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Enhancing surface liming rate on a no-till cropping system in an oxisol of Southern Brazilian

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The aim of the experiment is to evaluate the physical and chemical effects caused on the properties of red latosol containing high levels of organic matter in the aftermath of 40 months after surface liming and the effects on yield components of no-till maize. The experiment was conducted in an area of 1000 m^2 split into 40 plots of 25 m^2, and the experimental design adopted was randomized complete blocks with five treatments and four replications. The treatments consisted of five rates of lime: 0, 2.5, 5, 12.5 and 30 $ton.ha^{-1}$ (1 SMP pH 5.5). After 40 months of experiment installation, soil samples were taken in a total of four sub samples per plot, that were properly homogenized at different depths (0 to 5, 5 to 10 and 10 to 20 cm) and evaluated on chemical parameters (pH, H+Al, Ca, Mg, Al saturation and bases); on physical parameters (resistance to penetration and soil water infiltration) and on maize crop parameters (yield, height of insertion of first cob and plant's height). It was observed that equal and above 1 SMP to pH 5.5 ameliorated soil pH in the layers up to 20 cm after 40 months of application, interfering in the levels of Al+H, Ca, Mg, saturation of bases and saturation of aluminum. However, significant effects on soil pH were observed in a depth up to 10 cm. The application of different surface liming rates did not interfere on penetration resistance or soil water infiltration capacity. The effects on soil chemical properties with the rate of 1 SMP to pH 5.5 resulted in higher maize grain yield.

Key words: Chemical correction, soil physics, maize, acidity.

INTRODUCTION

The efficiency of surface liming in no-till cropping systems, particularly aiming subsoil acidity amelioration, and liming recommendation criteria for this purpose were widely investigated (Caires et al 2000; Rheinheimer et al., 2000; Amaral et al., 2004; Kaminski et al., 2005; Nolla and Anghinoni, 2006; Bortoluzzi et al., 2014). However, when soil pH is not properly ameliorated at the moment of implementation of a no-till cropping system, the rates

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of surface liming on elevated acidity soils with elevated levels of organic matter may not be enough for amelioration in an efficient way.

In a consolidated no-till cropping system Fidalski et al. (2015) observed that liming incorporated into about 20 cm deep of the limestone with plow and harrow, had not exhibited any advantage in relation with surface liming (zero cm incorporation). Yagi et al. (2014) observed that the soil limestone incorporation reduced the carbon frameworks of macro-aggregates in the layer of 0 to 0.10 m and concluded that surface liming is essential for the maintenance or even enhancement of carbon stocks in the soil. Surface liming in no-till cropping systems for a long period boosts an increment of soil organic carbon and total nitrogen (Briedis et al., 2012).

Surface liming is an effective practice, and it is important to maximize grain yield of no-till crops, also the acidity amelioration of deeper soil layers is more pronounced with the use of higher limestone rates (Rodrighero et al., 2015). Veronese et al. (2012) verified that the higher the rate, the greater the progress of the alkaline front in the soil, and the higher the grain yield even with deep liming. Moreira et al. (2017) suggested that applications of limestone in soil up to a rate necessary to achieve 70% of base saturation are not related with micronutrient deficiency in no-till soybeans. Caires et al. (2006) suggested that liming application aims to elevate the bases saturation to 70% with surface liming on a single application or within three consecutive years. The likelihood correspondence between the saturation of bases and the pH of reference crops, for soils in south Brazil (Rio Grande do Sul and Santa Catarina states), utilized by the Slightly Modified Shoemaker-McLean-Pratt Single Buffer Method for limestone prescriptions (SMP method), would be: pH = 5.5 correspond to V (Base saturation) = 65%; pH = 6.0 correspond to V = 75% and pH = 6.5 correspond to V = 85% (CQFS-RS/SC, 2016).

Therefore, it turns out to be still necessary to the assessment of efficient rates for surface liming in soils with elevated potential acidity and high organic matter content, looking for alternative strategies for soil amelioration at depth without tillage, and so at deeper soil layers. Thus, the experiment aimed to evaluate the physical and chemical effects of surface liming for a long time (40 months) on the properties of a brown Oxisol containing high levels of organic matter, and the effects on yield components of no-till maize.

