Determination of Reactivity Rates of Silicate Particle-size Fractions[1]

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ABSTRACT

The efficiency of sources used for soil acidity correction depends on reactivity rate (RR) and neutralization power (NP), indicated by effective calcium carbonate (ECC). Few studies establish relative efficiency of reactivity (RER) for silicate particle-size fractions, therefore, the RER applied for lime are used. This study aimed to evaluate the reactivity of silicate materials affected by particle size throughout incubation periods in comparison to lime, and to calculate the RER for silicate particle-size fractions. Six correction sources were evaluated: three slags from distinct origins, dolomitic and calcitic lime separated into four particle-size fractions (2, 0.84, 0.30 and <0.30-mm sieves), and wollastonite, as an additional treatment. The treatments were applied to three soils with different texture classes. The dose of neutralizing material (calcium and magnesium oxides) was applied at equal quantities, and the only variation was the particle-size material. After a 90-day incubation period, the RER was calculated for each particle-size fraction, as well as the RR and ECC of each source. The neutralization of soil acidity of the same particle-size fraction for different sources showed distinct solubility and a distinct reaction between silicates and lime. The RER for slag were higher than the limits established by Brazilian legislation, indicating that the method used for limes should not be used for the slags studied here.

Key words: soil acidity, steel slag, ECC.

RESUMO

Determinação de Taxas de Reatividade das Frações Granulométricas de Silicatos

A eficiência dos corretivos de acidez do solo depende da taxa de reatividade (RE) e do poder de neutralização (PN), sendo indicada pelo poder relativo de neutralização total (PRNT). Para os silicatos, existem poucos estudos que estabeleçam taxas de reatividade para suas frações granulométricas e, portanto, utilizam-se as mesmas taxas de reatividade do calcário. Assim, este estudo teve como objetivo avaliar a reatividade de materiais silicatados, em função de sua granulometria, no decorrer de períodos de incubação, em comparação com a do calcário, e calcular a eficiência relativa de reatividade das frações granulométricas dos silicatos. Utilizaram-se seis materiais corretivos, sendo três escórias de aciaria de origens distintas, calcários dolomítico e calcítico, separados em quatro frações granulométricas (material retido entre as peneiras ABNT 10; 10-20; 20-50 e < 50), e a wollastonita como tratamento adicional. A combinação dos tratamentos foi aplicada a três solos de diferentes classes texturais. A dose foi aplicada em quantidades iguais de material neutralizante (óxidos de cálcio e magnésio), possibilitando ter como variação apenas a granulometria do material. Após 90 dias de incubação dos corretivos, calculou-se a eficiência relativa de reatividade para cada fração granulométrica, a reatividade (RE) e o PRNT experimental dos corretivos. As reações de neutralização da acidez do solo de uma mesma fração granulométrica, com os diferentes corretivos, mostraram que ocorrem solubilidade e reação distintas entre silicatos e calcários. As taxas de eficiência relativa para a reatividade das escórias foram superiores às determinadas pela legislação brasileira, podendo-se inferir que o método utilizado para calcários não é adequado para os silicatos.

Palavras-chave: acidez do solo, escórias de aciaria, granulometria.

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INTRODUCTION

Soil acidity is one of the major chemical attributes related to plant growth as it affects the occurrence of phytotoxic elements and the availability of most nutrients. Lime is the most used corrective to neutralize soil acidity. However, studies show that silicate materials have great potential to improve soil chemical characteristics, mainly by increasing the pH. SiO_3^{2-} is the neutralizing agent in silicates, which reacts with water releasing OH^- ions that neutralize H^+ and Al^{3+} phytotoxic (Prado *et al.*, 2001), consequently increasing Ca, Mg and base saturation (Brassioli *et al*., 2009; Corrêa *et al*., 2009). Slags are a silicon source (Souza & Korndorfer 2010) as well as enhancing nutrient uptake by plants (Fonseca *et al*., 2011).

