

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.

⁽¹⁾ Dissertation of the first author submitted to the Post Graduate Program in Soil Management. Santa Catarina State University (UDESC). Held with funding from CAPES. Received for publication June 20, 2011 and approved on March 15, 2012.

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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 aluminico, 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 flocculação 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 (27° 44' 40" S; 49° 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 CaCO₃, 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⁺, Ca²⁺, Mg²⁺, and Al³⁺, 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 _{H₂O}	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_{H₂O}: 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 $0.05 \text{ mol L}^{-1} \text{ HCl}$ and $0.0125 \text{ mol L}^{-1} \text{ H}_2\text{SO}_4$, 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 $1 \text{ mol L}^{-1} \text{ KCl}$, Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrophotometry and Al^{3+} quantified by acid-base titration with $0.0125 \text{ mol L}^{-1} \text{ NaOH}$ (Tedesco et al., 1995). Organic carbon was determined by the Walkley & Black method modified by Tedesco et al. (1995), by oxidation with $1.25 \text{ mol L}^{-1} \text{ K}_2\text{Cr}_2\text{O}_7$ in a concentrated acid medium of H_2SO_4 and titration with $0.25 \text{ mol L}^{-1} \text{ FeSO}_4$. 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 $0.5 \text{ mol L}^{-1} \text{ Ca}(\text{CH}_3\text{COO})_2$ buffer solution at pH 7.0 and quantified by acid-base titration with $0.0125 \text{ mol L}^{-1} \text{ NaOH}$ (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°C . 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 $\text{cmol}_c \text{kg}^{-1}$ 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 $10 \text{ g kg}^{-1} \text{ Mg}$, 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

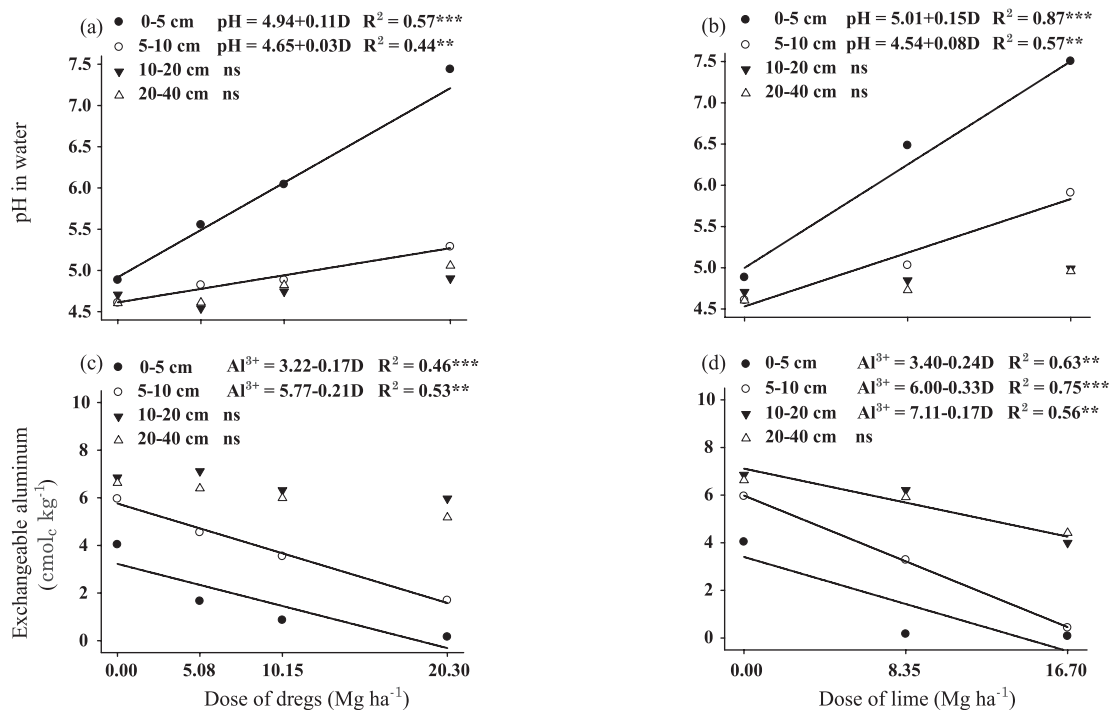


Figure 1. pH in water and exchangeable aluminum (Al^{3+}) in the layers of a Humic Cambisol amended with doses (D) of dregs (a, c) and lime (b, d), applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, *** and ns: significant at 5, 1, 0.1 % and not significant, respectively).

