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APPLICATION OF ALKALINE WASTE FROM PULP INDUSTRY TO ACID SOIL WITH PINE[1]

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ABSTRACT

In Brazil extensive areas are covered with pine forests, planted for pulp and paper production. This industry generates solid alkaline waste, such as dregs. The application of this dregs to forest soils is an alternative for soil acidity correction and plant nutrient supply, as well as a solution for its proper disposal. The purpose of this study was to compare the residual effect of surface application of dregs and dolomitic lime on (a) changes in the physical and chemical properties of an acidic soil and (b) pine tree development. The experiment was carried out in 2004 in Bocaina do Sul, Santa Catarina, consisting of the application of increasing dreg and lime rates to a *Pinus taeda* L. production area, on a Humic Cambisol, in a randomized block design with four replications and 10 x 10 m plots. The treatments consisted of levels of soil acidity amendments corresponding to the recommendations by the SMP method to reach pH 5.5 in the 0–20 cm layer, as follows: no soil amendment; dregs at 5.08 (1/4 SMP), 10.15 (1/2 SMP) and 20.3 Mg ha^{-1} (1 SMP); and lime at 8.35 (1/2 SMP) and 16.7 Mg ha^{-1} (1 SMP). Soil layers were sampled in 2010 for analyses of soil chemical and physical properties. The diameter at breast height of the 6.5 year old pine trees was also evaluated. Surface application of dregs improved soil chemical fertility by reducing acidity and increasing base saturation, similar to liming, especially in surface layers. Dregs, comparable to lime, reduced the degree of clay flocculation, but did not affect the soil physical quality. There was no effect of the amendments on increase in pine tree diameter. Thus, the alternative to raise the pH in forest soils to 5.5 with dregs is promising for the forestry sector with a view to dispose of the waste and increase soil fertility.

Index terms: dregs, lime, alkaline front, soil physical quality, *Pinus taeda* L.

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RESUMO: *APLICAÇÃO DE RESÍDUO ALCALINO DA INDÚSTRIA DE CELULOSE EM SOLO ÁCIDO CULTIVADO COM PÍNUS*

No Brasil existem extensas áreas com plantio de pínus para a produção de papel e celulose, processo que gera resíduos sólidos alcalinos, como o dregs. O uso desse resíduo em solos florestais é uma alternativa para correção da acidez do solo, fornecimento de nutrientes às plantas e seu próprio descarte. O objetivo deste trabalho foi avaliar o efeito residual da aplicação superficial de dregs, comparando-o com o calcário dolomítico, nos atributos físicos e químicos de um solo ácido e no desenvolvimento de pínus. O experimento foi implantado em 2004 em Bocaina do Sul, SC, em um Cambissolo Húmico alumínico, constituindo da aplicação superficial de doses crescentes de dregs e calcário em uma área de produção de Pinus taeda *L. O delineamento experimental utilizado foi em blocos ao acaso com quatro repetições e parcelas com dimensão de 10 x 10 m. Os tratamentos consistiram de níveis de corretivos da acidez do solo correspondentes à recomendação indicada pelo método SMP para atingir pH 5,5 na camada de 0–20 cm, sendo: sem corretivo; dregs nas doses de 5,08 (1/4 SMP), 10,15 (1/2 SMP) e 20,3 Mg ha^{-1} (1 SMP); e calcário nas doses de 8,35 (1/2 SMP) e 16,7 Mg ha^{-1} (1 SMP). Amostras de solo em camadas foram coletadas em 2010 para análise de atributos químicos e físicos do solo. O diâmetro à altura do peito das plantas de pínus com 6,5 anos também foi avaliado. A aplicação superficial de dregs melhorou a fertilidade química do solo, com diminuição da acidez e aumento da saturação por bases de forma semelhante ao calcário, principalmente nas camadas superficiais. O dregs, assim como o calcário, diminuiu o grau de floculação da argila, mas não prejudicou a qualidade física do solo. Quanto ao crescimento em diâmetro do pínus, não houve efeito dos corretivos. Assim, a aplicação de dregs em solos florestais para elevar o pH a 5,5 é uma alternativa para o setor florestal, como forma de descarte do resíduo e aumento da fertilidade do solo.*

Termos de indexação: dregs, calcário, frente de alcalinização, qualidade física do solo, Pinus taeda *L.*

INTRODUCTION

Santa Catarina is one of the largest pulp and paper producers in Brazil. An area of 169 thousand hectares of the State is covered with planted forests, of which 90 % consist of *Pinus* sp. (ABRAF, 2010). The ease of adaptation of pine to acid soils, which cover most areas in the south of the country, indicate the species for planting in extensive areas, making it an important source of raw material (Kronka et al., 2005).

This high suitability for forestry is the basis of an important industrial center for pulp and paper in Santa Catarina. But the great quantity of waste generated by the pulp and paper factories causes environmental problems (Rodrigues, 2004), due to the incomplete recovery of the chemical reagents used to digest the wood fiber (Cohn & Ribeiro, 2002). An alternative disposal of these dregs is application to the soil, which can serve as a medium to clarify these dregs due to its physical, chemical and biological characteristics (Bellote et al., 1998).

Among the waste products generated by the pulp and paper industry are dregs (Bellote et al., 1998), i.e., dregs consisting of the removed impurities, e.g., carbon, mud particles, metal hydroxides and sulfates, and iron, silica, calcium and aluminum salts (Cohn & Ribeiro, 2002). It was shown that dregs can be used as soil amendments in forest plantations (Almeida et al., 2007), because they raise the pH and increase nutrient availability (Bellote et al., 1998). These factors are important for southern Brazil where soils are, with few exceptions, highly acidic and little fertile, limiting even forestry activities. In addition, waste from the pulp and paper industry is less expensive than commercial lime when used in the same region as the generating units (Almeida et al., 2008).

In contrast to dolomitic lime, dregs have a low magnesium and high sodium content (Almeida et al., 2007) and their use may therefore have a negative influence on plant growth. The high Ca/Mg ratio may induce Mg deficiency in plants if applied at high quantities to soils with low Mg availability (Miotto, 2009), due to the competition between Ca and Mg for the soil adsorption sites and root uptake (Medeiros et al., 2008). The application of a high Na quantities, in turn, may increase the dispersion of clay and organic colloids (Albuquerque et al., 2002). This can affect some physical properties, e.g., reduce macroporosity and increase surface sealing (Reichert & Norton, 1994). Sodium has a large hydrated radius, which prevents it from approaching negatively charged solid surfaces (Sposito, 1989; Almeida et al., 2008).

Although pine is not very demanding in terms of soil fertility (Ferreira et al., 2004), different yield levels have been observed when planted on different soils (Ferreira et al., 2004; Morales et al., 2010). Moreover, since forest plantations are not destined for human food consumption, there are some advantages to the application and use of waste products.