In Brazil, steel mills provide slag, an abundant silicate source, at a very low cost. Slag has already been used in agriculture in the United States, Japan, and China. Many studies have recently reported on the viability of using slag in several crops such as soybean (Corrêa *et al*., 2008), rice (Barbosa Filho *et al*., 2004), sugar cane (Brassioli *et al*., 2009), and sorghum (Barbosa *et al*., 2008), among others. Yet further information on these materials is required, especially related to RER for particle-size fractions.

Efficiency and quality of sources used in soil acidity correction are indicated by ECC and depend on the RER of particle-size fractions, (LOPES *et al.*, 1990). No information is available regarding the reactivity of silicate particle-size fractions, thus carbonate reactivity rates are used.

The RER of corrective sources established for particle-size fractions are determined based on liming materials. Reactivity values established by ABNT (Brazilian Technical Standards Association) standard sieves 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. These values represent the percentage of reaction in the soil for three months (Brasil, 2006). However, particles from silicate sources are more porous, due to the fusion during the steel making processes, which increases the specific surface area of the slag fractions ensuring greater reaction speed of dissociation. The presence of the accompanying anion SiO_3 confers a six or seven-fold increase of solubility compared to lime, where CO_3 is the anion (Alcarde, 1992). Therefore, rates of RER applied to lime are not appropriate to determine silicate reactivity, because the rates underestimate the neutralization capacity of silicate sources and, consequently, overestimate the amount to be applied for soil acidity correction.

It is essential to study the RER for silicate particle-size fractions to establish appropriate recommendations for soil acidity correction. This study aimed to evaluate the reactivity of silicate materials affected by particle size during incubation periods in comparison to lime reactivity, and to calculate the RER for silicate particle-size fractions.

MATERIALS AND METHODS

The study was conducted under greenhouse conditions in Botucatu, São Paulo State, Brazil. Treatments were tested in three soils collected in Botucatu: Rhodic Hapludox (RH), Typic Quartzipsamment (TQ) and Alfisol Ferrudalfs (AF) (Soil Taxonomy, 2010) (Table 1). The experimental design was completely randomized with four replications, analyzed as a 5 x 4 +1 factorial, five sources for soil acidity correction (Table 2) and four particle-size fractions, and an additional treatment (wollastonite).

It was used three slags from distinct origins (slags 1 and 2, originated from steel provided by Mannesmann® and Silifertil®, respectively and slag 3 originated from stainless steel provided by Recmix®), as well as wollastonite, dolomitic lime, and calcitic lime. Wollastonite is an international standard of calcium silicate, mostly used in studies to compare different silicate sources.

Except for wollastonite, the sources were separated into four particle-size fractions established by Brazilian legislation for lime (Brasil, 2006), described as ABNT #10 - corresponding to particles retained by #10 sieve, with diameter > 2 mm; ABNT #20 - corresponding to particles sieved through #10, but not #20, with diameter between 2-0.84 mm; ABNT #50 - corresponding to particles sieved through #20, but not #50, with diameter between 0.84-0.30

Table 1. Soil chemical and textural attributes of RH (Rhodic Hapludox), AF (Alfisol Ferrudalfs) and TQ (Typic Quartzipsamment)

Chemical attributes	Soil		
	RH	AF	TQ
P resin (mg dm^{-3})	3	4	5
Organic matter (g dm^{-3})	30	18	9
pH (CaCl$_2$)	4.1	4.4	4.1
K (mmol$_c$ dm^{-3})	0.4	0.6	0.8
Ca (mmol$_c$ dm^{-3})	8	7	20
Mg (mmol$_c$ dm^{-3})	1	1	6
H+Al (mmol$_c$ dm^{-3})	69	71	22
Sum of bases (mmol$_c$ dm^{-3})	9	9	27
CEC (mmol$_c$ dm^{-3})	79	80	49
Base saturation (%)	12	11	55
B (mg dm^{-3})	0.34	0.41	0.36
Cu (mg dm^{-3})	0.70	8.6	1.3
Fe (mg dm^{-3})	83	36	60
Mn (mg dm^{-3})	0.7	11.3	18.3
Zn (mg dm^{-3})	0.0	0.2	0.7
Si (mg kg^{-1})	4	8	4
Texture			
Clay (g kg^{-1})	274	607	126
Sand (g kg^{-1})	669	169	836
Silt (g kg^{-1})	57	224	38

mm; ABNT < 50 - corresponding to particles sieved through #50, with diameter < 0.30 mm.

