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Article

Different limestone particle sizes for soil acidity correction, Ca and Mg supply and corn yield

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Abstract

The aim of this study was to evaluate the soil acidity correction and the grain yield responses for the lime application in different granulometric particles. The limestone particle sizes incorporated into the distroferric red Oxisol were: 0.20 mm to 0.30 mm; 0.30 mm to 0.56 mm; 0.56 mm to 0.82 mm and 0.82 mm to 2.00 mm, at doses of 1.3 t ha^{-1}; 2.6 t ha^{-1}; 3.9 t ha^{-1} and 6.6 t ha^{-1} respectively, and a control respectively, and a control (no lime incorporation in the soil). The soil chemical characteristics pH, H+Al^{3+}, Al^{3+}, Ca^{2+} e Mg^{2+} were evaluated at 6 months and 18 months after the lime application. The corn yields were evaluated during the 2008/2009 and 2009/2010 crop years. Higher limestone contents and lower particle size resulted in the same effect on soil acidity correction, reducing Al^{3+} and increasing Ca^{2+} and Mg^{2+} in the soil when the 0.30 mm limestone was incorporated, with residual effect at 18 months. Highest corn yield was obtained when the 0.82 mm to 2.00 mm particle size was incorporated in the first crop year, when compared to the lowest limestone particle size used.

Keywords: *Zea mays*, particle size, no-tillage system, Oxisol

Introduction

Currently the corn crop in Brazil present a planted area of 15.6 million hectares, totaling a production of 81.8 million tons, with an average yield of 5420 kg ha^{-1} (Conab, 2015). In this sense, corn is the second most planted crop in Brazil, and has great relevance for human and animal food, being important to improve corn yield. Thus, the soil acidity correction and higher Ca and Mg contents can favor the corn yield and development.

The soil acidity results in higher aluminium availability (toxic at high concentrations for cultivated plants), low base saturation and lower availability of phosphorus, limiting agricultural production in several areas of the world (Nascente & Cobucci, 2015). This problem is solved by the liming practice. Thus, this practice results in increased pH, supply of Ca and Mg to the soil, neutralization of exchangeable Al and modifications of the effective cation exchange capacity, adjusting soil chemical properties according to each crop (Raymundo et al. 2013; Oliveira et al. 2010; Soratto et al. 2010; Moreira & Fageria, 2010).

The practice of liming is done correcting the soil acidity, mainly using limestone. The soil correctives are evaluated according to their power to neutralize soil acidity, which is known as the relative power of total neutralization (PRNT). The

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PRNT is calculated from the Neutralization Power (PN) and the Reactivity (RE) of the corrective. The NP indicates the chemical potential of the corrective agent to neutralize the acidity and the RE, which depends on the corrective grain size, indicates the speed of the soil acidity correction (Caires et al., 2010). The granulometry assumes an important role in the choice of a limestone, since its dissolution depends on its contact with the soil (Gonçalves et al., 2011). The rate of limestone reactivity depends on its granulometry, since the neutralization rate of the acidity is conditioned to the surface area of the corrective in contact to soil (Rodrighero et al., 2015, Natale et al., 2010). There is a consensus that limestone with granulometric fractions above 2.00 mm are ineffective, and granulometry less than 0.3 mm are effective (Quaggio, 2000). In the Brazilian legislation (Brazil, 2006), limestone with a particle size fraction of 2.00 to 0.84 mm presents 20% of RE, particle sizes between 0.84 mm and 0.30 mm presents 60% of RE, with fractions 0.30 mm showing 100% of RE. However, Bellingiere et. al. (1992) found that there was little difference in soybean yield due to the use of different limestone fractions, using the size fractions of the current brazilian legislation.

However, Natale and Coutinho (1994) report that soybean yield was proportional to the relative efficiency (ER) of limestone fractions, showing that fractions between 2.0 and 0.6 mm presented ER of 77%, 0.6 to 0.3 mm presented ER of 93% and less than 0.3 mm resulted in ER of 100%. The application of limestone with a particle size of less than 0.25 mm provided the same effect of increase soil pH and on the reduction of Al^{3+} in acid soils, when compared to the use of limestone with a particle size of 2.00 mm (Alvarez et al. al., 2009). Thus, the rate of limestone reactivity may not be linked only to its granulometry.