The purpose of this study was to evaluate the residual effect of the surface application of dregs in comparison to dolomitic lime on (a) changes in the physical and chemical properties of a Humic Cambisol as well as on (b) the growth of *Pinus taeda* L.

MATERIAL AND METHODS

The experiment was carried out in Bocaina do Sul, SC (27º 44' 40" S; 49º 56' 40" W, 860 m asl). The climate at this location is humid mesothermal with mild summers (Cfb), according to the Köppen classification. Rains are well distributed throughout the year and mean annual rainfall and temperature are 1,500 mm and 15.6 °C respectively (Santa Catarina, 2011).

The soil is a Humic Cambisol (Embrapa, 2006) with a clay loam texture with 410 g kg^{-1} sand, 240 g kg^{-1} silt and 350 g kg^{-1} clay. Prior to the experiment, the area had been covered by native vegetation, without previous acidity amendment or fertilization. The main soil chemical properties are described in table 1.

The experiment was set up in November 2004 and consisted of surface application of increasing dregs and lime rates to a *Pinus taeda* L. production system with 6-month-old trees, spaced 2.0 x 2.5 m. A randomized experimental block design was used with four replications and 10 x 10 m plots. Treatments consisted of soil amendment levels based on the recommendation of the SMP method to achieve pH 5.5 in the 0–20 cm layer (CQFSRS/SC, 2004). The following treatments were established: without amendment; dregs rate of 5.08 Mg ha^{-1} (1/4 SMP); dregs rate of 10.15 Mg ha^{-1} (1/2 SMP); dregs rate of 20.3 Mg ha^{-1} (1 SMP); dolomitic lime rate of 8.35 Mg ha^{-1} (1/2 SMP); and dolomitic lime rate of 16.7 Mg ha^{-1} (1 SMP). Soil amendments were applied by hand to the surface of the whole area, without incorporation. No fertilization for soil amendment nor fertilization at planting were performed for the pine trees.

The soil amendment rates were determined from the initial SMP index of the soil (4.3), resulting in the need for 15 Mg ha^{-1} $CaCO_3$, with an effective neutralizing power (ENP) of 100 %. The following amendments were used: dolomitic lime (filler) with ENP of 90 % and dregs derived from a pulp and paper industry located in the municipality of Correia Pinto (SC), with the following characteristics: neutralizing value (NV) 80 %; moisture 22 %; pH 10.7; 300 g kg^{-1} Ca; 10 g kg^{-1} Mg, and 34 g kg^{-1} Na.

During the first year of the experiment, weeding was done mechanically. Treatments were reapplied in October 2006, at the same rates applied in 2004. Again the soil amendments were applied by hand to the soil surface of the whole area, without incorporation. This reapplication only two years after the first rates and, consequently, above the need for soil amendment, had the purpose of simulating practices commonly used by the producers in the region, testing whether higher dregs rates would cause problems for the soil or pine tree growth.

In October 2010, disturbed and undisturbed soil samples were collected for chemical and physical analyses. The chemical analyses (layers 0–5; 5–10; 10–20 and 20–40 cm) determined and calculated the following properties: pH in water, contents of exchangeable K^+, Na^+, Ca^{2+}, Mg^{2+}, and Al^{3+}, extractable P, total organic carbon, effective CEC

Table 1. Chemical analysis of the 0–20 cm layer of the Humic Cambisol. Bocaina do Sul, SC

Layer	pH_{H_2O}	Al	Ca	Mg	P	K	TOC
		cmol$_c$ kg^{-1}			mg kg^{-1}		g kg^{-1}
0–20 cm	4.7	6.0	1.8	1.5	2.4	204	46

pH_{H_2O}: pH in water; Al: exchangeable aluminum; Ca: exchangeable calcium; Mg: exchangeable magnesium; P: extractable phosphorus; K: exchangeable potassium; TOC: total organic carbon. Analyses performed according to Tedesco et al. (1995).

base saturation, Al^{3+} saturation and Na^{+} saturation. The pH in water was determined at a 1:1 ratio by potentiometer reading; exchangeable Na^{+} and K^{+} and extractable P were extracted by the double acid extraction method (Mehlich-1) with acid solution of 0.05 mol L^{-1} HCl and 0.0125 mol L^{-1} H_2SO_4, Na^{+} and K^{+} were quantified by flame photometry and P quantified by UV-VIS spectrophotometer absorbance; exchangeable Ca^{2+}, Mg^{2+} and Al^{3+} were extracted with a neutral saline solution of 1 mol L^{-1} KCl, Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrophotometry and Al^{3+} quantified by acid-base titration with 0.0125 mol L^{-1} NaOH (Tedesco et al., 1995). Organic carbon was determined by the Walkley & Black method modified by Tedesco et al. (1995), by oxidation with 1.25 mol L^{-1} $K_2Cr_2O_7$ in a concentrated acid medium of H_2SO_4 and titration with 0.25 mol L^{-1} $FeSO_4$. Effective CEC, base saturation, Al^{3+} saturation, and Na^{+} saturation were calculated according to Embrapa (1997). To calculate base saturation, potential non-exchangeable acidity was extracted with a 0.5 mol L^{-1} $Ca(CH_3COO)_2$ buffer solution at pH 7.0 and quantified by acid-base titration with 0.0125 mol L^{-1} NaOH (Embrapa, 2009).

The soil physical analyses (layers 0–5; 5–10 and 10–20 cm) determined the following properties: total porosity, macroporosity, soil density, flocculation degree, aggregate stability and soil penetration resistance. For these analyses, two undisturbed samples were collected in metallic rings (volume 141.4 cm^3, height 5 cm, diameter 6 cm) per layer and plot. These samples were saturated, subjected to a tension of 6 kPa on a sand tension table and dried in a laboratory oven at 105 ºC. Total porosity was determined by the moisture difference between the saturated soil and the dry soil; macroporosity by the moisture difference between the saturated soil and at a tension of 6 kPa (Embrapa, 1997); and soil density by the volumetric ring method according to Blake & Hartge (1986). Disturbed soil samples were collected to determine the flocculation degree by the pipette method (Gee & Bauder, 1986) through dispersion in NaOH for determination of the total clay content, and in water for water dispersible clay. Wet aggregate stability was determined by wet sieving of subsamples (diameter 4.76 to 8.00 mm) according to Kemper & Chepil (1965), and the results expressed as mean geometric diameter. Soil penetration resistance was determined by an electronic soil compaction meter (Falker) to a depth of 20 cm, measuring 20 resistance values in this layer (1 measurement cm^{-1}) at five sampling points per plot, with a cone (diameter 12.82 mm) and maximum measuring speed of 50 mm s^{-1}, manually controlled. These resistance measures were grouped in layers, obtaining a mean resistance value.

At the time of soil sampling, the diameter at breast height of the pine tree plants at 6.5 years of age was determined with a tree calipers for six plants per plot.