A previous experiment was carried out for three months to establish the doses to be used. The same materials tested in this experiment were separated in particle-size fractions and applied at increasing amounts (0, 1, 2, 4, and 8 t ha^{-1}) in the three soils. The previous study allowed to obtain the neutralization fitting curve for each source and particle-size to calculate the dose to increase the pH ($CaCl_2$) of each soil class to 5.5 (Table 3). In the first experiment, the 2-mm fraction of slag 1 and lime, except calcitic lime applied in TQ, did not influence soil pH; therefore, the dose could not be calculated. In this case, it was used the dose calculated for the 0.84-mm fraction.

The experimental units consisted of plastic pots with punched lids. Each filled with 1 kg of soil and the material to increase the pH ($CaCl_2$) to 5.5, according to particle-size and source (Table 3). The soil moisture was kept at 70% of field capacity, through weekly weighing. At the end of each incubation period (30, 60, and 90 days), soil samples were collected to determine the pH ($CaCl_2$) (Raij *et al.*, 2001). Considering the pH variations after 90 days, it was evaluated the RER for particle-size fractions. According to Brazilian legislation, reactivity of dolomitic lime is considered 100% for particle-size fractions < 0.30 mm. Therefore, this was considered the reference value to calculate the increase in all other fractions and corrective sources.

It was analyzed the RER for each fraction and source to calculate an average value for all three soils. This value was used to calculate the RR of corrective sources according to their particle size (Table 2) in the equation:

$$\%RR = \left(\frac{F1 \times RE1}{100}\right) + \left(\frac{F2 \times RE2}{100}\right) + \cdots\cdots + \left(\frac{Fn \times REn}{100}\right)$$

being: F1, F2 ..... Fn = rate of particle-size fractions

RE1, RE2 ..... REn = rate of relative efficiency reactivity for each particle-size fraction

Afterwards, the ECC was calculated for each correction source, hereby denominated Experimental *ECC*, in the following equation:

Table 2. Chemical attributes of sources of soil acidity correction used in this study

Characteristics*	Slags			Wollastonite	Dolomitic lime	Calcitic Lime
	1	2	3			
			(%)			
CaO	36.40	40.60	47.00	43.00	47.80	58.90
MgO	14.40	11.80	10.50	2.92	14.50	5.00
ABNT sieves **			**% particles retained**			
#10	0.8	0	8.35	0	0.07	0.09
#20	17.47	13.10	12.84	0	1.87	1.10
#50	30.27	30.23	57.97	0	14.91	11.90
< 50	51.46	56.67	20.84	100	83.15	86.91
NP	71.00	78.00	87.00	60.00	105.00	96.00
RR	73.26	77.43	72.26	100.00	92.47	94.27
ECC	52.00	60.00	63.00	60.00	97.00	90.00

*Determined according to Alcarde (2009). Slag 1 and 2: steel; Slag 3: stainless steel. **ABNT #10 – fractions > 2.00 mm; ABNT #20 – fractions from 2.00 to 0.84 mm; ABNT #50 – fractions from 0.84 to 0.30 mm; ABNT <50 – fractions < 0.30 mm. NP - Neutralization Power; RR – reactivity rate; ECC – effective calcium carbonate.