MATERIALS AND METHODS

The experiment was carried out in an experimental field at the University of Caxias do Sul on the municipality campus of Vacaria, Rio Grande do Sul state, Brazil, with geographic coordinates of latitude 28º31´S, longitude 50º 54´W and elevation of 965 m above sea level. The soil was a brown Oxisol (Embrapa, 2013), with native pasture presenting the following chemical features (Tedesco et al., 1995): pH 4.5; SMP (Slightly Modified Shoemaker-McLean- Pratt Single Buffer Method for limestone prescriptions) index 4.5; organic matter 60 $g.kg^{-1}$; calcium 1.4 $comol_c.dm^{-3}$; magnesium 1.0 $comol_c.dm^{-3}$; aluminum 6.4 $comol_c.dm^{-3}$; H+Al 24.4 $comol_c.dm^{-3}$; effective cation exchange capacity 9 $comol_c.dm^{-3}$; cation exchange capacity at pH 7.0, 27 $comol_c.dm^{-3}$; aluminum saturation 71.1%; bases saturation 9.6%; phosphorus 1 $mg.dm^{-3}$; sulfur 5.1 $mg.dm^{-3}$; and potassium 74 $mg.dm^{-3}$.

The treatments were applied in a single time at December 20, 2012 to study the residual effect of liming, in twenty plots of 25 m^2 (5x5 m) arranged in completely randomized blocks, with four replications (blocks) and five rates of calcitic lime applied on soil surface. Since for the region being tested there is a recommendation from the Soil Chemistry and Fertility Commission for the states of Santa Catarina and Rio Grande do Sul, Brazil (CQFS-RS / SC, 2016), which limits the surface application of limestone to 5.0 ton ha-1 if soil analysis has recommended higher doses. If the doses are below 5.0 ton ha^{-1}, the dose may be applied in its entirety.

Therefore, the doses were: 0 ton.ha-1 (control); 2.5 $ton.ha^{-1}$ (50% of the maximum rate recommended for superficial liming); 5 $ton.ha^{-1}$ (maximum rate recommended for surface liming); 12.5 $ton.ha^{-1}$ (necessary rate to enhance the pH of this soil to 5.5 based in a soil analysis by SMP method), and 30 $ton.ha^{-1}$ (6 times the maximum rate for surface liming). The rates adjusted to the actual effective neutralizing power of the limestone utilized (68 to 70%) in this area, was kept native grassland without animal occupation for 3 seasons (2012 to 2015) and finally in the cropping season of 2015/2016, was cultivated maize of the variety Pioneer 30F53. At the first fortnight of May 2016, 40 months after surface lime application, the residual effect of lime mobility over the physical and chemical parameters of the soil as well as yield components of maize was evaluated (Plant height, insertion of the cob corn, maize yield).

It was executed six evaluations in each plot for soil penetration resistance with the use of an electronic measurer Penetrolog PLG1020, from Falker® at a depth of 0 to 40 cm, resulting in 24 evaluations per treatment. The evaluations of the rate of water infiltration in the soil were executed through the Soil Quality Test Kit method (USDA-ARS, 1998) using four replications per plot, totalizing 16 replications per treatment. For the evaluation of chemical features of the soil, four samples were collected per plot and were homogenized, at the soil depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm. In each plot 20 measurements were made for the variables plant height, considering from the soil surface to the base of the maize tassel and the height of first feasible cob. Additionally, it harvested the cobs manually in an area of 2x3 m into each plot. The cobs were threshed with a maize mechanical thresher of the brand Lavrale®, where the grains were weighted, and the values were adjusted to a humidity of 13%.

The results of the evaluations were subjected to analysis of variance (ANOVA) using WinStat (1.0 version). In case of significance, the effects of the rates were compared through analysis of regression and depth effects were compared by the Tukey averages test at 5% probability. The criteria are to fit regression equations were the magnitude of the coefficient of determination (r^2) is significant at 5% probability.

RESULTS AND DISCUSSION

The physical parameters evaluated, penetration resistance (PR) and soil water infiltration was not influenced by the enhancement of surface liming rate. The soil water infiltration had a mean of 325 $mm.h^{-1}$, which is considered as fast by the Soil Quality Kit Test Guide (USDA-ARS, 1998). Notwithstanding, despite the method to be more sensitive than the traditional ones, it

Table 1. pH H_2O, H + Al, calcium, magnesium, saturation of bases and saturation of aluminum in different soil depths and doses of soil surface liming on no-till cropping system.