Results were subjected to normality analysis by the Shapiro-Wilk test and, when necessary, transformed before analysis of variance by the F test ($p < 0.05$). The quantitative factor (amendment rate) was analyzed per soil layer, with adjustment of linear or quadratic regression equations for the dregs rates and linear equations for the lime rates. The zero rate treatment was used as control for both soil amendments. Differences between amendments at equivalent rates were analyzed by linear contrasts. The models PROC REG and PROC GLM of the statistical program SAS 9.1.3 (SAS, 2007) were used for the regressions and contrasts, respectively.

RESULTS AND DISCUSSION

Soil chemical properties

Chemical properties were affected by surface application of amendments (dregs and lime). Significant differences were observed in increases in pH, exchangeable Ca^{2+} and Mg^{2+} content, Ca/Mg ratio, base saturation and effective CEC, and in the reduction of Al^{3+} content and saturation, with more intense effects at higher amendment rates and in surface layers.

Increasing amendment rates raised the soil pH linearly down to a depth of 10 cm. Soil amendment by dregs and lime reached the 5–10 cm layer (Figure 1). The highest dregs rate raised the soil pH to 7.2 in the 0–5 cm layer and to 5.3 in the 5–10 cm layer (Figure 1a) and by lime to 7.4 in the 0–5 cm layer at rates corresponding to 1 SMP. The pH level was higher than recommended in the surface layer due to amendment reapplication at doses exceeding the requirement and to the accumulation of amendments on the soil surface.

In a study of lime surface application to two soils of Rio Grande do Sul (with 380 and 580 g kg^{-1} clay), Pöttker & Ben (1998) found an increase in pH only in the 0–5 cm layer after 36 months. Rheinheimer et al. (2000) however observed a pH increase to approximately 5.5, down to a depth of 15 cm 48 months after the application of 17 Mg ha^{-1} lime to a Gray Argisol (Plinthaquult medium texture). Lime leaching in the profile depends on the lime rate and type, the soil physical properties, organic matter content, water regime of each region (Caires et al., 1998; Rheinheimer et al., 2000; Amaral et al., 2004) and the crop system. In addition, there is no migration of liming effects into the soil profile when the quantity applied to the surface is less than that necessary to neutralize Al^{3+} in the surface layers (Rheinheimer et al., 2000).

With the increasing rates, the dregs reduced the exchangeable Al^{3+} content linearly down to a depth of 10 cm (Figure 1c), while with lime the effect was observed down to 20 cm (Figure 1d). The highest rates reduced the exchangeable Al^{3+} contents to nearly zero $cmol_c$ kg^{-1} in the surface layer. In many studies with surface application of lime (Caires et al., 1998; Pöttker & Ben, 1998; Rheinheimer et al., 2000) and dregs (Albuquerque et al., 2002; Medeiros et al., 2009) similar results were reported.

When the amendment is not incorporated, an alkaline front is generated at the soil surface. This has been attributed to the descending movement of the fine particles when the soil physical characteristics are favorable to the movement of the basic anions resulting from dissolution of the amendment (Amaral & Anghinoni, 2001). An adequate rainfall volume also supports the dissolution of lime particles, as well as of ion leaching (Amaral et al., 2004). In forests, leaf interception reduces the rainfall that effectively reaches the soil surface. On the other hand, preservation of the soil structure favors formation of macropores, which contribute to water percolation and incorporation of components of the amendments.

The exchangeable Ca^{2+} contents increased linearly, down to the 10–20 cm layer, with increasing amendment rates (Figure 2a,b). Lime also increased the exchangeable Mg^{2+} content down to a depth of 20 cm (Figure 2d). Dregs, with only 10 g kg^{-1} Mg increased the exchangeable Mg^{2+} content in the 5–10 cm layer (Figure 2c); nevertheless, increases in soil Mg content are not expected from application due to the low Mg content of this element in the waste. In a Brown Latosol (Haplohumox), Ciotta et al. (2004) concluded that the reapplication of lime rates of 4.5 and 3.0 Mg ha^{-1} (in two growing seasons) raised the pH down to a depth 15 cm and the Ca^{2+} and Mg^{2+} contents down to a depth of 20 cm after 12 years. Rheinheimer et al. (2000), however found increased Ca^{2+} and Mg^{2+} contents down to a depth of 10 cm after 48 months of application of 8.5 Mg ha^{-1} lime.

The application of amendments on the soil surface creates an alkaline front, where the adsorption of Na^+, K^+, Ca^{2+} and Mg^{2+} increases due to the creation of variable negative charges generated with the raising pH (Teixeira, 2003). However, the mobility of the basic cations in the soil profile may be favored by the formation of ionic pairs with inorganic compounds from the products of dissolution of the amendment (Amaral & Anghinoni, 2001) or through

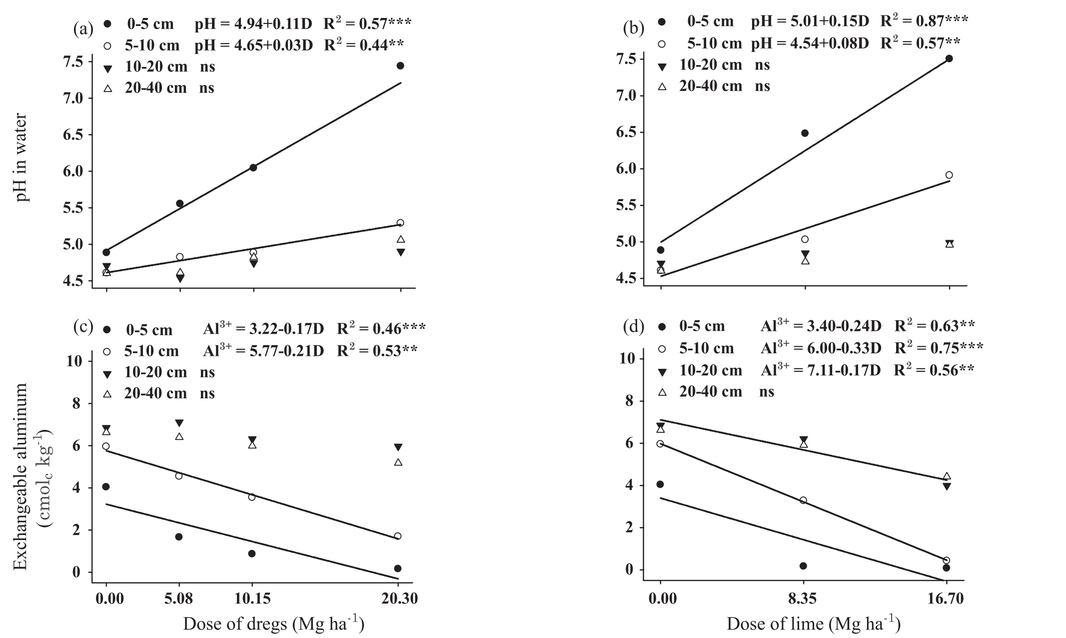

Figure 1. pH in water and exchangeable aluminum (Al^{3+}) in the layers of a Humic Cambisol amended with doses (D) of dregs (a, c) and lime (b, d), applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, * and ns: significant at 5, 1, 0.1 % and not significant, respectively).**

hydrosoluble organic compounds originating from decomposition of plant dregs deposited on the soil surface (Rheinheimer et al., 2000).