Table 3. Doses of sources to increase the pH to 5.5 according their particle-size fractions

Sources**	Rhodic Hapludox				Typic Quartzipsamment				Alfisol Ferrudalfs			
	ABNT sieves *											
	#10	#20	#50	< 50	#10	#20	#50	< 50	#10	#20	#50	< 50
	t ha^{-1}											
S1	22.5	22.5	13.2	9.5	13.5	13.5	6.1	3.0	51.1	51.1	23.1	11.0
S2	67.2	38.3	10.6	9.8	19.6	14.6	9.1	2.8	78.2	61.3	10.6	10.4
S3	31.0	14.2	9.9	8.5	37.5	9.1	3.0	2.4	75.8	26.9	12.0	10.6
DL	21.3	21.3	7.8	5.3	19.5	19.5	3.0	1.5	19.7	19.7	8.7	7.1
CL	8.8	8.8	6.3	6.0	10.8	8.1	2.3	1.6	22.3	22.3	8.0	7.3
W	——	——	——	8.4	——	——	——	3.3	——	——	——	10.8

*ABNT #10 – fractions > 2.00 mm; ABNT #20 – fractions from 2.00 to 0.84 mm; ABNT #50 – fractions from 0.84 to 0.30 mm; ABNT <50 – fractions < 0.30 mm.**S1 and S2: steel slag; S3: stainless steel slag; DL: dolomitic lime; CL: calcitic lime; W: wollastonite.

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

being: NP = neutralization power, obtained in laboratory

RR = reactivity rate

The NP was determined by the acid base titration method (Alcarde, 2009). The results were submitted to the analysis of variance (F test). The means were compared in the Tukey test ($p \leq 0.05$) whenever significant differences occurred.

RESULTS AND DISCUSSION

Considering the same particle-size fraction of corrective sources (Tables 4, 5 and 6), the pH results showed distinct solubility and reaction between silicates and carbonates. Therefore, physical characteristics of different fractions may have affected the speed of reaction and solubilization, given that amounts of Ca and Mg oxide were applied equally in all treatments. Particle-size fractions smaller than 0.30 mm (ABNT < 50) showed higher pH at the beginning of the incubation period and small variations between correction sources, this particle size is thinner and showed greater surface contact with the soil, increasing solubility. However, over time, larger particles were soluble and modified the pH. This shows that the particle size can influence reactivity, even after the use of high doses. Larger fractions take a longer time to start neutralizing soil acidity and reach pH 5.5, compared to thinner particles. Longer incubation periods of larger particles possibly increase pH values more than thinner particles, which immediately influence soil properties, but do not extend residual effects.

Table 4. The pH of Rhodic Hapludox affected by different sources of soil acidity correction, according their particle-size fractions, after 30, 60, and 90 incubation days

Sources	**pH ($CaCl_2$)**			
	S < 50	**S #50**	**S #20**	**S #10**
		30 days		
Slag 1	5.7 bcA	5.4 aB	4.6 bC	4.3 cD
Slag 2	5.8 abcA	5.2 abB	5.0 aB	5.0 aB
Slag 3	6.0 aA	5.5 aB	5.0 aC	4.7 bD
Calcitic lime	5.9 abA	5.1 bcB	4.4 bC	4.1 cC
Dolomitic lime	5.6 cA	4.9 cB	4.9 aB	4.2 cC
C.V. %	2.7			
Wollastonite	5.7 bc	—	—	—
C.V. %	1.5	—	—	—
		60 days		
Slag 1	5.9 aA	5.7 abB	5.2 bC	4.6 cD
Slag 2	6.1 aA	5.7 abB	5.7 aB	5.6 aB
Slag 3	6.1 aA	5.9 aB	5.6 aC	5.2 bD
Calcitic lime	5.9 aA	5.6 bcB	4.8 cC	4.3 cD
Dolomitic lime	5.9 aA	5.4 cB	5.5 abB	4.6 cC
C.V. %	2.8			
Wollastonite	5.9 a	—	—	—
C.V. %	2.1	—	—	—
		90 days		
Slag 1	5.9 aA	5.7 abA	5.3 cB	4.6 cC
Slag 2	5.9 aA	5.7 abB	6.0 aA	5.8 aA
Slag 3	6.1 aA	6.0 aAB	5.8 abB	5.4 aA
Calcitic lime	5.9 aA	5.5 bB	4.8 cC	4.2 bcC
Dolomitic lime	5.9 aA	5.6 bB	5.5 bcB	4.4 cB
C.V. %	5.3			
Wollastonite	5.6 b	—	—	—
C.V. %	1.5	—	—	—

Means compared by the same capital letter in the row and small letter in the column do not differ significantly in the Tukey test (p de 0.05). 1 and 2: steel; 3: stainless steel. S #10 – fractions > 2.00 mm; S #20 – fractions from 2.00 to 0.84 mm; S #50 – fractions from 0.84 to 0.30 mm; S <50 – fractions < 0.30 mm.