Limestone with particle size fractions above> 0.3 mm presents a residual effect on the soil (Quaggio, 2000). This effect is important in soil conservation systems such as no-tillage systems, which can maintain the correction of soil acidity, increasing the intervals of limestone application.

According to this, it is verified that the reactivity and the residual effect of granulometric fractions of limestone between 2.00 mm and 0.3 mm are well understood. The application of limestone doses of different granulometries according to their reactivity provides the correction of soil acidity and promotes crop yield in the same way as using limestone filler (particle fraction <0.30mm).

The aim of this study was to evaluate the effect of the application of different limestone fractions on the acidity attributes and the Ca^{2+} and Mg^{2+} contents of the soil and corn yield during the first two years of a no-tillage system.

Materials and Methods

The experiment was installed on October, 2009 in a region near Goiânia (Go, Brazil), latitude 16° 36' 06,91" S, longitude: 49° 16'57,22" WO. The soil was characterized as a typical Rhodic Ferralsol (WRB, 2015). The region climate is classified according to Köppen, as tropical rainy, Aw savana, with a subhumid characteristic (Figure 1).

The experiment was carried out in a randomized block design with four repetitions. The present research consisted of twenty plots of 50 m² with five treatments, as specified in Table 1.

The limestone used in the experiment was collected with the aid of a shovel, stored in plastic bags and sent to the laboratory. The limestone used was extracted from metamorphic rocks and presented 38% of CaO and 13% of MgO. The granulometric fractions were separated by sieves in the laboratory. The granulometric fraction <30 mm, corresponded to the limestone that passed in the ABNT sieve n°50, the fraction with granulometry 0.30 mm to 0.50 mm is the limestone that was retained in the sieve ABNT n°50, the fraction with granulometry of 0.50 mm to 0.84 mm is the limestone that was retained in the ABNT sieve n°35, and the granulometry fraction of 0.84 mm to 2.00 mm is the limestone that was retained in the ABNT sieve n ° 20 (Table 1).

Limestone analysis followed the Manual of Official Analytical Methods for Mineral, Organic, Organo-Mineral, and Corrective Fertilizers described in the Normative Instruction 28/07 of the Brazilian Ministry of Agriculture, Livestock and Supply (MAPA) (Brazil, 2007). According to the Normative Instruction (IN) 35/06 from the MAPA (Brazil, 2006), in Brazil the soil acidity correctives

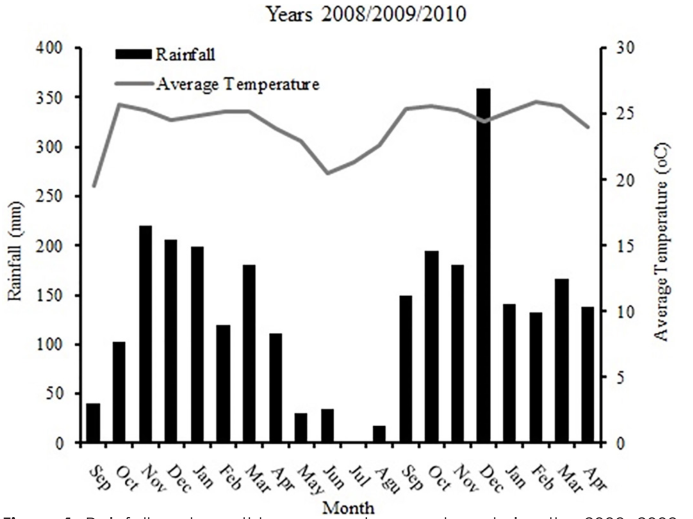

Figure 1. Rainfall and monthly average temperature during the 2008, 2009 and 2010 crop years. Source: INMET (Database – Local: 83423 – Goiânia, GO, Brazil).

Table 1. Description of the granulometry, reactivity, neutralization power (P.N.) and limestone doses used for soil chemical correction.

Granulometry	Sieve (ABNT[1])	Reactivity	PN[2]	PRNT	Lime dose
(mm)		%			($Mg\ ha^{-1}$)
Control		-	-	-	-
< 0.30	50	100	100	100	1.3
0.30-0.50	35	50	100	50	2.6
0.50-0.84	20	33	100	33	3.9
0.84–2.00	10	20	100	20	6.6

1ABNT – Brazilian association of technical standards. 2 PN – Neutralization power. 3PN – Reactive power of total neutralization.

must have PRNT of at least 45% to go to the market. However, the analysis results described in Table 1 show that limestones with fractions> 0.50 mm do not meet the PRNT requirements of the Brazilian Legislation. However, the use of these corrective materials should be evaluated, since there are indications of reactivity.