The Ca/Mg ratio was not altered with the application of increasing rates of dolomitic lime, remaining near 1 in all layers (Figure 2f). Nevertheless, dregs increased the Ca/Mg ratio down to the 20–40 cm layer (Figure 2e), reaching nearly 7 in the surface layer at the highest dose. According to the Southern Brazilian Committee for soil Chemistry and Fertility (CQFSRS/SC, 2004), most crops are not affected by Ca/Mg ratios from 0.5 to over 10, provided that neither of the two nutrients are deficient in the soil. In soils with adequate exchangeable Ca and Mg contents, the interaction between these two cations in plant uptake is weak or non-existent (Miotto, 2009).

The increase of dregs and lime rates linearly raised the effective CEC, with effects down to a depth of 10 cm with the application of dregs (Figure 3a) and down to 20 cm by liming (Figure 3b). Albuquerque et al. (2002) also found an increase in effective CEC in the 0–5 cm layer two months after surface application of dregs to a Latosol and Cambisol. Liming increases the effective CEC in acid soils with predominance of variable charge (Albuquerque et al., 2000), as is the case of most soils in southern Brazil.

With the increase of basic cations in the soil, base saturation (V) increased with the doses, with linear increases down to a depth of 40 cm for both amendments (Figure 3c,d). Base saturation in the surface layer increased at the highest rates of dregs and lime, to 89 and 96 %, respectively. In the

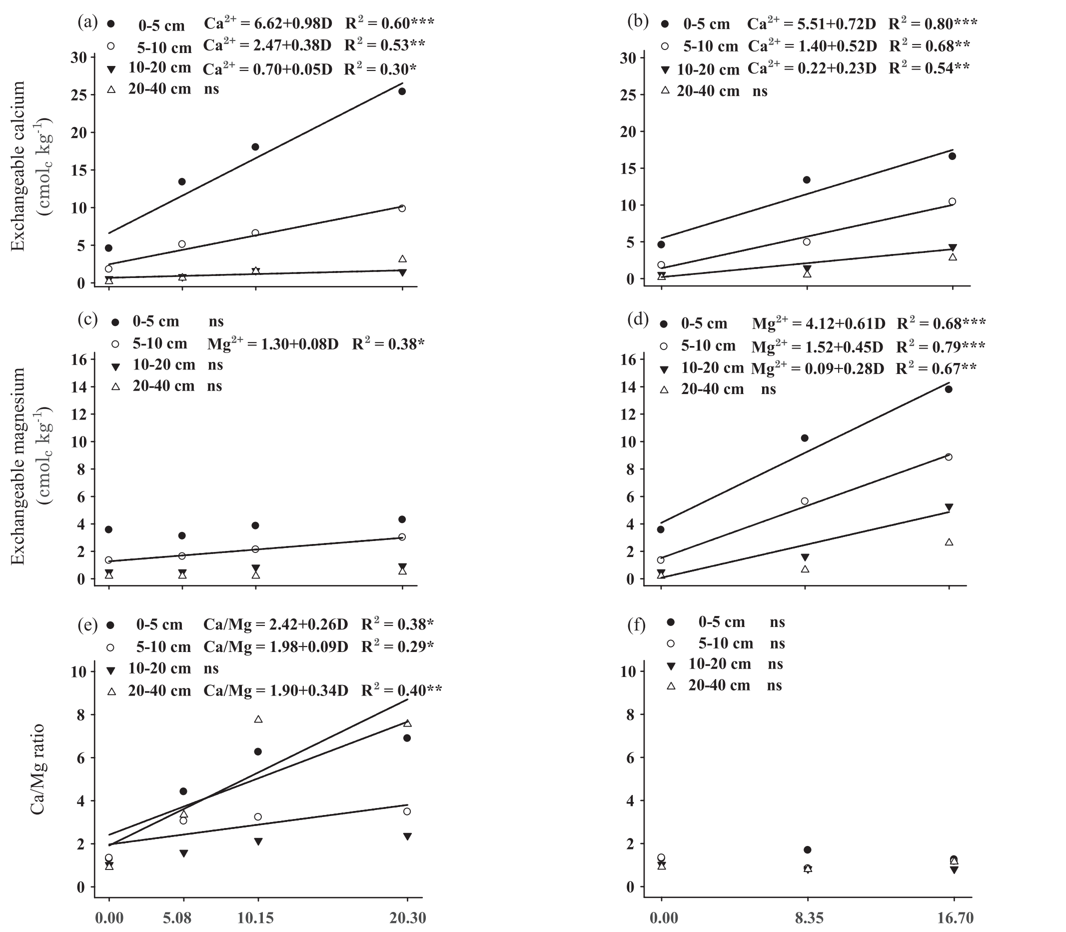

Figure 2. Exchangeable calcium and magnesium (Ca^{2+}, Mg^{2+}) and Ca/Mg ratio in the layers of a Humic Cambisol amended with doses (D) of dregs (a, c, e) and lime (b, d, f) applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, * and ns: significant at 5, 1, 0.1 % and not significant, respectively).**

mean values of layers to a depth of 20 cm, V was greater at the full rate of lime than of dregs, with around 56 %. The Southern Brazilian Committee for Soil Chemistry and Fertility (CQFSRS/SC, 2004) recommends a V of 65 % for a satisfactory development of most crops.

Aluminum saturation (m) decreased down to the 20–40 cm layer with increasing rates of both amendments (Figure 3e,f). Al^{3+} saturation decreased to below 10 % down to a depth of 5 cm at rates corresponding to 1/2 and 1 SMP of dregs and lime, and down to 10 cm only at the highest lime rate.

There was a significant linear increase in the exchangeable Na^+ content down to a depth of 10 cm with increasing dregs rates. The highest rate raised the Na^+ content in the 0–5 cm layer to 104 mg kg^{-1} (Figure 4a). Lime also raised the Na^+ content linearly in the 0–5 cm layer, with a maximum content of 57 mg kg^{-1} (Figure 4b). In the study of Albuquerque et al. (2002), the Na^+ content in the 0–5 cm layer increased to 108 and 170 mg kg^{-1} with dregs rates equivalent to 1/2 SMP, respectively, in a Latosol and a Cambisol, two months after surface application. At the same rate, Na^+ also increased in the 5–10 cm layer to 16 mg kg^{-1} in the Latosol and to 21 mg kg^{-1} in the Cambisol.