Gonçalves *et al.* (2011) studied limes of different particle sizes and observed a quick increase of the lime pH in thinner particles. This is explained because the reaction of corrective sources is highly affected by the material grinding and smaller-size particles react quickly, however, the residual effect is kept for a shorter period than in materials with larger-size particles. Except for fractions between 2-0.84 mm (ABNT #20) in RH and TQ, calcitic and dolomitic limes showed similar effects on soil correction, within the same particle size fraction, regardless of the incubation period and soil type. Slags showed distinct effects depending on particle size (Tables 4, 5 and 6).

The chemical component of slags varies according to the furnace type, steel grades, and pretreatment method (Yi *et al.*, 2012), which may justify these differences between slags. Besides, slags are obtained through distinct industrial processes, which leads to recrystallization affected by Ca and Mg levels and cooling time, influencing solubility (Pereira *et al.*, 2010). Materials are submitted to different types of cooling processes that may also affect slag composition, by either air or *quenching*. When slag is cooled by air, recrystallization of its components occurs reducing solubility when applied to the soil, consequently, decreasing the material reactivity (Prado *et al*., 2001).

Slag 1 and both limes with particle size fractions greater than 2 mm (ABNT #10) did not affect the pH in RH and AF. This was expected once it was not possible to establish appropriate doses to increase the pH to 5.5 in the previous experiment. Conversely, slags 2 and 3 that had established doses to increase the pH to 5.5 did show positive effects in neutralizing soil acidity.

The RER was influenced by sources for soil acidity correction and varied depending on soil type (Table 7).

Table 5. The pH of Alfisol Ferrudalfs (AF) affected by sources of soil acidity correction, according their particle-size fractions, after 30, 60, and 90 incubation days

Sources	**pH ($CaCl_2$)**			
	S < 50	**S #50**	**S #20**	**S #10**
	30 days			
Slag 1	6.0 aA	6.2 aA	5.6 aB	4.5 bcC
Slag 2	5.9 aA	5.2 bB	5.5 aB	4.7 bC
Slag 3	6.2 aA	6.1 aAB	5.6 aBC	5.8 aC
Calcitic lime	6.0 aA	5.4 bB	4.8 bC	4.4 cD
Dolomitic lime	5.9 aA	5.4 bB	4.9 bC	4.4 cD
C.V. %	2.9			
Wollastonite	5.9 a	—	—	—
C.V. %	2.5	—	—	—
	60 days			
Slag 1	6.4 aA	6.8 aA	6.4 aA	5.0 bcB
Slag 2	6.3 aA	5.9 cB	6.4 aA	5.3 bC
Slag 3	6.4 aA	6.6 abA	6.5 aA	6.7 aA
Calcitic lime	6.5 aA	6.2 bcA	5.4 bB	4.7 cC
Dolomitic lime	6.3 aA	6.3 abA	5.5 bB	4.8 cC
C.V. %	3.4			
Wollastonite	6.3 a	—	—	—
C.V. %	3.6	—	—	—
	90 days			
Slag 1	6.0 aB	6.5 aA	6.7 aA	5.1 cC
Slag 2	5.8 aB	5.4 cB	6.6 aA	5.7 bB
Slag 3	6.0 aC	6.2 abBC	6.4 aAB	6.8 aA
Calcitic lime	6.1 aA	5.9 bB	5.6 bC	4.6 dD
Dolomitic lime	5.9 aA	5.9 bA	5.6 bA	4.5 dB
C.V. %	3.8			
Wollastonite	6.0 a	—	—	—
C.V. %	2.0	—	—	—

Means compared by the same capital letter in the row and small letter in the column do not differ significantly in the Tukey test (p d” 0.05). Slag 1 and 2: steel; Slag 3: stainless steel. S #10 – fractions > 2.00 mm; S #20 – fractions from 2.00 to 0.84 mm; S #50 – fractions from 0.84 to 0.30 mm; S <50 – fractions < 0.30 mm.