Depth (cm)	Limestone dose (ton.ha^{-1})				
	0	2.5	5.0	12.5	30
			pH H_2O		
0.0 - 5	4.70^{B}	5.45^{A}	5.83^{A}	6.80^{A}	7. 47^{A}
5.0 - 10.0	4.97^{AB}	5.10^{B}	5.27^{B}	5.42^{B}	5.82^{B}
10.0 - 20.0	5.07^{A}	4.97^{B}	5.00^{B}	5.10C	5.20^{C}
Coefficient of variation (CV%)			3.09		
H+ Al (comol$_c$.dm.$^{-3}$)					
0.0 - 5	15.49^{A}	7.42^{B}	5.12^{C}	2.07^{C}	1.02^{C}
5.0 - 10.0	12.85^{A}	11.40^{A}	8.12^{B}	7.27^{B}	4.27^{B}
10.0 - 20.0	13.85^{A}	13.85^{A}	15.92^{A}	11.65^{A}	9.55^{A}
CV(%)			19.19		
Ca (comol$_c$.dm.$^{-3}$)					
0.0 - 5	3.80^{A}	7.75^{A}	9.30^{A}	14.95^{A}	17.02^{A}
5.0 - 10.0	2.77^{AB}	3.32^{B}	4.00^{B}	4.50^{B}	7.22^{B}
10.0 - 20.0	1.15^{B}	1.30^{C}	1.45^{C}	1.65^{C}	2.95^{C}
CV(%)			21.18		
Mg (comol$_c$.dm.$^{-3}$)					
0.0 - 5	1.82^{A}	2.67^{A}	2.75^{A}	2.50^{A}	1.65^{A}
5.0 -10.0	1.28^{B}	1.35^{B}	1.25^{B}	1.33^{B}	1.70^{A}
10.0 - 20.0	0.48^{C}	0.55^{C}	0.58C	0.60^{C}	1.00^{B}
CV(%)			22.22		
Saturation of bases (comol$_c$.dm.$^{-3}$)					
0.0 - 5	28.07^{A}	59.60^{A}	70.27^{A}	89.37^{A}	94.80^{A}
5.0 - 10.0	25.40^{AB}	30.37^{B}	40.30^{B}	45.32^{B}	68.00^{B}
10.0 - 20.0	11.62^{B}	12.35^{C}	12.00^{C}	17.25^{C}	30.85^{C}
CV(%)			19.30		
Saturation of aluminium (comol$_c$.dm.$^{-3}$)					
0.0 - 5	24.37^{B}	4.35^{C}	2.25^{C}	0.00^{C}	0.00^{A}
5.0 - 10.0	38.42^{B}	31.17^{B}	24.02^{B}	16.92^{B}	2.15^{B}
10.0 - 20.0	57.27^{A}	57.27^{A}	57.37^{A}	58.35^{A}	28.42^{B}
CV(%)			32.40		

Analyses of variance significant (F≥0.01). Averages followed by the same capital letter in the column do not differ from each other (Tukey at 5% probability).

is efficient in detecting great differences in the rate of water infiltration (Santi et al., 2012).

PR differed only among the depths evaluated and presented in the depths of 0 to 40 cm a mean of 1099 kPa. Values above 2000 kPa are proven to be a critical value for root elongation according to Reinolds et al. (2002) and were achieved at depths beginning from 20 cm, reaching a maximum of 2717 kPA at depths of 30 to 40 cm. Similarly, Bortoluzzi et al. (2014) found values of PR above 2 Mpa only at depth of 20 cm, while the greatest value for PR (2882 kPa) was found in the layer of 30 to 40 cm. However, the authors stated that greater values of PR seem not to affect root distribution of the treatments.

The chemical parameters evaluated exhibited significant interaction among rates of surface liming and the depths evaluated is based on analysis of variance (p ≤0, 05). The depth effects at each dose are shown in Table 1 and the effects of doses at each depth are presented in Figures 1 to 4.