The soil was sampled in the area of the experiment in the 0.00-0.2 m depth layer. The need for liming (NC) was calculated by the base saturation method: NC = (V2-V1) xT / 100 xf, where 'V2' is the base saturation required by the crop (50% was the value applied), 'V1' is the current soil base saturation, 'T' is the current total cation exchange capacity (CEC) of the soil and 'f' is the correction factor as a function of the limestone PRNT.

The liming calculation was based on soil analysis results before the experiment installation (Table 2). The calculated dose was 1.30 $Mg\ ha^{-1}$ considering the incorporation depth of 0.00-0.20 m and the PRNT of the limestone of 100%. The limestone doses were corrected according to the PRNT of the granulometric fractions used by the correction factor, as recommended by Sousa & Lobato, (2004). The reactivity (RE) of the limestone is proportional to its granulometry. Thus, using doses proportional to their reactivity, we equate RE of all fractions to analyze the effect of grain size fractions on soil acidity correction, soil Ca and Mg contents and corn yield.

The limestone was chosen based on soil analysis results (Table 2). The soil presented Ca:Mg relation of 1:1, being the Mg content lower than 8.0 $mmol_c dm^{-3}$. According to this, it is recommended the use of agricultural limestone. The aim was to keep the Ca:Mg contents from 1:1 to 10:1, according to Sousa & Lobato (2004) recommendations.

The experimental area was left with no crop planted during two years prior to the experiment. Before that, it was used as a demonstration area for crops such as soybeans, corn and wheat. In those two years, the area was

Table 2. Chemical and textural characterization of the soil at the experimental area - 0.00-0.2 m depth.

pH	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^{+}+Al^{3+}$	K^{+}	CEC	P	V	O.M.	Sand	Silt	Clay	Ki[(1)]	Kr[(2)]
(H_2O)	-------------------mmol$_c$ dm^{-3}-------------------						mg dm^{-3}	%	----------------g kg^{-1}------------					
5.8	6	5	2	39	1.9	52	1.7	25	20	370	175	455	1.07	0.62

(1)Ki: molar ratio SiO2:Al2O3; (2)Kr: molar ratio SiO2:(Al2O3 + Fe2O3).

harrowed annually to control invasive weeds.

The soil of the experiment was prepared with a harrow of 12 discs of 32 inches each, six months before the experiment was implemented and the different doses and granulometries of limestone were applied two months before the corn sowing. The limestone with different doses and granulometries were applied and incorporated only once, as commonly done by farmers in the 'Cerrado' region. The incorporation of limestone was carried out at a depth of 0.20 m. The experiment was fallow and the soil was cover with weeds that grew naturally before planting.

For sowing the corn, the weeds were controlled using 3.5 L ha^{-1} of glyphosate and 1L ha^{-1} of 2.4-D with a fnal volume of 100 L ha^{-1}. The corn crop was planted on December 15, 2008, for the first crop year (2008/2009), and on December 23, 2009, for the second crop year (2009/2010). The hybrid used was the '30A04 yield guard' with 0.9m of line spacing and six plants per linear meter. The maize was fertilized in the planting groove with 28 kg ha^{-1} of N, 98 kg ha^{-1} of P_2O_5 and 70 kg ha^{-1} of K_2O, using formulated fertilizer 08-28-20 (NPK) with 1.5% of micronutrients (B and Zn). N fertilization was carried out 30 days after sowing, using 45 kg ha^{-1} of N as Urea (45% of N), manually applied along the crop line, and 60 kg ha^{-1} of K_2O using KCl (60% of K_2O) as the source. Corn was conducted by applying cultural treatments, such as weeds, diseases and pest control, according to the crop needs.