The increase in the soil Na^+ content did not raise sodium saturation (Sat_{Na}), remaining from 1.2 to 2.4 % down to a depth of 40 cm (Table 2). This occurred because 71 months after the first application and 48 months after reapplication of the soil amendments, there was a relevant increase in the effective CEC and leaching of much of the Na^+ to layers below those evaluated.

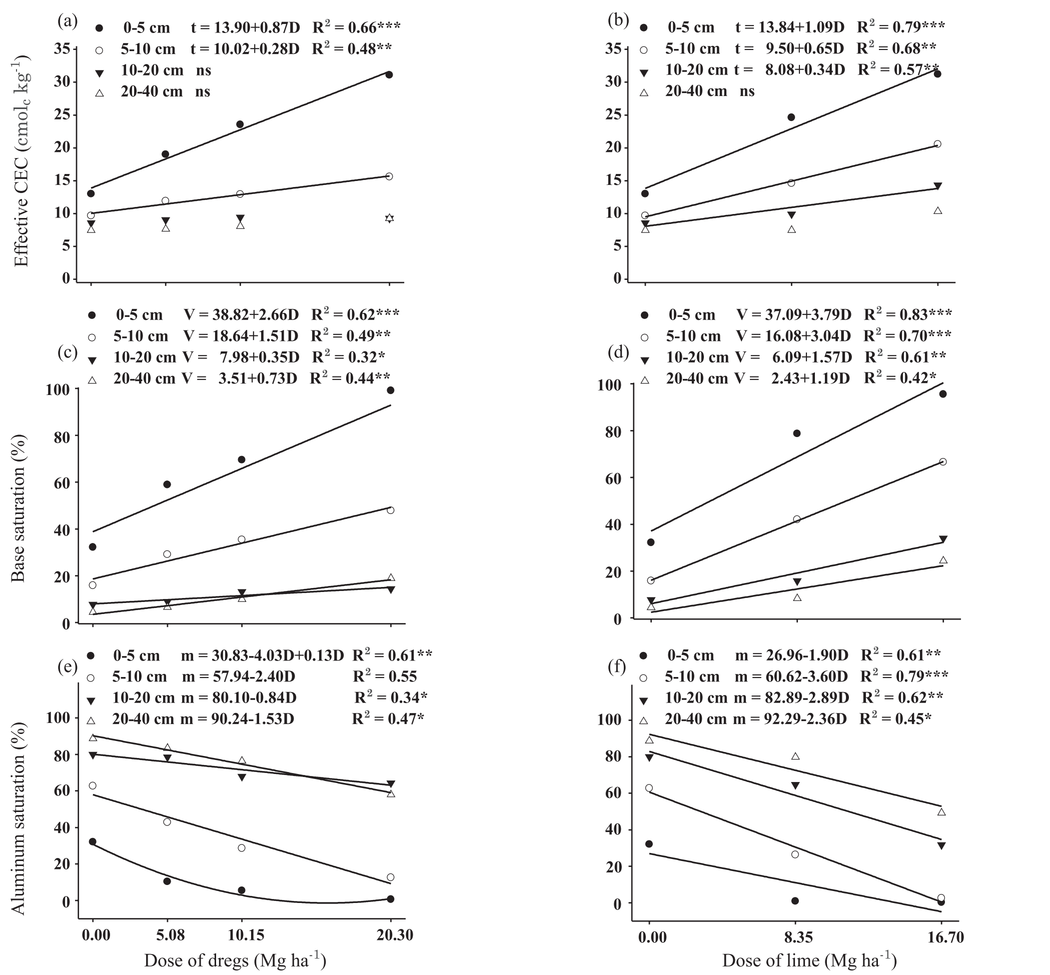

Figure 3. Effective CEC (t), base saturation (V) and aluminum saturation (m) in the layers of a Humic Cambisol amended with doses (D) of dregs (a, c, e) and lime (b, d, f), applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2009. (*, **, * and ns: significant at 5, 1, 0.1 % and not significant, respectively).**

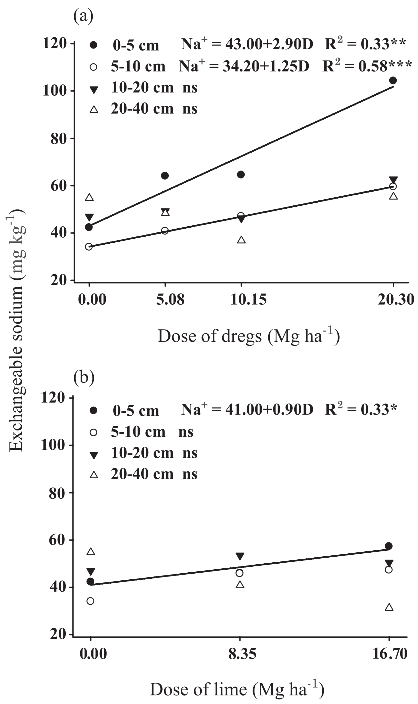

Figure 4. Exchangeable sodium (Na^+) in the layers of a Humic Cambisol amended with doses (D) of dregs (a) and lime (b) applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, * and ns: significant at 5, 1, 0.1 % and not significant, respectively).**

The contents of P, K^+ and total organic carbon (TOC) did not differ among the treatments (Table 2). The mean contents of P and K^+ in the 0–20 cm layer were 2.0 and 210 mg kg^{-1}, respectively. For the soil under study, the K^+ content was considered 'very high' (CQFSRS/SC, 2004) and P 'very low'. With regard to TOC, the contents were highest in the surface layers, which is common in systems with little or no degree of soil mobilization.

Since the nutrient contents were adequate fo plant growth, with the exception of P (CQFSRS SC, 2004), it was concluded that surface liming 4 months after reapplication of the soil amendment was efficient down to 5 cm at the highest dreg rate (20.3 Mg ha^{-1}) and down to 10 cm only for th highest lime rate (16.7 Mg ha^{-1}). The effect of limin on highly buffered soils is normally restricted to few centimeters (Ernani, 2008); in addition, rainfal on forest soils is decreased by leaf interceptio (Balbinot et al., 2008).

Linear contrasts among corresponding dreg and lime rates are shown in table 3. The pH an K^+ and TOC contents did not differ between dreg and lime. In the contrasts between lime and dreg at the 1/2 SMP dose (L50 and D50, respectively differences were only observed for Mg^{2+} content i the 0–5 and 5–10 cm layers, with higher content in the lime treatment and for the Ca/Mg ratio in a layers, due to high Ca and low Mg addition in th dregs treatment. Nevertheless, at 1 SMP, othe properties also differed between lime and dreg treatments (L100 and D100, respectively). Dreg increased Na^+ and the Ca/Mg ratio and the Sat_{Na} down to a depth of 40 cm, and Ca^{2+} and P in th 0–5 cm layer. Lime in turn increased the Mg^{2+} contents throughout the profile and Ca^{2+}, V an effective CEC contents in the 10–20 cm layer, a well as Al^{3+} saturation.