In the soil tested, the parameters of each experimental plot (different limestone doses) presented natural variability with increasing depth for pH H_2O, Ca, Mg, Base Saturation and Aluminum Saturation (Table 1). With

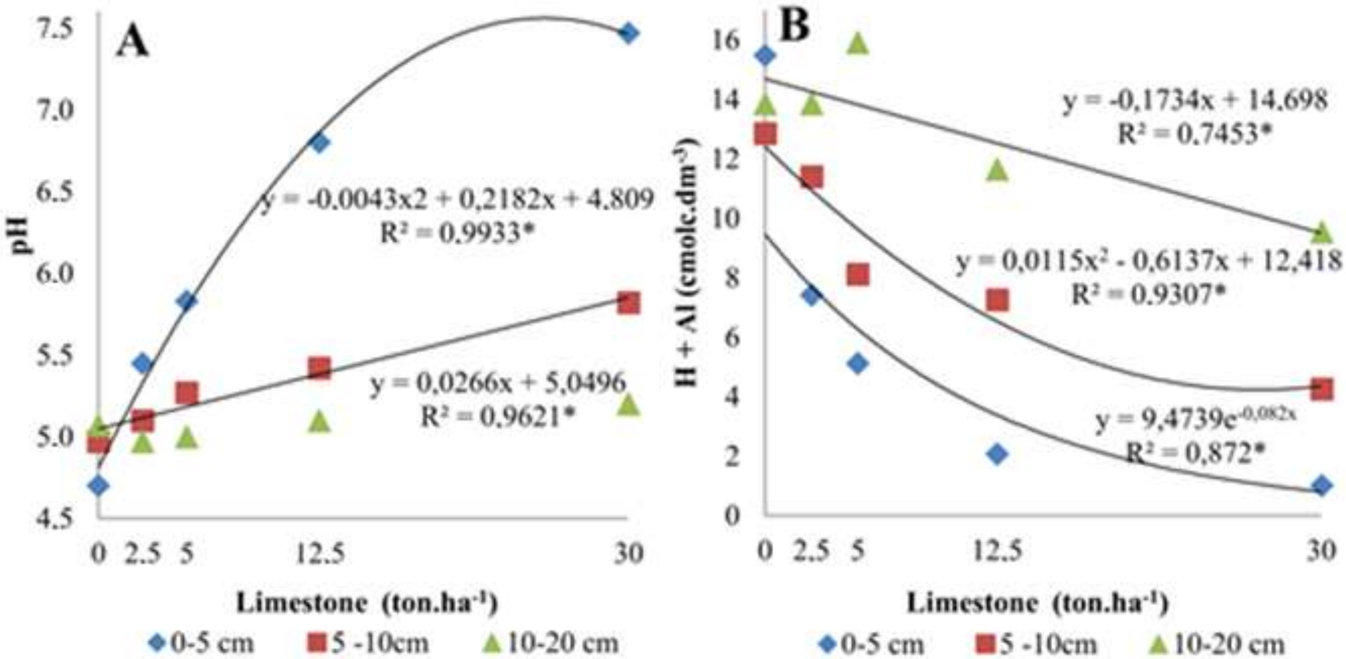

Figure 1. pH H_2O (A) and H+Al (B) as function of different rates of soil surface liming on no-till cropping system in at the soil depths of 0-5, 5-10 and 10-20 cm. *Coefficient of determination significant at 5% of probability and ANOVA (F≥0.01).