The soil chemical evaluation was performed in each plot after the experiment implantation, at the flowering stage of the crop, after 60 days of planting, and together with the period of 6 and 18 months after the limestone application. Thus, soil samples were collected in the layers 0-0.1 m, 0.1-0.2 m and 0.2-0.4 m depth in the 2008/2009 harvest, that is, at 6 months after limestone application, and in the layers 0-0.05 m, 0.05-0.1 m, 0.1-0.2 m and 0.2-0.4 m depth for the 2009/2010 crop year, 18 months after the limestone application. The use of soil analysis in the 0-0.05 m depth layer is due to the fact that no soil rotation was performed due to the implantation of the no-tillage system (SPD). The analysis was performed at 18 months after the limestone application aiming to evaluate its residual effect on soil chemical attributes.

The soil samples were collected by removing one sample in the line and six samples between planting lines, forming the plot sample. The sampling points were random within the plot, being sampled the central planting line of the plot.

The collected samples were sent to the LASF / EA / UFG. In the laboratory, the following attributes were evaluated: pH (H_2O), H+Al, Al^{3+}, Ca^{2+} and Mg^{2+} following the methodology described by Silva (2011). The corn ears were harvested within a useful 20m^2 plot on 04/15/2009 and on 04/25/2010 representing the grain yield of 2009 and 2010, respectively. The corn were milled and corn grains were weighted by correcting grain moisture to 13%. Corn grain yield was extrapolated to kg ha^{-1}.

The soil depth was used as a factor to evaluate changes in soil attributes related to the different granulometric fractions of limestone applied. The results obtained at 6 and 18 months after limestone application were evaluated separately. After grouping the data in months after the application of limestone and depth, the F test was used in the analysis of variance and the means were compared by the Tukey´s test (α = 0.05). The data were statistically analyzed using the R statistical software (R Foundation for Statistical Computing, 2008).

Results and Discussion

The higher pH values were observed at 6 months. However, the potential acidity (H + Al) and exchangeable acidity (Al^{3+}) of the soil were higher at 18 months. This effect was not observed in the area without the application of limestone. The limestone with the largest particle size (2.00 mm at 0.82 mm) showed residual effect at 18 months after its application (Figure 2). These results are in agreement with Anjos et al. (2011) and Natale et al. (2007), which verified the effectiveness of the application of limestone in the correction of soil acidity and the reduction of Al $^{3+}$, active acidity (H^+) and potential acidity (H+Al).

Thus, it is verified that the reactivity of all the granulometric fractions influenced the active and potential acidity of the soil during a period of 18 months. Even though, it was observed a re-acidification of the soil after this period. However, the exchangeable Ca and Mg levels remained at adequate levels for corn cultivation.

Freiria et al. (2008), reported that the reaction of the limestone in the soil can vary in time, between 12 and 24 months, in the type used of limestone and in its granulometry. Thus, the PRNT of the limestone does not represent exactly its activity in the soil nor its time of reactivity. In this sense, limestone with higher granulometry and PRNT of less than 45% showed residual effect on soil acidity correction in SPD at 18 months in this study. The use of this type of limestone becomes a viable alternative for SPD implantation.

The reaction of corrective sources is highly affected by the materials millings and smaller size particles react faster, however, the residual effect is maintained for a shorter period than in materials with larger particle size. This result was also observed by Gonçalves et al. (2011) that applied limestone of different particle sizes and observed a rapid increase of pH in thinner particles.