Hence, it is essential to study soils with distinct chemical, physical, and mineralogical attributes, to estimate the RR of corrective sources.

Although this study did not aim to evaluate the influence of soil type on reactivity of correction sources, it was observed that the effects of particle-size fractions on acidity correction varied between soil types. Slags with particles varying from 0.84-0.30 mm (ABNT #50) did not differ from each other in RH, however, they differed in TQ and AF. Slags 1, 2 and 3 with particle-size fractions between 2.0-0.84 mm (ABNT #20) showed similar behavior in AF in all incubation periods. Nevertheless, in RH, slag 1 showed lower RER than in the other slags. These results can be explained by the distinct mineralogy of the clay fraction in all three soil types. Pandolfo & Tedesco (1996) reported that climate and soil conditions also influence the efficiency of corrective sources in neutralizing soil acidity.

The RER of silicate was higher than in carbonates, mainly in larger particle-size fractions, considering the average from all soil types (Table 7). These results do not corroborate Prado *et al*. (2004). The authors applied the amounts 0.00, 5.04, and 10.08 t ha^{-1} for ABNT sieves #10, #20, #50 and <50 of steel slag in an dystrophic Red Latosol and found RER close to the values established by Brazilian legislation for lime. The same amounts for each ABNT sieve and the evaluation only in one soil may have contributed to the differences between the results obtained by the authors and our results.

The RER of lime reactivity increased with smaller particle-size fractions. Slag particles between 0.30-0.84 mm and 0.84-2.0 mm showed higher RER than sizes smaller than 0.30 mm. RER in slag 3 was higher in particle sizes > 2.0 mm. Increasing RER of lime materials through reducing particle size is a consequence of lower solubility

Table 6. The pH of Typic Quartzipsamment affected by sources of soil acidity correction, according their particle-size fractions, after 30, 60, and 90 incubation days

Sources	**pH (CaCl$_2$)**			
	S < 50	**S #50**	**S #20**	**S #10**
	30 days			
6.3 aA	6.1 bcA	5.9 aA	4.9 cB	
Slag 2	6.3 aA	6.6 aA	5.5 bB	5.4 abB
Slag 3	6.2 abA	6.2 bA	6.1 aA	5.5 aB
Calcitic lime	5.8 bA	5.8 cdA	5.4 bB	5.0 bcC
Dolomitic lime	5.9 bA	5.6 dAB	6.0 aA	5.3 abcB
C.V. %	3.3			
Wollastonite	6.4 a	—	—	—
C.V. %	1.9	—	—	—
	60 days			
Slag 1	6.8 aA	6.7 aA	6.6 abA	5.4 cB
Slag 2	6.6 abB	7.0 aA	6.3 bcBC	6.0 abC
Slag 3	6.7 abAB	6.7 aAB	6.8 aA	6.4 aB
Calcitic lime	6.5 abA	6.3 bAB	6.0 cB	5.5 cC
Dolomitic lime	6.3 bA	6.3 bA	6.5 abA	5.7 bcB
C.V. %	3.0			
Wollastonite	6.7 a	—	—	—
C.V. %	2.2	—	—	—
	90 days			
Slag 1	6.4 aB	6.8 abA	6.5 abAB	4.5 dC
Slag 2	5.9 aB	7.0 aA	6.5 aAB	6.0 abB
Slag 3	6.2 aB	6.0 bcB	7.0 abA	6.3 aB
Calcitic lime	5.9 aA	5.8 cA	5.8 bA	5.0 cdB
Dolomitic lime	5.9 aA	6.0 bcA	6.0 bA	5.3 bcB
C.V. %	4.7			
Wollastonite	6.2 a	—	—	—
C.V. %	2.4	—	—	—

