Paper industry residues can be utilized to improve quality of a Humic Cambisol

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Abstract
The pulp and paper industry generates large amounts of residue that can cause environmental damage. On the other hand, the use of such residue in adequate amounts can improve soil quality. This study aims to evaluate chemical and physical properties of a Humic Cambisol and yields of annual crops after surface application of an alkaline residue (dregs) and limestone. The experimental design was randomized complete blocks with four replications, started in 2004 with liming on the soil surface. The treatments were: control with no correction; doses of limestone corresponding to 0.5 and 1 SMP; and doses of alkaline residue corresponding to 0.25, 0.5 and 1 SMP. The dose of 1 SMP was calculated to reach pH 6.0 in the layer of 0 to 0.10 m (CQFS RS/SC, 2004). Physical and chemical soil properties and crop yields were analyzed. The use of alkaline residues improved chemical properties, and did not modify soil physical properties. The yields of wheat and bean increased with correctives, and the highest production was obtained at the highest corrective rate. It is possible to use alkaline residue of the pulp industries when applied on the surface of the acid soil, without tillage.

Key Words
Liming, yield, dregs, soil acidity.

Introduction
In recent years, the pulp industry in Brazil has been expanding its production considerably. However, despite this growth, there is a prescent concern on solid waste management, some with potential for using in agricultural soils. The use of residues as a corrective may improve soil chemical and physical properties, and consequently increase crop yield. However, the replacement of limestone by alkaline residues from the pulp industry can be limited by the presence of sodium in these products, which can disperse clays and decrease aggregates stability (Albuquerque *et al.* 2002), and saturated hydraulic conductivity and form crust on the surface of bare soils. Another limitation is the high Ca/Mg ratio, which can reduce crop development (Medeiros *et al.* 2008). Thus, the use of residues for agricultural purposes will be dependent on their chemical characteristics and soil properties. Almeida *et al.* (2007) stated that this residue can correct soil acidity and is a source of plant nutrients. Such positive effects can also be detected in agricultural areas, however, in order to use this waste it is necessary to establish appropriate doses in long term experiments. This study aimed to evaluate the use of an alkaline residue to correct soil acidity and improve chemical and physical properties of a Humic Cambisol and associated crop yields.

Methods
The experiment was carried out under field conditions in Lages, SC, Brazil. The climate is humid mesothermal subtropical (Cfb, Köppen) and well distributed rains during the year, with average rainfall of 1.550 mm yr^{-1}. The maximum and minimum mean annual temperatures are 21.7 and 11.5ºC, respectively. The soil is classified as Humic Cambisol, clay loam, with a slope of 0.10 m m^{-1}, thickness of the A horizon of 0.60 m, previously used with native grasses for production of dairy cattle.

The experimental design was randomized blocks with 24 plots of size 8 x 8 m, with four replications. The treatments were: control with no correction; doses of limestone corresponding to 0.5 and 1 SMP; and doses of alkaline residue corresponding to 0.25, 0.5 and 1 SMP. The dose of 1 SMP was calculated to reach pH 6.0 in the layer of 0 to 0.10 m (CQFS-RS/SC, 2004). The composition of the residue used in the experiment was as follows: Ca = 300 g/kg; Mg = 10 g/kg; Na = 34 g/kg; and relative capacity of neutralizing value of 90 %. The limestone was composed of: Ca = 289 g/kg; Mg = 118 g/kg; Na = 0.1 g/kg; and relative capacity of neutralizing value of 86 %.

The correctives were spread on the soil surface after mowing the native grass cover. Half of the dose was applied in June 2004 and half in June 2006. During this period, the area was grazed. After 2006 the pasture was dissecated to grow annual crops in no-till system. Fertilization was based on analysis of the soil layer of 0 to 0.20 m depth, as recommended by CQFS-RS/SC (2004). Soil samples with altered and preserved structure were collected in layers of 0 to 0.05 m, 0.05 to 0.10 m and 0.10 to 0.20 m to determine soil chemical and physical properties: pH, total acidity, K, Na and extractable P, Ca, Mg and Al contents, organic carbon (OC), soil water content, total porosity, macroporosity, microporosity, bulk density, particle density, flocculation degree and mean weight diameter (MWD) of aggregates. Measurements of pH were performed according Tedesco *et al.* (1995); the total acidity (H + Al) was extracted with a solution of calcium acetate 0.5 mol/L at pH 7.0 and quantified by titration with sodium hydroxide (NaOH); K, Na and P were extracted by Mehlich with an acid solution of HCl 0.05 mol/L and H_2SO_4 0.025 mol/L; P was quantified by colorimetry; Na and K were quantified by flame photometry; Ca and Mg were extracted with neutral solution of potassium chloride (KCl) 1 mol/L and quantified by atomic absorption spectrophotometry; exchangeable Al determined by neutralization titration with NaOH; the OC was quantified by the method of Walkley & Black (Tedesco *et al.* 1995).