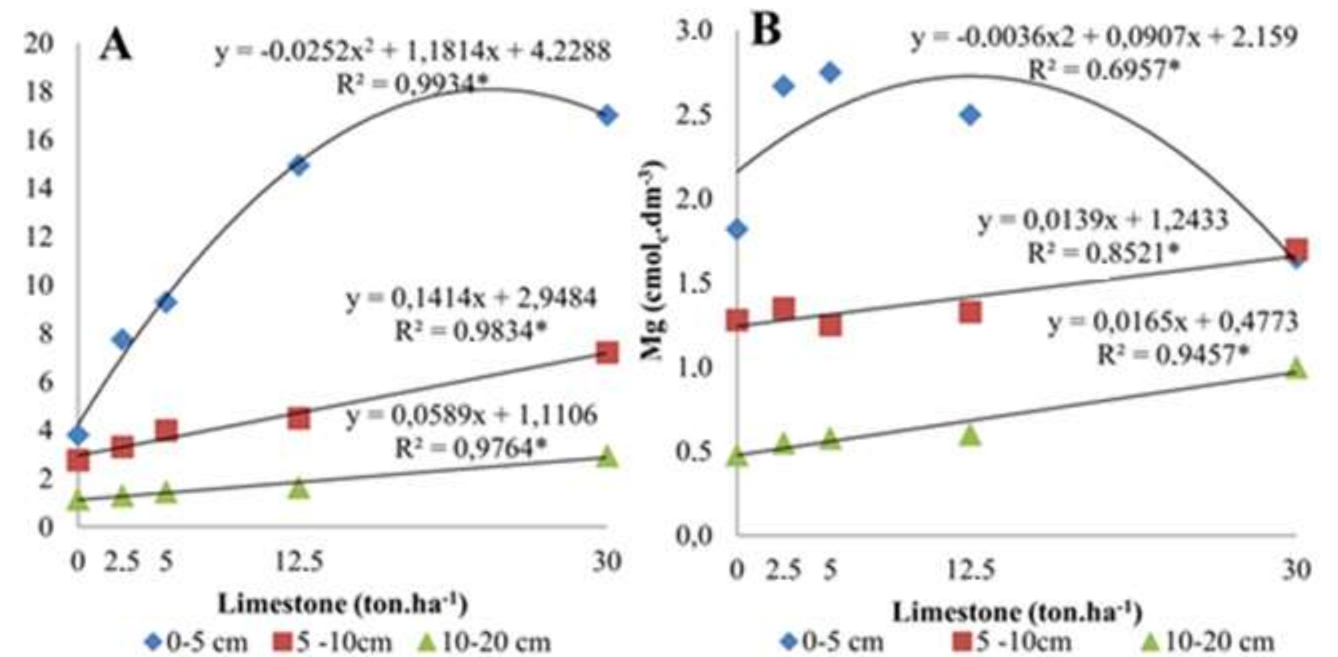

Figure 2. Calcium (A) and magnesium (B) as function of different rates of soil surface liming on no-till cropping system in at the soil depths of 0-5, 5-10 and 10-20 cm. *Coefficient of determination significant at 5% of probability and ANOVA (F≥0.01).

the application of limestone, this variation reduces to the pH of the soil and intensifies with the increment of the applied dose for the other evaluated parameters. The chemical gradient in the different depths with the application of surface limestone has already been observed in several studies (Rheinheimer et al., 2000;

