in increasing the pH and base saturation, before and after the first cutting (Table 3). When applied with the laboratory ECC, the slags kept the values of base saturation higher than those obtained with wollastonite and limestone, 30 days after application in the Alfisol Ferrudalfs.

The results were different for the Rhodic Hapludox, showing that the reactivity of the correctives varies according to the soil type. In the Rhodic Hapludox, laboratory ECC of the slags were similar to limestone and wollastonite in the two trials, and the experimental ECC of the slags had lower pH and Base saturation (Table 3).

Table 4. Dry matter (DM) and nutrient accumulation in shoots of alfalfa grown under different liming methods, at the first and second cuttings

Treatments	DMg per g per pot	N	P	K	Ca	Mg
			mg per pot			
			Rhodic Hapludox			
			1st cutting			
Lab slag 1	27.55 a	674.9	73.7 ab	489.1 ab	550.7 ab	77.2 bc
Exp slag 1	25.50 b	679.1	75.0 ab	475.9 ab	515.2 b	74.3 bc
Lab slag 2	28.33 a	754.6	87.3 a	540.6 a	517.1 ab	112.9 a
Exp slag 2	22.63 c	701.5	72.4 ab	440.7 b	378.2 c	85.0 b
Wollastonite	27.05 a	696.3	81.1 ab	556.8 a	570.8 a	65.2 c
Limestone	20.85 c	670.6	65.3 b	505.2 ab	317.4 d	113.7 a
C.V. %	10.4	13.9	15.4	12.6	7.6	9.2
			2nd cutting			
Lab slag 1	16.35 a	276.8 a	60.1 ab	287.5 a	406.2 a	65.4 b
Exp slag 1	14.52 bc	283.7 a	54.8 b	243.2 bc	317.1 b	54.9 bc
Lab slag 2	14.96 ab	227.6 b	57.5 b	248.7 abc	371.0 ab	93.6 a
Exp slag 2	15.86 ab	280.0 a	65.5 a	275.1 ab	329.3 b	88.4 a
Wollastonite	11.93 d	211.0 b	43.6 c	213.8 c	320.2 b	41.2 c
Limestone	12.94 cd	194.7 b	47.1 c	245.5 bc	232.3 c	81.3 a
C.V. %	7.6	15.4	8.8	10.4	11.0	14.4
			Alfisol Ferrudalfs			
			1st cutting			
Lab slag 1	26.90	839.1	76.4	653.1	531.5 a	74.9
Exp slag 1	22.40	739.1	60.9	588.1	420.8 ab	63.1
Lab slag 2	25.25	859.0	75.8	588.9	455.9 ab	86.9
Exp slag 2	27.00	878.3	82.8	639.7	468.0 ab	92.5
Wollastonite	24.10	794.5	78.8	582.2	465.9 ab	63.1
Limestone	21.93	723.1	63.8	496.1	339.2 b	99.7
C.V. %	13.1	24.4	24.2	21.1	27.8	32.5
			2nd cutting			
Lab slag 1	17.09 ab	336.6 ab	60.1 ab	265.4	445.0 ab	60.2 b
Exp slag 1	15.48 b	259.4 b	50.6 b	267.8	369.5 bc	48.8 b
Lab slag 2	20.39 a	326.2 ab	71.4 a	306.1	473.0 a	89.3 a
Exp slag 2	17.36 ab	343.4 ab	64.5 a	307.5	423.0 abc	85.7 a
Wollastonite	19.51 ab	327.0 ab	65.2 a	309.1	493.7 a	59.5 b
Limestone	18.91 ab	461.7 a	65.7 a	319.5	331.5 c	88.5 a
C.V. %	15.6	35.6	14.6	23.1	15.8	13.6

Means followed by the same letter in the column are not significantly different by the t test at 5% probability. * Lab: laboratory ECC; Exp: experimental ECC; slag 1: steel slag; slag 2: stainless steel slag.

The base saturation calculated with the experimental ECC was far below the required value, which implies that the relative efficiency of reactivity determined by the Brazilian legislation are appropriate for slag and consequently for the ECC calculation.

Base saturation of 80 % was not reached with the treatments. The closest values were obtained at 30 days of incubation, when laboratory ECC of slags and limestone were used, decreasing after the first alfalfa cutting. Prado & Natale (2004) reported a similar result in a study with ferrochrome steel slag applied twice as much as the rate required to raise the base saturation to 80 %; however, the base saturation reached only 66 %. Prado & Natale (2005) used calcium silicate to increase base saturation to 50 %, but obtained only 46%. Araújo *et al.* (2009), studying limestone with different reactivity levels, obtained base saturation up to 60% when liming was calculated to reach 80%. The authors attributed this result to the soil buffering effect. Soil mineralogy may influence the soil buffering effect and hinder the increase of base saturation (Silva *et al*., 2008).