A comparison between the soil amendment for changes in soil chemical properties shows similar efficiency of both, but some drawbacks t the application of dregs, e.g., a low Mg^{2+} conten and high Ca/Mg ratio and Na^+ contents.

Soil physical properties

Of the physical properties analyzed, th flocculation degree (FD) decreased linearly i the 0–5 cm layer with the surface application o increasing dregs and lime rates to the soil (Figure 5) FD decreased from 84 to 75 % at the highest dreg

Table 2. Mean value of chemical properties per layer of a Humic Cambisol amended with dreg and lim rates applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010

Treatments	Layer	P	K	Sat_{Na}	TOC
	cm	mg kg^{-1}		%	g kg^{-1}
Mean value	0–5	4.7[1]	245	1.2	54
	5–10	2.1	221	1.5	50
	10–20	0.7	188	2.3	41
	20–40	0.0	93	2.4	27

[1] Mean value of 24 observations; P: extractable phosphorus; K: exchangeable potassium; Sat_{Na}: sodium saturation; TOC: tota organic carbon.

Table 3. Estimate(1) of the linear contrasts between treatments for chemical properties of a Humic Cambiso amended with dregs and lime rates applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 201

Contrasts	pH	Al	Ca	Mg	Ca/Mg	P	K	Na	CEC_{ef}	V	m	Sat_{Na}	TOC
		—— $cmol_c$ kg^{-1} ——				——— mg kg^{-1} ———			$cmol_c$ kg^{-1}	——— % ———			g kg^{-1}
0–5 cm Layer													
L50 x D50	0.4^{ns}	-0.7^{ns}	-4.6^{ns}	6.4^{**}	-4.6^{*}	-0.7^{ns}	55.5^{ns}	-18.5^{ns}	1.1^{ns}	9.2^{ns}	-4.6^{ns}	-0.3^{ns}	3.7^{ns}
L100 x D100	0.2^{ns}	-0.1^{ns}	-8.8^{*}	9.5^{***}	-5.6^{*}	-4.4^{***}	-98.8^{ns}	-47.0^{*}	0.2^{ns}	6.0^{ns}	-0.3^{ns}	-0.6^{ns}	3.7^{ns}
5–10 cm Layer													
L50 x D50	0.1^{ns}	-0.3^{ns}	-1.7^{ns}	3.5^{**}	-2.4^{**}	-0.1^{ns}	36.0^{ns}	-1.3^{ns}	1.7^{ns}	6.6^{ns}	-2.3^{ns}	-0.1^{ns}	-1.5^{ns}
L100 x D100	0.6^{ns}	-1.3^{ns}	0.6^{ns}	5.8^{**}	-2.3^{**}	-0.1^{ns}	-47.5^{ns}	-12.3^{ns}	5.0^{ns}	18.7^{ns}	-10.0^{ns}	-0.8^{*}	4.4^{ns}
10–20 cm Layer													
L50 x D50	0.1^{ns}	-0.1^{ns}	-0.2^{ns}	0.8^{ns}	-1.3^{*}	0.2^{ns}	-17.3^{ns}	7.3^{ns}	0.5^{ns}	2.7^{ns}	-3.3^{ns}	0.2^{ns}	-3.6^{ns}
L100 x D100	0.1^{ns}	-2.0^{*}	2.9^{**}	4.3^{**}	-1.6^{*}	0.5^{ns}	-35.8^{ns}	-12.3^{ns}	5.1^{***}	19.6^{**}	-32.6^{**}	-1.3^{**}	6.9^{ns}
20–40 cm Layer													
L50 x D50	-0.1^{ns}	-0.1^{ns}	-1.0^{ns}	0.5^{ns}	-7.0^{*}	0.0^{ns}	12.8^{ns}	4.0^{ns}	-0.6^{ns}	-1.7^{ns}	3.4^{ns}	0.4^{ns}	-2.4^{ns}
L100 x D100	-0.1^{ns}	-0.8^{ns}	-0.3^{ns}	2.1^{**}	-6.4^{**}	0.0^{ns}	28.8^{ns}	-24.0^{**}	1.1^{ns}	5.4^{ns}	-8.8^{ns}	-1.2^{**}	0.7^{ns}

(1) Absolute difference in the value of the property between the treatments (positive values indicate a higher value in the first treatment) L50: lime rate of 1/2 SMP; L100: lime rate of 1 SMP; D50: dregs rate of 1/2 SMP; D100: dregs rate of 1 SMP; pH: pH in water; Al exchangeable aluminum; P: extractable phosphorus; K: exchangeable potassium; Na: exchangeable sodium; Ca: exchangeable calcium Mg: exchangeable magnesium; Ca/Mg: Ca/Mg ratio; CEC_{ef}: effective CEC; V: base saturation; m: aluminum saturation; Sat_{Na}: sodium saturation; TOC: total organic carbon; *, **, *** and ns: significant at 5, 1, 0.1 % and not significant, respectively.

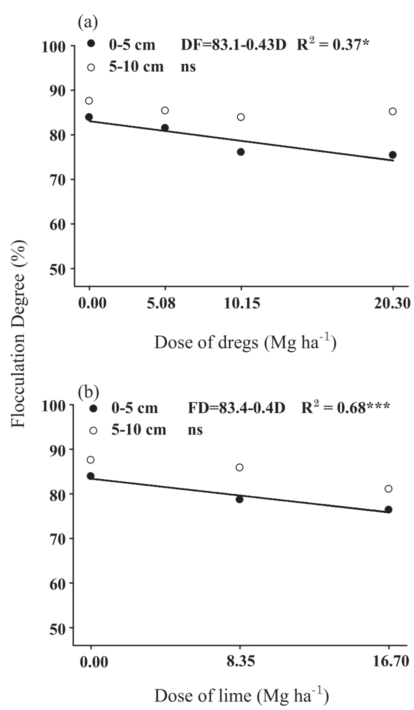

Figure 5. Flocculation degree (FD) in the layers of a Humic Cambisol amended with doses (D) of dregs (a) and lime (b) applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, * and ns: significant at 5, 1, 0.1 % and not significant, respectively).**

and lime rates. Clay dispersion and FD reductio with an increase in pH were observed in soils of th Santa Catarina Plateau (Albuquerque et al., 2000 2002; Medeiros et al., 2009) The reason may be th greater repulsion among soil particles through th increase of net negative charge and the thickness o the electric double layer caused by the substitutio of Al^{3+} by Ca^{2+} and Mg^{2+}, due to the application o soil amendments (Fontes et al., 1995).

The other soil physical properties did not diffe according to the amendment rates (Table 4). Th high total organic carbon (TOC) content contribute to decrease soil bulk density (BD), to a mean valu of 0.90 Mg m^{-3}. The low values of soil penetratio resistance (PR) (Table 4) coincide with the low BD The clay content and high organic matter conten are also responsible for the high soil aggregat stability, as already stated by Bertol et al. (2000 for soils of the Santa Catarina Plateau.