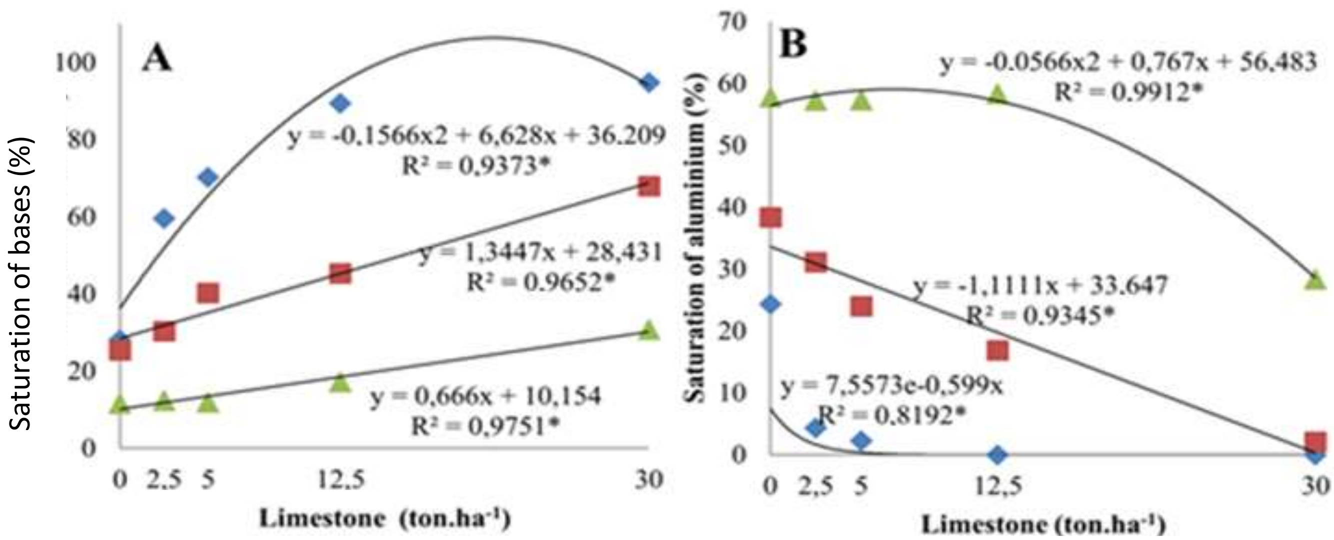

Figure 3. Saturation of bases (A), saturation of aluminium (B) as function of different rates of soil surface liming on no-till cropping system in at the soil depths of 0-5, 5-10 and 10-20 cm. *Coefficient of determination significant at 5% of probability and ANOVA (F≥0.01).

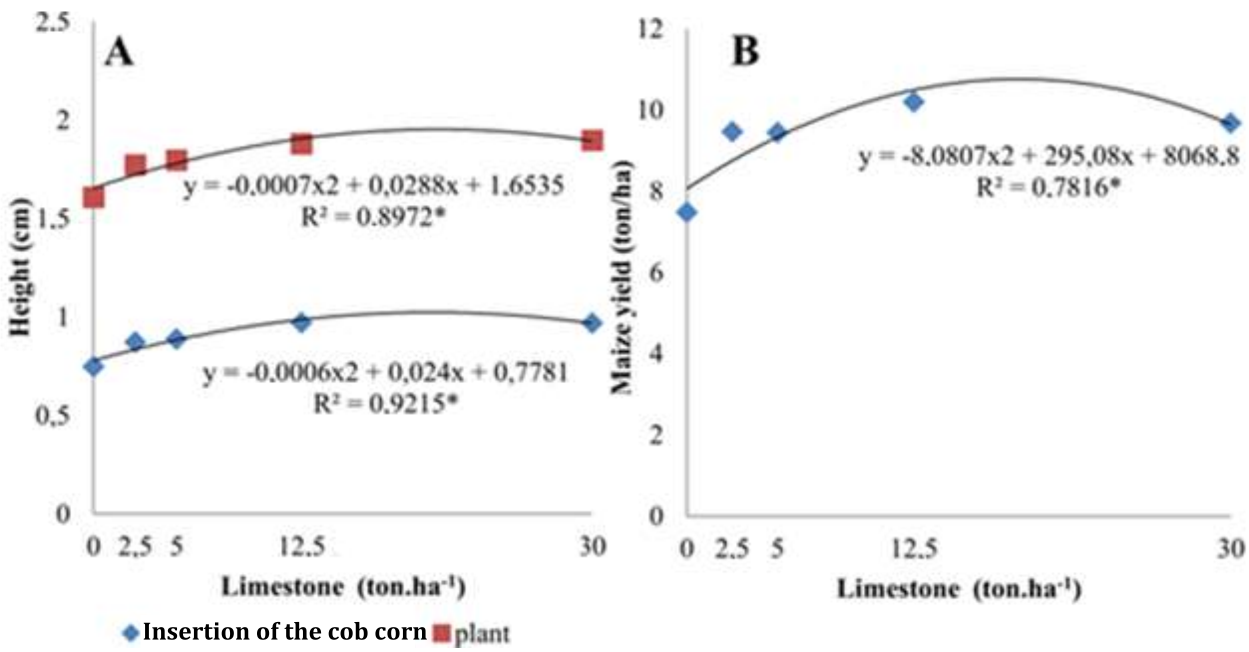

Figure 4. Plant height and height (A) and maize yield (B) as function of different rates of soil surface liming on no-till cropping system. * Coefficient of determination significant at 5% of probability and ANOVA (F≥0. 01).

Kaminski et al., 2005) and can be attributed to its low mobility when applied in this condition.

Surface liming stimulated the soil pH to increase, which intensified with the increment of the lime rates at depths of 0 to 5 and 5 to 10 cm (Figure 1A). However, the effect in the layer of 0 to 5 cm was quadratic, while the layer of 5 to 10 cm was linear, indicating a stabilization of the pH in the superficial layer at higher rates. In the layer of 10 to 20 cm the surface lime rates applied did not result in a significant effect.