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

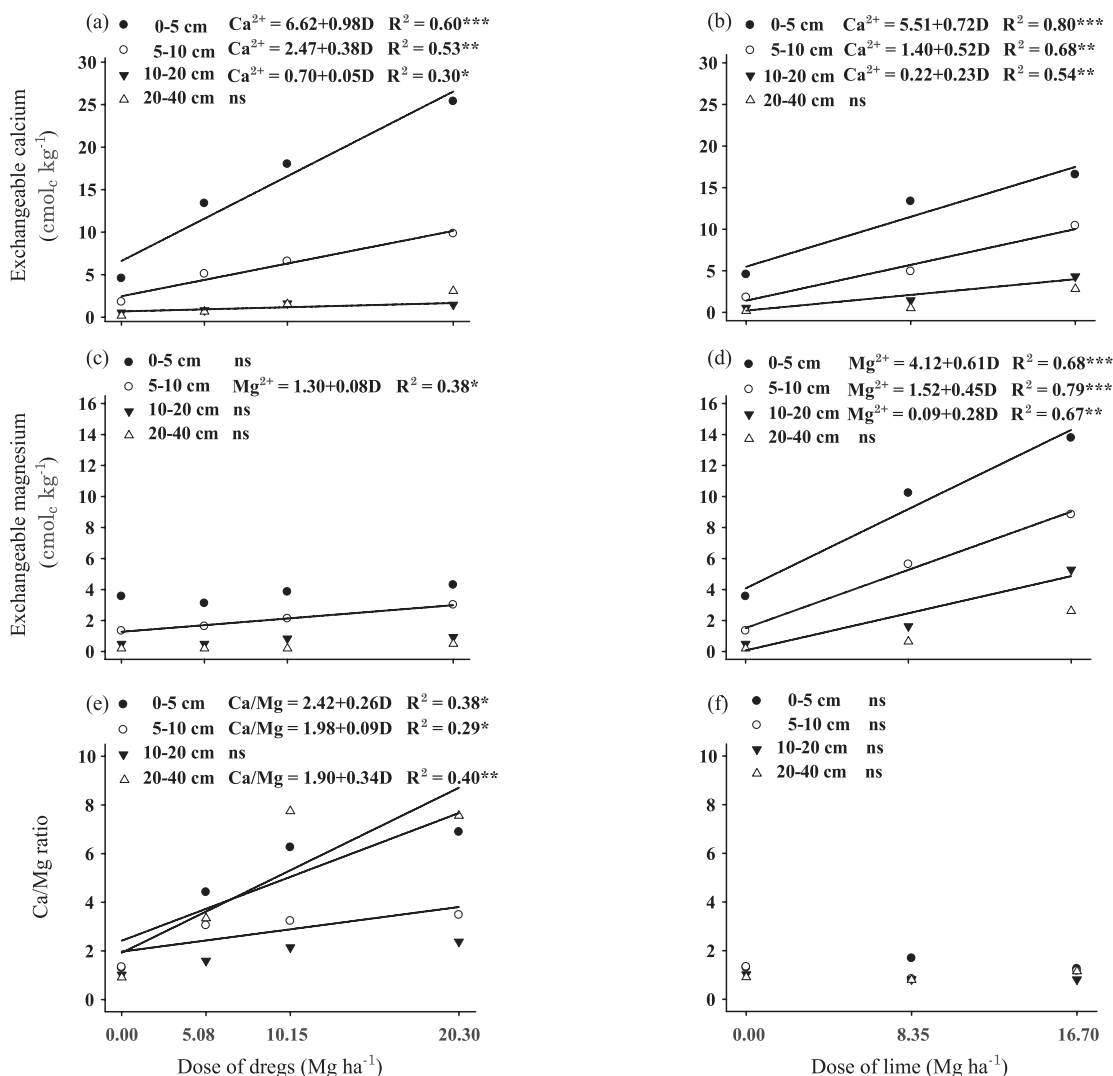


Figure 2. Exchangeable calcium and magnesium (Ca^{2+} , Mg^{2+}) and Ca/Mg ratio in the layers of a Humic Cambisol amended with doses (D) of dregs (a, c, e) and lime (b, d, f) applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, *** and ns: significant at 5, 1, 0.1 % and not significant,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