The porosity was measured in samples with preserved structure, using a sand tension table (EMBRAPA, 1997) with the suction of 0.60 m; bulk density was determining by drying the soil to 105°C (Blake and Hartge, 1986); the particle density was determined according EMBRAPA (1997); total porosity was calculated by ratio between bulk density and particle density; the degree of flocculation was calculated as the ratio between total clay and natural clay determined by the pipette method (Gee & Bauder, 1986); the mean weight diameter (MWD) was calculated to express the aggregate stability according to the method of Kemper & Chepil (1965). The wheat and beans yields were measured during three growing seasons.

Results

Sampling in 2004 was done 120 days after the application of lime. The organic carbon (OC) and extractable phosphorus were not affected by treatments, but the OC content decreased from 35 to 29 g/kg and phosphorus from 6.3 to 4.9 mg/kg with depth (Table 1). The analysis of the residue shows that it had a very high content of calcium, potassium and sodium (Albuquerque *et al.* 2002). The addition of limestone increased calcium and magnesium, and the residue increased calcium and sodium content. With the C50 magnesium increased in the layer of 0 to 0.10 m, while with C100 increased in the layer of 0 to 0.20 m. The residue added more calcium and less magnesium than the limestone. Thus, the Ca/Mg ratio increase, possibly causing imbalance of cations in the soil. In the 0 to 0.05 m the Ca/Mg ratio increased from 5.5 in control to 21.0 in the D100. The amount of sodium added was high, and increased its content in the layers of 0 to 0.05 and 0.05 to 0.10 cm (Table 1), mainly in the D100. The addition of basic cations increased the sum of bases (SB) in the control of 1.8 to 3.8 cmolc/L at C100 and to 4.1 cmolc/L in D 100, thus, the basis saturation increased and Al saturation decreased, mainly in the 0 to 0.05 cm.

Surface application of the residue and limestone increased pH only in the layer of 0 to 0.05 cm due to low solubility of the components used and the high soil acidity. The pH increased from 4.9 in the control to 5.3 in the C100 and 5.4 in the D100. With increasing pH, the Al saturation decreased from 36% in the control to 1% at 100C and 2% at D100.

In 2006, started the soil cultivation for grain production, and correctives were re-applied to raise pH to 6.0. Thus, the soil chemical properties were further amended with a greater increase in pH and reduced Al (data not shown). However, even with the soil cultivation under no-till system, soil physical properties did not change. In 2004 the degree of flocculation was of 79 %, the bulk density was 1.23 g/cm^3, the total porosity was 0.50 m^3/m^3, macroporosity was 0.04 m^3/m^3, and the weighted mean diameter was 5.8 mm. In 2007, after started the soil cultivation, the degree of flocculation was of 73 %, the bulk density was 1.26 g/cm^3, the total porosity was 0.50 m/m^3, and the weighted mean diameter was 6.2 mm. There was an increase in macroporosity from 0.04 to 0.08 m^3/m^3, possibly due to the localized tillage to sown annual crops. According to these results, the Humic Cambisol has a good physical quality.
With the changes in soil chemical properties, crop yields differed among the treatments with highest yield in the highest dose of correctives applied (Table 3). Even with lower doses of the residue and limestone, increases were effective for minimizing the toxic effect of Al to plants.

Table 1. Exchangeable cations, phosphorus, pH, organic carbon (OC), sum of bases (SB), effective capacity of cation exchange (CTCef), hydrogen plus aluminum, and aluminum saturation (m) after applying corrective in Humic Cambisol. Lages, SC, Brazil, 2004.