The levels of H^{+}+Al^{3+} exhibited reduction in all depths evaluated after the application with increased lime rate, being the layer of 0 to 5 cm and 5 to 10 cm the effect was quadratic, that is, with a tendency to stabilize at higher rates and at depth of 10 to 20 cm the effect was linear. These results demonstrate that the potential acidity was reduced until the depth of 20 cm (Figure 1B)

Despite surface liming did not alter the pH of the layer 10-20 cm (Figure 1A), it indeed altered the potential acidity in this layer with greater intensity at the higher rates applied. Soratto and Crusciol (2008) found similar results where liming promoted a decrease of the soil potential acidity (H+Al) in the layer up to 20 cm deep after surface liming inversely proportional to the rate applied.

The level of Ca^{2+} exhibited an increase accordingly to the increment of limestone rate applied, at all depths evaluated demonstrating that Ca^{2+} applied as limestone can reach depths higher than 10 cm after 40 months of surface liming (Figure 2A). The decrease of Ca^{2+} at depths greater than 20 cm was reported in other studies (Caires et al., 2000; Soratto and Crusciol, 2008; PaulettI et al., 2014), demonstrating that an improvement in the root zone environment was proportional to the rate applied at soil surface.

Magnesium presented a reduction of the levels in the layer of 0 to 5 cm at the highest lime rate tested (Figure 2B) and the increase of the levels in the layers of 5 to 10 and 10 to 20 cm according to the rate applied. This result can be the consequence of an interference with the high Ca^{2+} content of the superficial layer at excessive rates of surface liming, reason been that according to Caires et al. (1998), with the presence of limestone the magnesium leaching is more pronounced. The same authors observed that after 12 months of liming an increment in the level of magnesium in the layer of 5 to 10 cm, similarly with this experiment.

With increasing surface liming rates, it was observed that an increment in the saturation of bases and a reduction in the saturation of Al at all depths were evaluated (Figure 3A and B), reflecting the effects in H+Al and the levels of Ca^{2+} and Mg^{2+}. Therefore, evident improvement in the root zone environment up to a depth of 20 cm can be reached with the application of rates equivalent to 1 SMP to pH 5.5 in a soil with elevated levels of organic matter and potential acidity. It is important to point out that this effect on soil chemistry is less efficient than deep liming at the implementation of a no-till cropping system (Bortoluzzi et al., 2014) but an alternative to tillage in a consolidated no-till cropping system.

Maize yield components presented significant variations to the rates of surface liming applied. Plant height and height of first cob (Figure 4A) had a quadratic increase according to the increment of lime rate. Maize plants reached maximum height development with lime rate of 12.5 ton/ha and rate of 1 SMP to reach pH 5.5 in the layer of 0 to 20 cm. Caires et al. (2002) also reported an increment in maize plant height with the increment at the rates of limestone, in a latosol in Paraná state.

Maize yield also presented a significant quadratic increase with the increment of the rates of surface liming (Figure 4B), demonstrating a beneficial effect to soil for maize development. The increment of plant height and maize yield found in this experiment with the application of the rate obtained for 1 SMP to pH 5.5 are the consequence of the improvement of the soil features, being an indicative of the rate for soil amelioration through surface liming, in soil with elevated potential acidity. These results corroborate with the findings of Caires et al. (2000), where the rate of limestone for a maximum economic efficiency is indicated by the elevation of bases saturation method to 65%, for a soil sample collected at a depth of 0 to 20 cm, corresponded in this experiment to the rate of 15 ton/ha^{-1}. Therefore, considering the correlation between these methods, the results indicate that this criterion is adequate for the recommendation of surface liming rates in a no-till cropping system, even with rates higher than 5 ton/ha^{-1}.

Conclusion

The limestone application at surface, according to the total amount based on the soil analysis recommendation, is not a commonly used practice in the southern region of Brazil, since the fertilization and liming recommendation manuals establish 5.0 ton.ha-1 as the annual maximum limit for the superficial application, or its incorporation, if the recommended doses are higher than this value, when it is necessary the correction of the acidity in the depth of 10 to 20 cm. However, for the soils of the evaluated region, with high potential acidity and high levels of organic matter, the superficial application of the total limestone dose required to raise the pH H_2O to 5.5 (according to the recommendation based on soil analysis by the SMP method), is an effective alternative for improvements in soil chemical characteristics in the long term and increase in maize crop productivity without changes in soil physics, resulting in the maintenance of soil organic matter and in the economics of soil management activities associated with liming

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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