Means compared by the same capital letter in the row and small letter in the column do not differ significantly in the Tukey test (p d” 0.05). Slag 1 and 2: steel; Slag 3: stainless steel. S #10 – fractions > 2.00 mm; S #20 – fractions from 2.00 to 0.84 mm; S #50 – fractions from 0.84 to 0.30 mm; S <50 – fractions < 0.30 mm.

and faster acidity neutralization caused by enhanced surface contact between the soil and the source. However, the number of pores in silicates may also have influenced the silicate effects, improving hydrolysis and dissolution speed. Larger particles had their size reduced as internal specific surface increased, therefore, soil acidity correction was enhanced. Studies conducted under controlled conditions (Ramos *et al*., 2006) and in the field (Corrêa *et al*., 2007) showed that silicate sources are more efficient to correct soil acidity than lime. As mentioned before, abundant pores and increased surface area of silicates increase solubility and RER. Therefore, products from the dissociation process show higher mobility in deeper soil layers (Corrêa *et al*., 2007, 2008, 2009; Castro & Crusciol, 2013).

The RER of particles mainly for silicates sources was higher than reference values established by Brazilian legislation. Particle reactivity determined in laboratory is often higher than under field conditions, since the corrective source is mixed in the soil and moisture is kept at an appropriate level (Alcarde *et al*., 1989). Considering the mean of the soils the RER of lime and wollastonite was similar to the values established by Brazilian legislation (Table 7). The higher RR increased ECC values in silicates (Table 8), reducing the doses required for acidity correction.

Table 7. Relative efficiency of reactivity (RER) (%) of each particle-size of sources of acidity correction and averages of all three soils

Soil	Sources	ABNT sieves*			
		< 50	#50	#20	#10
Rhodic Hapludox (RH)	Slag 1	100	89	67	28
	Slag 2	100	89	106	94
	Slag 3	111	106	94	72
	Wollastonite	83	—	—	—
	Calcitic lime	100	83	78	17
	Dolomitic lime	100	78	39	6
Alfisol Ferrudalfs (AF)	Slag 1	106	133	144	56
	Slag 2	94	72	139	89
	Slag 3	106	117	128	150
	Wollastonite	106	—	—	—
	Calcitic lime	100	100	83	22
	Dolomitic lime	111	100	83	28
Typic Quartzipsamment (TQ)	Slag 1	133	147	140	7
	Slag 2	100	180	140	107
	Slag 3	120	133	173	133
	Wollastonite	120	—	—	—
	Calcitic lime	100	113	120	60
	Dolomitic lime	100	107	87	53
Means	Slag 1	113	123	117	30
	Slag 2	98	114	128	97
	Slag 3	112	119	132	118
	Wollastonite	103	—	—	—
	Calcitic lime	100	99	94	33
	Dolomitic lime	104	95	70	29

*ABNT #10 – fractions > 2.00 mm; ABNT #20 – fractions from 2.00 to 0.84 mm; ABNT #50 – fractions from 0.84 to 0.30 mm; ABNT <50 – fractions < 0.30 mm.

Table 8. Reactivity rate (RR), neutralization power (NP) and effective calcium carbonate (ECC) of sources of soil acidity correction.

Source	RR*	NP*	ECC*	Experimental** RR	Experimental** ECC
Slag 1	73.26	71	52	116.7	82.9
Slag 2	77.43	78	60	106.8	83.3
Slag 3	72.26	87	63	116.6	101.4
Wollastonite	100.00	60	60	103.0	61.8
Calcitic lime	92.47	105	97	99.7	104.7
Dolomitic lime	94.27	96	90	102.5	98.4

* Determined in laboratory. ** Determined in this study.

CONCLUSIONS

Dolomitic and calcitic limes tend to show similar RER for a given particle-size fraction whereas slags have their RER varying to the same particle size. Additionally, RER of slags used in this study are higher than the reference values established in Brazilian legislation, which shows that the method used for lime should not be used for the slags studies. Further studies should be conducted to verify whether the RR obtained experimentally could be considered in the ECC calculation for soil liming and appropriate plant growth.

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