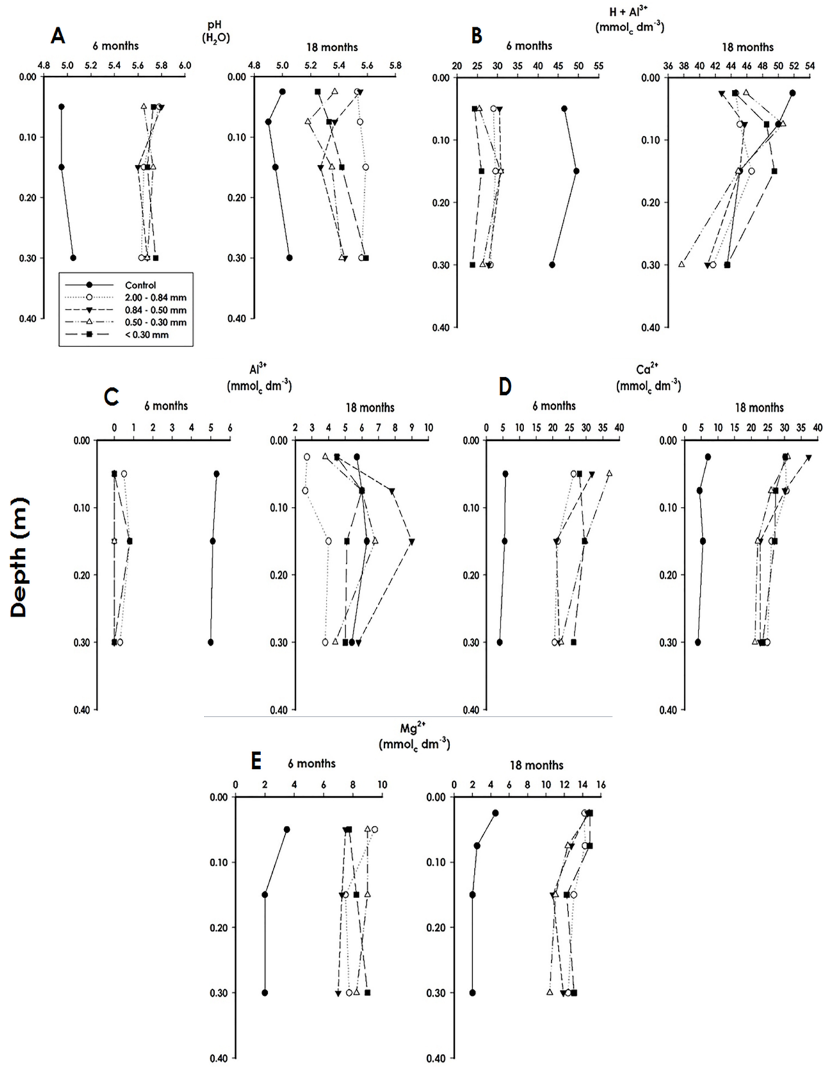

Figure 2. Effect of different granulometry and lime doses incorporated in the soil for the values of: A - pH in H_2O; B – potential acidity (H^++Al^{3+}); C - Al^{3+}; D - Ca^{2+} and E - Mg^{2+} in different soil depths at 6 and 18 months after the lime application.

Thinner limestone (<0.30 mm) resulted in an increase of pH to 5.75 in the 0.2-0.4 m layer of soil depth, but there were no significant differences between treatments in the first year. Thus, the thinner limestone was more efficient when compared to other treatments with higher particle sizes to raise pH in the first year, due to the use of higher doses of these limestones (Table 3).

Table 3. Soil pH values according to lime application in different granulometric fractions.

Months	Depth	Granulometry (mm)					Mean	C.V. (%)
		Control	2.00-0.82	0.82-0.56	0.56-0.30	0.30-0.20		
	M	$pH(H_2O)$						
6	0.00-0.10	4.95aA*	5.78aA	5.80aA	5.65aA	5.73aA	5.58a	2.84
	0.10-0.20	4.95aA	5.65aA	5.60aA	5.73aA	5.68aA	5.52a	2.27
	0.20-0.40	5.05aB	5.63aB	5.68aB	5.68ab	5.75aA	5.56a	1.35
	Mean	4.98A	5.68A	5.69A	5.68A	5.72A	-	-
	C.V. (%)**	1.58	2.19	3.63	3.78	1.26	-	-
18	0.00-0.05	5.00aB	5.53aA	5.55aA	5.37aA	5.25aAB	5.34a	4.55
	0.05-0.10	4.90aA	5.55aA	5.37aA	5.18aA	5.33aA	5.27a	4.22
	0.10-0.20	4.95aA	5.59aA	5.27aA	5.35aA	5.42aA	5.32a	5.43
	0.20-0.40	5.05aA	5.56aA	5.44aA	5.42aA	5.59aA	5.41a	4.62
	Mean	4.98B	5.56A	5.41A	5.42A	5.68aA	-	-
	C.V. (%)	3.45	2.37	3.87	3.76	2.03	-	-

*Means followed by the same lowercase letter in the column and uppercase letter in lines re not different according to Tukey´s test (P<0.05)