The contrasts between equivalent amendmen rates on soil physical properties are shown i table 5. There was a difference only for the P with the application of dregs or lime. The additio of dregs reduced the PR in greater intensity tha liming down to a depth of 20 cm, for both the dos corresponding to 1/2 SMP (D50) and the dos corresponding to 1 SMP (D100). These result indicate that the influence of the surface applicatio of corresponding dregs and lime rates on th soil physical quality did not differ very much si years after the beginning of the experiment. Th

Table 4. Mean value of physical properties per layer of a Humic Cambisol amended with dregs and lime rates applied to the surface in 2004/2006. Bocaina do Sul, SC, 2010

Treatments	Layer	BD	TP	Macro	MGD	PR (θ=0,37 m³ m⁻³)
	cm	Mg m⁻³	m³ m⁻³		mm	kPa
	0–5	0.88	0.70	0.23	4.3	366
Mean value(1)	5–10	0.92	0.67	0.19	5.2	704
	10–20	0.91	0.68	0.19	4.7	819

(1) Mean value of 24 observations; BD: soil bulk density; TP: total porosity; Macro: macroporosity; MGD: aggregate mean geometric diameter; PR: soil penetration resistance; θ: soil moisture.

Table 5. Estimate[1] of the linear contrasts between treatments for physical properties of a Humic Cambiso amended with dreg and lime rates applied to the surface in 2004/2006. Bocaina do Sul, SC, 2010

Contrasts	BD	TP	Macro	FD	MGD	PR
	Mg m⁻³	m³ m⁻³		%	mm	kPa
			0–5 cm layer			
L50 x D50	0.01ns	0.00ns	0.00ns	2ns	0.2ns	118***
L100 x D100	-0.02ns	0.02ns	-0.01ns	1ns	-1.1ns	400***
			5–10 cm Layer			
L50 x D50	0.01ns	0.00ns	0.00ns	2ns	0.1ns	78ns
L100 x D100	0.01ns	0.00ns	-0.02ns	-4ns	-0.3ns	374***
			10–20 cm Layer			
L50 x D50	-0.06ns	0.01ns	0.02ns	.	-0.1ns	489***
L100 x D100	0.00ns	0.01ns	-0.02ns	.	0.3ns	370***

(1) Absolute difference in the value of a property between treatments (positive values indicate a higher value in the first treatment) L50: lime rate of 1/2 SMP; L100: lime rate of 1 SMP; D50: dregs rate of 1/2 SMP; D100: dregs rate of 1 SMP; BD: soil bulk density TP: total porosity; Macro: macroporosity; FD: flocculation degree; MGD: aggregate mean geometric diameter; PR: soil penetration resistance; *, **, *** and ns: significant at 5, 1, 0.1 % and not significant, respectively.

difference between the amendments was evident only for PR, reducing the physical barriers for roots with the application of dregs.

Pine tree growth

There was no difference in the diameter at breast height of the pine trees resulting from the application of increasing dregs and lime rates, with a mean value of treatments of 16.6 cm (data not shown). There was also no difference between the corresponding dregs and lime doses.

Although the nutritional demand of pine trees is considered low, some authors observed that pine productivity is affected by changes in the soil physical and chemical properties, such as pH, organic matter, exchangeable bases, and water retention capacity (Rodrigues, 2004; Morales et al., 2010). Nevertheless, according to Gonçalves (1995), pine trees are not very sensitive to acid soil and can grow adequately in soils with high Al levels in agreement with the data obtained. In addition the soil under study has no physical barriers t root development, which allows water and nutrien uptake from a greater soil volume, and consequently an excellent plant development.

CONCLUSIONS

1. Surface application of dregs to acid soi improved the chemical fertility by reducing th acidity and increasing base saturation similarly t lime, mainly in the surface layers. However, dreg increased the sodium content and Ca/Mg ratio.

2. Dregs, comparable to lime, reduced the degre of clay flocculation by the increase of pH, but did no

affect aggregate stability and the other soil physical properties.

3. No effect of the soil amendments on diameter of pine trees was observed.

4. The application of dregs to forest soils to raise the pH to 5.5 is an alternative for the forestry sector of the Santa Catarina Plateau as a form of waste disposal and to increase soil fertility.

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LITERATURE CITED

ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FLORESTAS PLANTADAS – ABRAF. Anuário estatístico da ABRAF 2010: ano base 2009. Brasília, 2010.140p.

ALBUQUERQUE, J.A.; ARGENTON, J.; FONTANA, E.C.; COSTA, F.S. & RECH, T.D. Propriedades físicas e químicas de solos incubados com resíduo alcalino da indústria de celulose. R. Bras. Ci. Solo, 26:1065–1073, 2002.

ALBUQUERQUE, J.A.; BAYER, C.; ERNANI, P.R. & FONTANA, E.C. Propriedades físicas e eletroquímicas de um Latossolo Bruno afetadas pela calagem. R. Bras. Ci. Solo, 24:295-300, 2000.

ALMEIDA, H.C.; ERNANI, P.R.; ALBUQUERQUE, J.A.; MACABÔ JUNIOR, J. & ALMEIDA, D. Influência da adição de um resíduo alcalino da indústria de papel e celulose na lixiviação de cátions em um solo ácido. R. Bras. Ci. Solo, 32:1775–1784, 2008.

ALMEIDA, H.C.; ERNANI, P.R.; MARIN, H.H.; ESCAPINI, E.H. & MACABÔ JUNIOR, J. Influência da adição de um resíduo industrial alcalino na velocidade de neutralização da acidez do solo, adsorção de sódio e disponibilidade de magnésio para o trigo. R. Ci. Agrovet., 6:104-113, 2007.

AMARAL, A.S. & ANGHINONI, I. Alteração de parâmetros químicos do solo pela reaplicação superficial de calcário no sistema plantio direto. Pesq. Agropec. Bras., 36:695-702, 2001.

AMARAL, A.S.; ANGHINONI, I.; HINRICHS, R. & BERTOL, I. Movimentação de partículas de calcário no perfil de um Cambissolo em plantio direto. R. Bras. Ci. Solo, 28:359-367, 2004.

BALBINOT, R.; OLIVEIRA, N.K.; VANZETTO, S.C.; PEDROSO K. & VALERIO, A.F. O papel da floresta no ciclo hidrológico em bacias hidrográficas. R. Amb., 4:131-149, 2008.

BELLOTE, A.F.J.; SILVA, H.D.; FERREIRA, C.A. & ANDRADE G.C. Resíduos da indústria de celulose em plantios florestais. B. Pesq. Flor., 37:99-106, 1998.