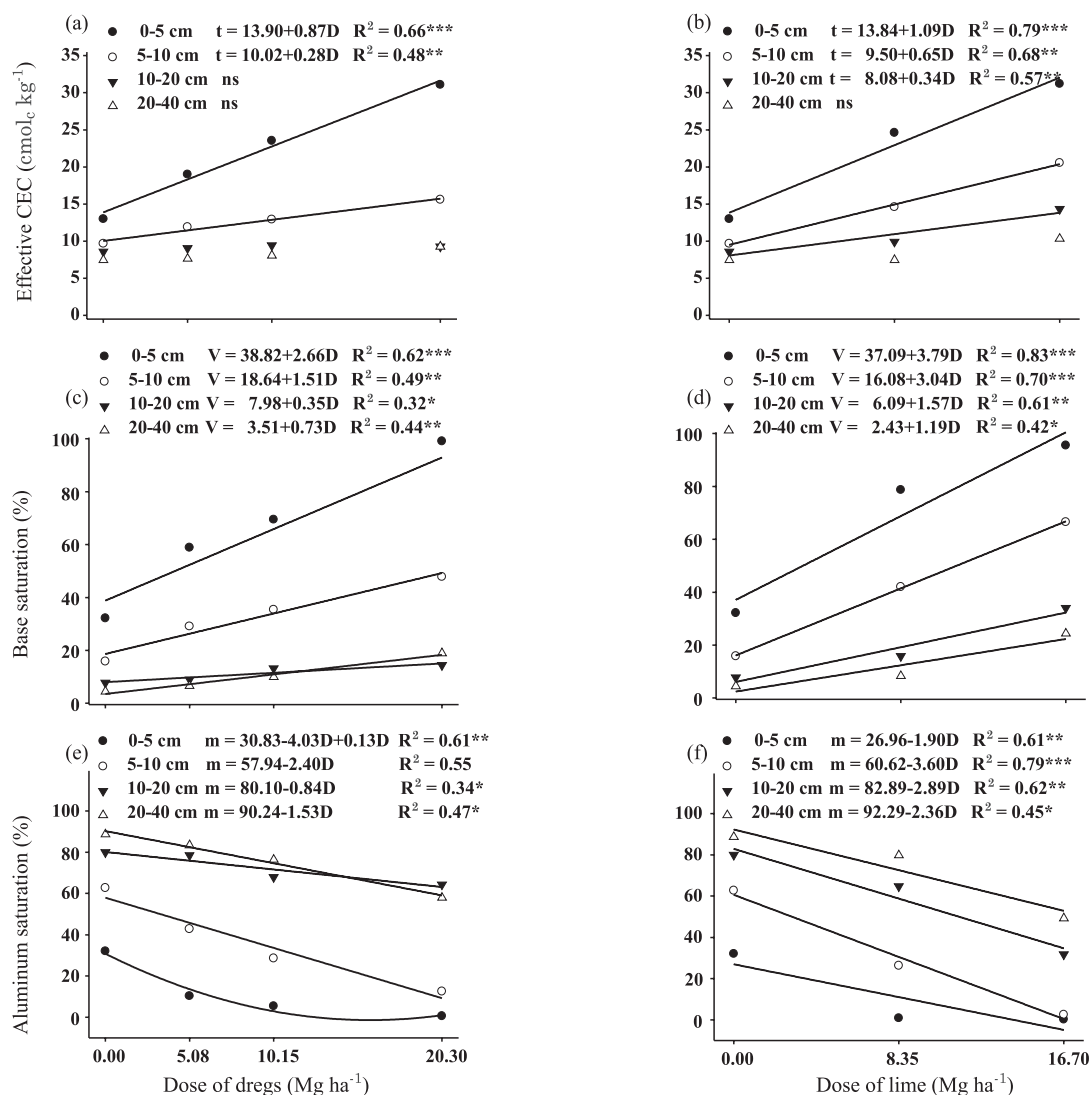


Figure 3. Effective CEC (t), base saturation (V) and aluminum saturation (m) in the layers of a Humic Cambisol amended with doses (D) of dregs (a, c, e) and lime (b, d, f), applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2009. (*, **, *** and ns: significant at 5, 1, 0.1 % and not significant,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

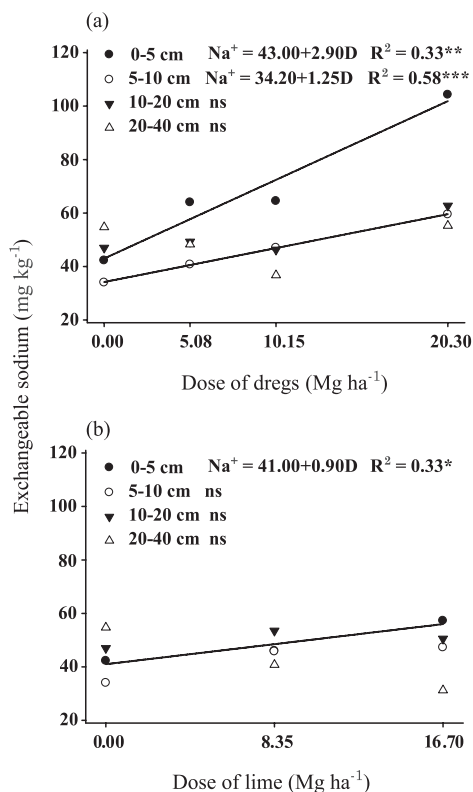


Figure 4. Exchangeable sodium (Na^+) in the layers of a Humic Cambisol amended with doses (D) of dregs (a) and lime (b) applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, *** and ns: significant at 5, 1, 0.1 % and not significant, respectively).

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 for plant growth, with the exception of P (CQFSRS/SC, 2004), it was concluded that surface liming 48 months after reapplication of the soil amendments was efficient down to 5 cm at the highest dregs rate (20.3 Mg ha^{-1}) and down to 10 cm only for the highest lime rate (16.7 Mg ha^{-1}). The effect of liming on highly buffered soils is normally restricted to a few centimeters (Ernani, 2008); in addition, rainfall on forest soils is decreased by leaf interception (Balbinot et al., 2008).

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

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

Soil physical properties

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

Table 2. Mean value of chemical properties per layer of a Humic Cambisol amended with dreg and lime 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: total organic carbon.

Table 3. Estimate⁽¹⁾ of the linear contrasts between treatments for chemical properties of a Humic Cambisol amended with dregs and lime rates applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010

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.