The increase in Ca content in the soil Rhodic Hapludox was higher with silicate, 30 days after the corrective application (Table 3). However, at 90 days, the Ca content was reduced due to the alfafa cultivation and there was no significant difference between limestone and silicates (Table 3). The results obtained for the soil reflected in the plant, and, overall, we observed that silicates provided greater calcium accumulation than limestone in alfalfa shoots (Table 4).

Limestone and slag 2 (laboratory ECC) were the most effective to provide Mg to the soils and plant accumulation (Tables 3 and 4). The chemical composition of the correctives (Table 1) shows that the slag 1 has MgO content very similar to limestone and higher than that of slag 2; however, this was not reflected on the exchangeable Mg contents in the soils, which indicates that slag 1 was less efficient to solubilize Mg to the exchangeable form.

Regardless of the treatments, the pH, Ca and Mg contents and base saturation decreased with alfalfa cultivation. Soil re-acidification may be attributed to proton exudation due to cation absorption by the plants, in addition to the fact that Ca and Mg were supplied for acidity correction only at the beginning of the experiment.

Besides the corrective effect, studies on the use of slag in agriculture are on the rise because slag is a silicon source. There are several reports in the literature related to Si increase in crops with the use of steel slag, such as in rice crops (Barbosa Filho *et al*., 2004) and sugarcane plantations (Sousa *et al*., 2010).

Slag application significantly increased the Si content in soils as compared to limestone (Table 5). The Si content was similar in the different slags studied (Table 1). However, slag 2 was more efficient for Si availability in

Table 5. Silicon content in the soil after 30 and 90 days of incubation and silicon accumulation in alfalfa grown under different liming methods, in the first and second cuttings

Treatments	Silicon content		Silicon accumulation	
	mg dm^{-3}		mg per pot	
	30 days	90 days	1st cutting	2 nd cutting
	Rhodic Hapludox			
Lab slag 1	10 b	10 a	108.6 a	45.82 ab
Exp slag 1	8 c	7 b	67.06 bc	32.15 c
Lab slag 2	12 a	10 a	106.35 ab	51.92 a
Exp slag 2	9 bc	8 b	71.65 abc	42.23 b
Wollastonite	3 d	4 c	50.29 c	30.85 c
Limestone	3 d	4 c	57.06 c	20.02 d
C.V. %	10.9	14.7	34.3	16.3
	Alfisol Ferrudalfs			
Lab slag 1	17 b	18 b	68.21 b	50.90 b
Exp slag 1	15 c	13 d	43.85 b	40.38 b
Lab slag 2	17 b	22 a	138.24 a	55.04 ab
Exp slag 2	18 a	16 c	124.20 a	49.70 b
Wollastonite	6 d	8 e	68.29 b	66.67 a
Limestone	7 d	8 e	49.02 b	44.23 b
C.V. %	8.3	6.9	24.9	19.3

Means followed by the same letter in the column are not significantly different by the t test at 5% probability. * Lab: laboratory ECC; Exp: experimental ECC; slag 1: steel slag; slag 2: stainless steel slag.

soils, with higher accumulation in the plant when it was cultivated in the Alfisol Ferrudalfs (Table 5). According to Pereira *et al*. (2004), slag may show differences in Si solubility, depending on the type of steel produced and the type of furnace used to produce it.

The similarity between limestone and slag 1 in plant Si accumulation in the Alfisol Ferrudalfs is attributed to the similar DM content between the treatments. Si accumulation was lower in the second cutting than in the first one for all treatments because of its lower DM production (Table 4).

Silicates provided the greatest P accumulation compared to limestone for alfalfa cultivated in the Rhodic Hapludox (Table 4). Corrêa *et al*. (2008) and Sobral *et al*. (2011) reported that the growing use of slag in agriculture is because silicate anions in slag

Table 6. Micronutrient content in the soils in the treatments after 30 days of incubation