BERTOL, I.; ALMEIDA, J.A.; ALMEIDA, E.X. & KURTZ, C Propriedades físicas do solo relacionadas a diferentes níveis de oferta de forragem de capim-elefante-anão cv. Mott Pesq. Agropec. Bras., 35:1047-1054, 2000.

BLAKE, G.R. & HARTGE, K.H. Bulk density. In: KLUTE, A., ed Methods of soil analysis. 2.ed. Madison, American Society of Agronomy, 1986. p.363-375.

CAIRES, E.F.; CHUEIRI, W.A.; MADRUGA, E.F. & FIGUEIREDO, A. Alterações de características químicas do solo e resposta da soja ao calcário e gesso aplicados na superfície em sistema de cultivo sem preparo do solo. R Bras. Ci. Solo, 22:27-34, 1998.

CIOTTA, M.N.; BAYER, C.; ERNANI, P.R.; FONTOURA, S.M.V. WOBETO, C. & ALBUQUERQUE, J.A. Manejo da calagem e os componentes da acidez de Latossolo Bruno em plantio direto. R. Bras. Ci. Solo, 28:317-326, 2004.

COHN, P.E. & RIBEIRO, R.N. Medição “on line” do alcali tota nos licores branco e verde empregando tecnologia FT-NIR In: CONGRESSO E EXPOSIÇÃO ANUAL DE CELULOSE E PAPEL, 25., São Paulo, 2002. Trabalhos Técnicos. São Paulo, Associação Brasileira Técnica de Celulose e Papel 2002. p.1-10.

COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO - CQFSRS/SC. Manual de adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarina. 10.ed Porto Alegre, Sociedade Brasileira de Ciência do Solo Núcleo Regional Sul, 2004. 400p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA EMBRAPA. Manual de análises químicas de solos, plantas e fertilizantes. 2.ed. Brasília, Informação Tecnológica 2009. 627p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA EMBRAPA. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro 2006. 306p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Serviço Nacional de Levantamento e Classificação dos Solos. Manual de métodos de análise de solo. 2.ed. Rio de Janeiro, 1997. 212p.

ERNANI, P.R. Química do solo e disponibilidade de nutrientes Lages, O Autor, 2008. 230p.

FERREIRA, C.A.; DA SILVA. H.D. & BELLOTE, A.F.J. Pesquisa sobre nutrição de pinus no Sul do Brasil. R. Madeira 83:36-43, 2004.

FONTES, M.P.F.; GJORUP, G.B.; ALVARENGA, R.C. & NASCIF, P.G.S. Calcium salts and mechanical stress effects on water dispersible clay of Oxisols. Soil Sci. Soc. Am. J., 59:224-227, 1995.

GEE, G.W. & BAUDER, J.W. Particle-size analysis. In: KLUTE, A., ed. Methods of soil analysis. Physical and mineralogical methods. 2.ed. Madison, American Society of Agronomy, Soil Science Society of America, 1986. Part 1. p.383-411.

GONÇALVES, J.L.M. Recomendações de adubação para *Eucalyptus*, *Pinus* e espécies típicas da Mata Atlântica. Piracicaba, 1995. 25p. (Documentos Florestais)

KEMPER, W.D. & CHEPIL, W.S. Size distribution of aggregates. In: BLACK, C.A.; EVANS, D.D.; WHITE, J.L.; ENSMINGER, L.E. & CLARCK, F.E., eds. Methods of soil analysis. Madison, American Society of Agronomy, Soil Science Society of America, 1965. Part 1. p.499-510.

KRONKA, F.J.N.; BERTOLANI, F. & PONCE, R.H. A cultura do Pinus no Brasil. São Paulo, Sociedade Brasileira de Silvicultura, 2005. 156p.

MEDEIROS, J.C.; ALBUQUERQUE, J.A.; MAFRA, A.L.; BATISTELLA, F. & GRAH, J. Calagem superficial com resíduo alcalino da indústria de papel e celulose em um solo altamente tamponado. R. Bras. Ci. Solo, 33:1657-1665, 2009.

MEDEIROS, J.C.; MAFRA, A.L.; ALBUQUERQUE, J.A.; ROSA, J.D. & GATIBONI, L.C. Relação cálcio: magnésio do corretivo da acidez do solo na nutrição e no desenvolvimento inicial de plantas de milho em um Cambissolo Húmico álico. Semina: Ci. Agr., 19:93-98, 2008.

MIOTTO, A. Calcários calcítico e dolomítico e alterações nos atributos de solos e plantas sob sistema de plantio direto. Santa Maria, Universidade Federal de Santa Maria, 2009. 78p. (Tese de Mestrado)

MORALES, C.A.S.; ALBUQUERQUE, J.A.; ALMEIDA, J.A.; MARANGONI, J.M.; STAHL, J. & CHAVES, D.M. Qualidade do solo e produtividade de *Pinus taeda* no Planalto Catarinense. Ci. Flor., 20:629-640, 2010.

PÖTTKER, D. & BEN, J.R. Calagem para uma rotação de culturas no plantio direto. R. Bras. Ci. Solo, 22:675-684, 1998.

REICHERT, J.M. & NORTON, L.D. Fluidized bed bottom-ash effects on infiltration and erosion of swelling soils. Soil Sci. Soc. Am. J., 58:1483-1488, 1994.

RHEINHEIMER, D.S.; SANTOS, E.J.S.; KAMINSKI, J.; BORTOLUZZI, E.C. & GATIBONI, L.C. Alterações de atributos do solo pela calagem superficial e incorporada a partir de pastagem natural. R. Bras. Ci. Solo, 24:797-805, 2000.

RODRIGUES, C.M. Efeito da aplicação de resíduo da indústria de papel e celulose nos atributos químicos, físicos e biológicos do solo, na nutrição e biomassa do *Pinus taeda*. Curitiba, Universidade Federal do Paraná, 2004. 109p. (Tese de Mestrado)

SANTA CATARINA. Governo do Estado de Santa Catarina. Municípios de Santa Catarina – Bocaina do Sul. <http://www.sc.gov.br/portalturismo/Default.asp? CodMunicipio=241ePag=1>. Accessed 10 Jan, 2011.

SAS INSTITUTE INC. SAS 9.1.3 (TS1M3) for Windows Microsoft. Cary, 2007.

SPOSITO, G. The chemistry of soils. New York, Oxford University Press, 1989. 277p.

TEDESCO, M.J.; GIANELLO, C.; BISSANI, C.A.; BOHNEN, H. & VOLKWEISS, S.J. Análises de solo, plantas e outros materiais. 2.ed. Porto Alegre, Universidade Federal do Rio Grande do Sul, 1995. 174p. (Boletim Técnico de Solos, 5)

TEIXEIRA, J.B. Utilização de resíduos sólidos alcalinos de indústrias de celulose na correção da acidez do solo. Porto Alegre, Universidade Federal do Rio Grande do Sul, 2003. 105p. (Tese de (Mestrado)