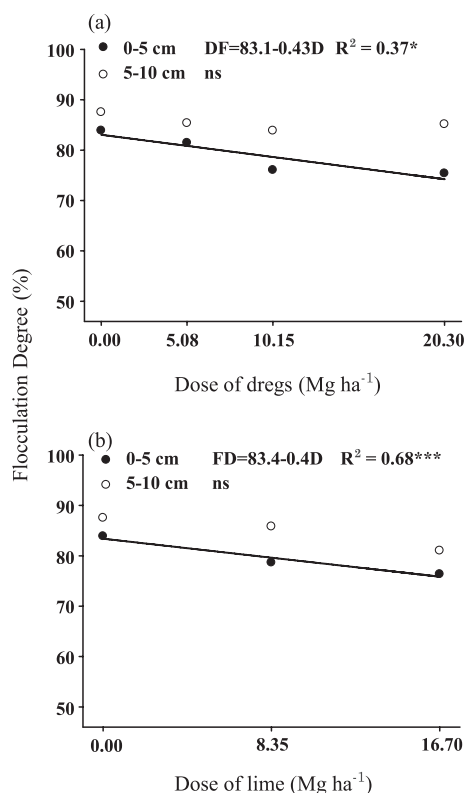


Figure 5. Flocculation degree (FD) in the layers of a Humic Cambisol amended with doses (D) of dregs (a) and lime (b) applied to the soil surface in 2004/2006. Bocaina do Sul, SC, 2010. (*, **, * and ns: significant at 5, 1, 0.1 % and not significant, respectively).**

and lime rates. Clay dispersion and FD reduction with an increase in pH were observed in soils of the Santa Catarina Plateau (Albuquerque et al., 2000, 2002; Medeiros et al., 2009). The reason may be the greater repulsion among soil particles through the increase of net negative charge and the thickness of the electric double layer caused by the substitution of Al³⁺ by Ca²⁺ and Mg²⁺, due to the application of soil amendments (Fontes et al., 1995).

The other soil physical properties did not differ according to the amendment rates (Table 4). The high total organic carbon (TOC) content contributed to decrease soil bulk density (BD), to a mean value of 0.90 Mg m⁻³. The low values of soil penetration resistance (PR) (Table 4) coincide with the low BD. The clay content and high organic matter content are also responsible for the high soil aggregate stability, as already stated by Bertol et al. (2000) for soils of the Santa Catarina Plateau.

The contrasts between equivalent amendment rates on soil physical properties are shown in table 5. There was a difference only for the PR with the application of dregs or lime. The addition of dregs reduced the PR in greater intensity than liming down to a depth of 20 cm, for both the dose corresponding to 1/2 SMP (D50) and the dose corresponding to 1 SMP (D100). These results indicate that the influence of the surface application of corresponding dregs and lime rates on the soil physical quality did not differ very much six years after the beginning of the experiment. The

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 ($\theta=0,37 \text{ m}^3 \text{ m}^{-3}$)
	cm	Mg m^{-3}	$\text{m}^3 \text{ m}^{-3}$		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. Estimate¹ of the linear contrasts between treatments for physical properties of a Humic Cambisol 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}	$\text{m}^3 \text{ m}^{-3}$		%	mm	kPa
			0–5 cm layer			
L50 x D50	0.01 ^{ns}	0.00 ^{ns}	0.00 ^{ns}	2 ^{ns}	0.2 ^{ns}	118 ^{***}
L100 x D100	-0.02 ^{ns}	0.02 ^{ns}	-0.01 ^{ns}	1 ^{ns}	-1.1 ^{ns}	400 ^{***}
			5–10 cm Layer			
L50 x D50	0.01 ^{ns}	0.00 ^{ns}	0.00 ^{ns}	2 ^{ns}	0.1 ^{ns}	78 ^{ns}
L100 x D100	0.01 ^{ns}	0.00 ^{ns}	-0.02 ^{ns}	-4 ^{ns}	-0.3 ^{ns}	374 ^{***}
			10–20 cm Layer			
L50 x D50	-0.06 ^{ns}	0.01 ^{ns}	0.02 ^{ns}	.	-0.1 ^{ns}	489 ^{***}
L100 x D100	0.00 ^{ns}	0.01 ^{ns}	-0.02 ^{ns}	.	0.3 ^{ns}	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 to root development, which allows water and nutrient uptake from a greater soil volume, and consequently, an excellent plant development.

CONCLUSIONS

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

2. Dregs, comparable to lime, reduced the degree of clay flocculation by the increase of pH, but did not

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.

ACKNOWLEDGEMENTS

The authors are indebted to the Santa Catarina State University (UDESC) and the National Council for Scientific and Technological Development (CNPq) for the research productivity grants of the second and third author and to Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES) for the scholarship (Master's degree) of the first author. They also wish to thank the Professor Alexandre Ferreira de Macedo of the Department of Forestry Engineering of the UDESC, for granting the permission to use the experimental area.

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