Treatments	B	Cu	Fe	Mn	Zn
	mg dm^{-3}				
	Rhodic Hapludox				
Lab slag 1	0.80	0.9 b	33 ab	11.3 a	2.0
Exp slag 1	0.69	0.9 b	36 a	9.2 b	2.6
Lab slag 2	0.69	0.9 b	32 ab	4.1 c	2.0
Exp slag 2	0.75	1.0 ab	35 ab	3.0 c	1.6
Wollastonite	0.75	1.2 a	29 b	0.8 d	1.6
Limestone	0.80	0.9 b	32 ab	1.0 d	1.7
C.V. %	14.0	17.5	13.8	22.8	38.3
	Alfisol Ferrudalfs				
Lab slag 1	0.85	8.1	20 b	13.6 a	1.9 abc
Exp slag 1	0.76	6.5	26 a	10.5 b	2.4 a
Lab slag 2	0.83	8.4	16 b	7.8 c	1.8 bc
Exp slag 2	0.78	8.2	17 b	7.5 c	2.1 ab
Wollastonite	0.87	7.5	14 b	4.1 e	1.5 c
Limestone	0.77	8.0	16 b	6.1 d	1.9 abc
C.V. %	19.1	20.0	22.5	10.6	18.1

Means followed by the same letter in the column are not significantly different by the t test at 5% probability. * Lab: laboratory ECC; Exp: experimental ECC; slag 1: steel slag; slag 2: stainless steel slag.

Table 7. Micronutrient accumulation in shoots of alfalfa grown under different liming methods in the first cutting

Treatments*	B	Cu	Fe	Mn	Zn
	mg per pot				
	Rhodic Hapludox				
Lab slag 1	2.03 ab	0.21 a	2.32 ab	4.05 a	0.95 abc
Exp slag 1	1.93 b	0.18 ab	2.37 ab	3.99 a	1.24 a
Lab slag 2	2.28 a	0.22 a	2.83 a	3.05 b	0.92 bc
Exp slag 2	1.62 cd	0.16 b	2.23 ab	2.08 c	1.06 ab
Wollastonite	1.83 bc	0.17 ab	2.59 a	2.09 c	0.72 c
Limestone	1.42 d	0.16 b	1.70 b	1.55 d	0.72 c
C.V. %	10.0	15.9	21.8	8.6	22.6
	Alfisol Ferrudalfs				
Lab slag 1	1.67	0.23	2.50 ab	7.19 ab	0.93
Exp slag 1	1.42	0.18	2.35 ab	9.09 a	0.88
Lab slag 2	1.68	0.23	2.77 a	4.11 c	0.86
Exp slag 2	1.67	0.16	2.75 a	7.57 ab	1.29
Wollastonite	1.53	0.19	2.54 ab	5.03 bc	1.33
Limestone	1.37	0.18	1.80 b	3.70 c	0.87
C.V. %	22.7	35.7	25.8	29.1	50.3

Means followed by the same letter in the column are not significantly different by the t test at 5% probability. * Lab: laboratory ECC; Exp: experimental ECC; slag 1: steel slag; slag 2: stainless steel slag.

compete with P for the same adsorption sites when they are adsorbed, preventing or hindering P adsorption.

One advantage of silicate over limestone is its ability to make micronutrients available in the soil (Sobral *et al*., 2011). When slag is used to neutralize soil acidity, the reduction in micronutrient availability due to the increased pH is minimized because steel slag has micronutrients in its chemical composition (Prado *et al*., 2002).

Slag has several metal oxides in its chemical composition, among them Mn (Prado *et al*., 2001), which may have influenced the Mn content in the soil (Table 6) and was reflected in plant accumulation (Table 7).

Although Mn content in the soil with the application of slag 1 may be considered high (Raij *et al*., 1996), no toxicity in alfalfa plants was observed in the current study. Possibly because the Si made available to the plant through slag application minimized the toxicity caused by Mn. The reduction in toxicity of Mn and other metals caused by the action of Si in plants was also reported by Iwasaki *et al*. (2002). According to El-Jaoual & Cox (1998), the mechanism consists of avoiding the adsorption and translocation of the elements to the shoot or improving their distribution in the plant.

There was significant difference between the correctives for the micronutrients Cu, Fe and Zn in the Rhodic Hapludox and Fe and Zn in the Alfisol Ferrudalfs (Table 7) showing higher contents with the application of slags.

Slags provided higher DM means than limestone for both cuttings in the Rhodic Hapludox (Table 4). Its positive effect on DM production may be attributed to the greater supply of Ca, P and Si from the steel slag, since the acidity correction occurred with the application of both correctives, limestone and silicates.

The increase in DM production with the use of slag corroborates Fonseca *et al*. (2009), who applied slag and limestone rates to produce marandu grass. The increase in DM production is explained by the silicon content in the slag, which makes the leaves more upright and, thus, enhance the ability to absorb sunlight and process photosynthesis (Korndorfer *et al*., 2002)

CONCLUSION

The methods to determine limestone ECC can be applied for steel slag. Slag application corrected soil acidity with consequent accumulation of Ca, P, and Si in alfalfa plants, favoring the DM production.

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