	Na	K	Ca	Mg	P	Al	pH	OC	SB	CTCef	H+Al	m
	- - mg/kg - -		- - $cmol_c$/kg - -		mg/kg	cmolc/kg		g/kg	- - - - cmolc/kg - - - -			%
						0 to 0.05 m						
Control[A]	27 B[B]	226	1.9	0.3 BC	6.6	1.6 AB	4.9	35	2.9	4.5	6.0	36
D25	56 B	192	3.9	0.2 C	6.1	1.9 A	5.0	35	4.9	6.8	5.0	28
D50	55 B	229	5.4	0.3 C	6.3	0.6 AB	5.3	35	6.5	7.2	5.7	9
D100	97 A	206	6.3	0.3 C	5.7	0.1 B	5.4	34	7.5	7.6	5.5	1
C50	24 B	213	3.6	0.7 AB	6.8	0.6 AB	5.2	36	4.9	5.6	5.7	11
C100	31 B	212	4.7	0.9 AB	6.4	0.1 B	5.3	37	6.2	6.3	4.9	2
Mean	48	213 a	4.3 a	0.5	6.3 a	0.7	5.2 a	35 a	5.5 a	6.2 a	5.4 b	12 b
						0.05 to 0.10 m						
Control	23 B	132	0.8	0.1 NS	5.8	2.8 NS	4.6	30	1.4	4.2	6.5	67
D25	43 AB	123	0.9	0.1	4.9	2.6	4.8	30	1.5	4.1	6.5	63
D50	44 AB	133	1.6	0.2	5.1	2.9	4.7	29	2.3	5.2	6.8	56
D100	69 A	125	2.0	0.1	5.4	2.4	4.8	30	2.8	5.1	6.3	46
C50	28 B	172	1.5	0.2	5.1	2.5	4.8	31	2.2	4.7	6.6	52
C100	25 B	132	2.1	0.4	5.4	2.0	4.8	32	2.9	4.8	6.4	41
Mean	39	136 b	1.5 b	0.2	5.3 b	2.5	4.8 b	30 b	2.2 b	4.7 b	6.5 a	54 a
						0.10 to 0.20 m						
Control	22 NS	93	0.6	0.1 NS	5.2	3.1 AB	4.6	29	1.0	4.1	7.0	75
D25	37	104	0.6	0.1	4.6	2.9 AB	4.8	29	1.1	4.0	6.6	72
D50	26	86	1.3	0.1	4.7	3.5 A	4.6	27	1.7	5.2	7.1	67
D100	56	104	1.4	0.1	4.9	2.6 AB	4.9	28	2.0	4.6	6.3	57
C50	18	109	0.9	0.2	4.7	2.7 AB	4.7	30	1.5	4.2	6.9	65
C100	24	109	1.7	0.3	5.2	1.6 B	4.7	30	2.4	4.0	6.5	40
Mean	30	101 c	1.1 b	0.2	4.9 b	2.7	4.7 b	29 c	1.6 b	4.3 b	6.7 a	63 a
						Mean of 0 to 0.20 m						
Control	24	150	1.1 B	0.2	5.9	2.5	4.7	31	1.8 B	4.3	6.5	59 A
D25	45	139	1.8 AB	0.2	5.2	2.5	4.9	31	2.5 AB	5.0	6.0	54 AB
D50	42	149	2.8 AB	0.2	5.3	2.3	4.9	31	3.5 AB	5.9	6.5	44 ABC
D100	74	145	3.2 A	0.2	5.3	1.7	5.0	30	4.1 A	5.8	6.0	35 BC
C50	23	165	2.0 AB	0.4	5.5	1.9	4.9	32	2.9 AB	4.8	6.4	43 ABC
C100	26	151	2.8 AB	0.5	5.7	1.2	4.9	33	3.8 A	5.1	5.9	27 B

[A] Control = no correction; D25, D50 and D100 corresponds to doses of residue corresponding to 0.25, 0.5 and 1 SMP and C50 and C100 corresponds to doses of limestone corresponding to 0.5 and 1 SMP.
[B] Upper case letters on column indicate significant differences between treatments in the same layer, or on the mean of the layers. Lower case letters on column indicate significant differences between layers on the mean of treatments. ns = means between treatments did not differ by Scheffe test ($P<0.05$). The absence of letters indicates that the effect of the treatment or layer was not significant by F test.

Table 2. Flocculation degree, bulk density, total porosity, macroporosity, microporosity and mean weight diameter (MWD) after application of correctives in the Humic Cambisol. Lages, SC, Brazil, 2004.

Flocculation degree	Bulk density	Total porosity	Macroporosity	Microporosity	MWD
%	g/cm^3	m^3/m^3	m^3/m^3	m^3/m^3	mm
		Mean of 0 to 0.10 m			
79	1.23	0.50	0.04	0.46	5.8

Table 3. Wheat and beans yields, after application of residues in the years of 2004 and 2006, to a Humic Cambisol. Lages, SC, Brazil, 2009.

Treatment	Crop/year		
	Wheat/2006	Wheat/2008	Beans/2009
	kg/ha	kg/ha	kg/ha
Control[A]	1,700 b	545 b	1,770 b
D25	2,253 ab	1,360 ab	2,308 ab
D50	2,475 ab	1,450 ab	2,694 ab
D100	2,993 a	1,784 a	3,050 a
C50	2,580 ab	1,590 a	2,699 ab
C100	2,919 a	1,827 a	2,736 ab

[A] Control = no correction; D25, D50 and D100 corresponds to doses of residue corresponding to 0.25, 0.5 and 1 SMP; and C50 and C100 corresponds to doses of limestone corresponding to 0.5 and 1 SMP respectively. Means followed by the same letter did not differ by Scheffe test ($P<0.05$).

Conclusion

The use of alkaline residues increased soil pH, the content and saturation of exchangeable bases, the cationic exchange capacity and the Ca/Mg ratio, and reduced Al saturation. However, it did not modify soil physical properties. The highest yields of wheat and beans were for the higher corrective rate. It is possible to use alkaline residue of the pulp industries when applied on the surface of the Humic Cambisol cultivated with no-till system to improve soil chemical conditions, with positive effects on crop response.

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