**C.V. (%): coefficient of variation.

No signifficant difference was observed in soil pH mean values according to the limestone granulometry used, differing only from the area without limestone application at 18 months. This was also observed in the 0-0.05 m depth layer. However, the higher soil pH means in the 0-0.4 m depth layer were observed using the limestone with a grain size of 0.30 mm to 0.20 mm. Thus, the greatest limestone granulometry was efficient in raising the pH of the soil when compared to the thinner granulometry, due to the increase in limestone doses. Gonçalves et al. (2011) observed higher pH values in the treatments using limestone with thinner particle size (PRNT of 95%) compared to limestone with PRNT of 56% at 24 months after application and more evident reductions of total acidity in the no-tillage system area. However, in this research it was verified that the pH values at 18 months were lower due to the acidification provided by the corn cultivation in a no-tillage system and bases removal due to acid weathering.

Limestone granulometries above 0.30mm resulted in the same effect for soil potential acidity (H+Al) when compared to the use of thinner particles of limestone at 6 months after application, due to the adjustments of the doses according to reactivity. However, after 18 motnhs, no signifficant difference for the H+Al values was observed according to the use of

Table 4. Soil potential acidity with limestone application in different granulometric fractions.

Months	Depth	Granulometry (mm)					Mean	C.V. (%)
		Control	2.00-0.82	0.82-0.56	0.56-0.30	0.30-0.20		
	M	$H^+ + Al^{3+}$ ($mmol_c$ dm^{-3})						
6	0.00-0.10	46.5aA	29.0aAB	30.5aAB	25.5aB	24.3aB	31.2a	16.71
	0.10-0.20	49.5aA	29.5aAB	30.8aAB	30.8aAB	26.0aB	33.3a	21.92
	0.20-0.40	43.5aA	28.3aB	27.8aB	26.3aB	23.8aB	29.0a	17.08
	Mean	46.5A	28.9B	29.7B	27.5B	24.7B	-	-
	C.V. (%)**	15.40	6.94	10.52	16.23	10.58	-	-
18	0.00-0.05	51.8aA	44.6aA	42.8aA	45.9abA	44.5aA	45.9a	6.76
	0.05-0.10	50.0aA	45.1aA	45.7aA	50.6aA	48.5aA	48.0a	15.37
	0.10-0.20	45.1aA	46.6aA	45.1aA	44.9bcA	49.5aA	46.2a	17.16
	0.20-0.40	43.5aA	41.7aA	41.0aA	37.7cA	43.5bA	40.1b	19.79
	Mean	45.9A	44.5A	43.7A	44.8A	46.5A	-	-
	C.V. (%)	8.88	15.27	13.98	10.07	7.88	-	-

*Means followed by the same lowercase letter in the column and uppercase letter in lines are not different according to Tukey´s test (P<0.05)

**C.V. (%): coefficient of variation.

limestone with different granulometries (Table 4).

The different limestone granulometries demonstrated the same efficiency in reducing the soil exchangeable acidity (Al^{3+}) when compared to the treatment without applying limestone in the 0.00-0.4 m profile of the soil at 6 months (Table 5). This effect was possible due to correction of limestone doses as a function of the reactivity of each granulometry studied. Araújo, et al. (2009) evaluated the application of limestone with different degrees of reactivity in the corn crop and observed higher plant growth, reducing the exchangeable Al^{3+} levels using calcareous PRNT of 88.3% and 76.2%. Thus, it is evident that limestone with lower PRNT promotes the reduction of the exchangeable Al^{3+} as the limestones with higher PRNT values, when applied proportional to their reactivity.

Table 5. Exchangeable aluminum of the soil with the application of limestone with different granulometric fractions.

Months	Depth	Granulometry (mm)					Mean	C.V. (%)
		Control	2.00-0.82	0.82-0.56	0.56-0.30	0.30-0.20		
	M	Al^{3+} ($mmol_c$ dm^{-3})						
6	0.00-0.10	5.3aA	0.5aB	0.0aB	0.0aB	0.0aB	1.2a	263.31
	0.10-0.20	5.1aA	0.8aAB	0.0aB	0.0aB	0.8aAB	1.3a	329.14
	0.20-0.40	5.0aA	0.3aB	0.0aB	0.0aB	0.0aB	1.1a	447.21
	Mean	5.1A	0.5B	0.0B	0.0B	0.30	-	-
	C.V. (%)**	21.20	40.82	0.00	0.00	141.42	-	-
18	0.00-0.05	5.7aA	2.7aA	4.5aA	3.8aA	4.5aA	4.2a	94.82
	0.05-0.10	6.0aA	2.6aA	7.8aA	6.0aA	6.0aA	5.7a	86.19
	0.10-0.20	6.3aA	4.0aA	9.0aA	6.8aA	5.1aA	6.2a	75.51
	0.20-0.40	5.4aA	3.8aA	5.8aA	4.4aA	5.0aA	4.9a	71.76
	Mean	5.8A	3.3A	6.8A	5.2A	5.17A	-	-
	C.V. (%)	30.96	40.22	38.93	54.12	51.95	-	-

*Means followed by the same lowercase letter in the column and uppercase letter in lines re not different according to Tukey´s test (P<0.05) **C.V. (%): coefficient of variation.

In the present study, the limestone with higher granulometry (2.00 mm to 0.82 mm) showed residual effect at 18 months after its application. The residual effect of the corrective materials is important to maintain soil fertility, providing higher plant nutrient input and favoring its development.

The exchangeable Ca^{2+} and Mg^{2+} levels increased as a function of the use of different granulometry and limestone amounts at 6 and 18 months after application, when compared to the area without limestone application. However, there was no difference between the limestone fractions used to raise the Ca^{2+} and Mg^{2+} contents in the soil (Table 6 and 7). Higher granulometry uses resembled the use of finer magnesium limestone particles for Ca2 + and Mg2 + contents in pasture soil (Alvarez et al., 2010). Similar result was provided by the use of limestone fractions of 2.00 mm to 0.30 mm.

Table 6. Exchangeble Ca contents in the soil according to the application of limestone with different particle sizes.

Months	Depth	Granulometry (mm)					Mean	C.V. (%)
		Control	2.00-0.82	0.82-0.56	0.56-0.30	0.30-0.20		
	m	Ca^{2+} ($mmol_c$ dm^{-3})						
6	0.00-0.10	5.75aB*	26.25aA	31.75aA	37.00aA	28.00aB	25.75a	43.08
	0.10-0.20	5.50aB	21.5aA	21.00aA	29.72aA	29.5aA	21.45ab	20.83
	0.20-0.40	4.00aB	20.5aA	22.00aA	22.50bA	26.25aA	19.05bc	19.44
	Mean	5.08B	22.75A	24.91A	29.75A	27.91A	-	-
	C.V. (%)**	23.04	19.53	47.39	12.93	13.94	-	-
18	0.00-0.05	7.00aB	30.25aA	31.02aA	31.02aA	30.30aA	27.17a	23.83
	0.05-0.10	4.5aB	30.6aA	26.00aA	26.00aA	27.35aA	23.72a	19.26
	0.10-0.20	5.5aB	26.12aA	22.70aA	21.95aA	27.05aA	20.66a	23.79
	0.20-0.40	4.0aB	24.85aA	22.70aA	26.32aA	23.47bA	19.23a	22.93
	Mean	5.25B	27.96A	28.21A	26.32A	27.04A	-	-
	C.V. (%)	12,35	14,55	22,27	15,34	13,39	-	-

*Means followed by the same lowercase letter in the column and uppercase letter in lines re not different according to Tukey´s test (P<0.05)

**C.V. (%): coefficient of variation.

Table 7. Exchangeble Mg contents in the soil according to the application of limestone with different particle sizes.

Months	Depth	Granulometry (mm)					Mean	C.V. (%)
		Control	2.00-0.82	0.82-0.56	0.56-0.30	0.30-0.20		
	M	Mg^{2+} ($mmol_c$ dm^{-3})						
6	0.00-0.10	3.50aB*	9.50aA	7.50aA	9.00aA	7.75aA	7.45a	29.46
	0.10-0.20	2.00aB	7.50aA	7.25aA	9.00aA	8.25aA	6.80a	13.51
	0.20-0.40	2.00aB	7.75aA	7.00aA	8.25aA	9.00aA	6.80a	26.06
	Mean	2.50B	8.25ª	7.25A	8.75A	8.33A	-	-
	C.V. (%)**	23.51	23.12	16.73	11.27	12.81	-	-
18	0.00-0.05	4.50aB	14.23aA	14.55aA	14.73aA	14.83aA	12.56a	13.81
	0.05-0.10	2.50aB	14.28aA	12.78aA	12.40aA	14.78aA	11.34a	11.57
	0.10-0.20	2.00aB	13.05aA	10.78aA	11.05aA	12.28aA	9.83b	16.90
	0.20-0.40	2.00aB	12.43aA	11.90aA	12.75aA	13.08aA	9.97b	14.91
	Mean	2.75B	13.49A	12.50A	12.73A	13.74	-	-
	C.V. (%)	14.88	14.32	16.07	14.67	13.46	-	-

*Means followed by the same lowercase letter in the column and uppercase letter in lines re not different according to Tukey´s test ($P<0.05$)

**C.V. (%): coefficient of variation.

Thus, there was a compensation of the lower reactivity of the limestones with higher granulometries, adjusting the doses of these limestones in comparison to the limestone of lower granulometry with reactivity of 100%. Therefore, the application of limestones with larger particle sizes with adequate doses to their reactivity provides adequate Ca and Mg supply when the no-tillage system is used. In addition, these limestone fractions increased Ca^{2+} and Mg^{2+} levels at 18 months, demonstrating their residual effect on the soil.

The reactivity of limestone with particle sizes above 0.56 mm was slower, modifying the Ca: Mg ratio, correcting the soil and favoring crop yield. Natale et al. (2007) reports that the greater contact between the corrective and the sources of acidity results in an adequate effect of the practice of liming, which should guarantee the efficient use of water and soil nutrients, increasing the crop yield. Thus, the use of limestone with a grain size of 2.00 mm to 0.82 mm was more efficient to favor corn yield in the first year (Table 8).

Table 8. Corn grain yield (kg ha^{-1}) according to the applications of different particle sizes of limestone during two crop years (2009 and 2010).

Granulometry (mm)	2009	2010	Mean	C.V. (%)
Control	4.895,5bA*	5.310,01bA	5102,76b	28.38
2,00 - 0,82	9.888,21aA	7.007,99aB	8.448,10a	10.89
0,82 - 0,56	7.775,02abA	7.516,13aA	7.645,58ab	23.65
0,56 - 0,30	7.018,28bB	7.853,13aA	7.435,71ab	26.06
0,30 - 0,20	5.482,67bB	7.092,68aA	6.287,68ab	9.81
Mean	7.411,94A	6.955,99A		
C.V.(%)**	15.57	12.61		

*Means followed by the same lowercase letter in the column and uppercase letter in lines re not different according to Tukey´s test ($P<0.05$)

**C.V. (%): coefficient of variation.

Limestones with higher granulometries resulted in similar corn yield when compared to the use of limestone with lower granulometry in the second crop year, when applied proportional to its reactivity. Similar results for pasture was observed by Alvarez et al. (2010), when the larger limestone granulometry increased the yield when compared to the use of lower particle sized limestone.

The highest average of corn grain yield was found with the use of limestone of 2.00 mm to 0.82 mm of granulometry in the first year. The lowest corn yields were observed when the lower granulometry was used, which reacted faster in the soil in the cited year. It was observed higher corn yield during the second year when compared to the first year with the use of limestone with a lower particle size than 0.56 mm, and the opposite being observed for particle sizes above 0.56 mm. The highest corn yields reached 9,888.21 kg ha^{-1} in the first crop year and 7,853.13 kg kg ha^{-1} for the second crop year, above the the national average of the 2009 and 2010 harvests, which were 4,316 kg ha^{-1} and 4,236 kg ha^{-1}, respectively (CONAB, 2011). The application and incorporation of different particle sizes and limestone doses resulted in no significant difference for maize production in the second year. However, limestone with a grain size of 2.00 mm to 0.82 mm provided the yield of 8,448.10 kg ha^{-1}, being the best average corn yield of the evaluated periods.

Conclusions

The limestone use, in proportional doses according to its PRNT, with granulometric fractions from 2.00 to 0.30 mm lead to the correction of soil acidity.

Limestones with different granulometric fractions lead to residual effect in the soil, increasing Ca and Mg contents at 18 months after application.

The use of limestones with higher granulometry is an alternative for the no-tillage system implementation due to the soil residual afect, maintainning the soil fertility and increasing the period between successive applications.

Higher corn yields are achieved with the use of limestone from 2.00 to 0.84 mm during the first year of the crop.

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