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Tillage system and lime application in a tropical region: Soil chemical fertility and corn yield in succession to degraded pastures

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ABSTRACT

The chemical degradation of soils, due to acidity, and erosion processes, resulting from a traditional tillage system method, are one of the main factors responsible for decreasing the productive capacity of tropical pastures. Thus, establishing the crop-livestock integration system (CLIS) by applying lime on surface without disrupting the soil is interest. The objectives of this study were to evaluate the chemical changes in a soil following surface application or incorporation of lime and to determine the effects of liming on plant nutrition, corn (*Zea mays* L.) grain yields, and various yield components in cultivated areas of degraded *Brachiaria decumbens* Stapf pasture. A randomized block experimental design with a split-plot arrangement consisting of two management systems (tillage and no-tillage system) and three lime rates (0.0; 2.7 and 5.4 Mg ha^{-1}) was used. The highest reactivity of calcium carbonate was observed after six months of liming, since during the sampling time the level of exchangeable Ca^{2+} and Mg^{2+} decreased to 0.05 m depth, and increased Al^{3+} and soil acidity to 0.3 m. The incorporation of lime did not increase the movement or reaction of the bases in the degraded soil profile. Therefore, surface liming under perennial forage crop residues (*B. decumbens* Stapf. pasture) provided the best alternative to increase the soil pH index at a depth of up to 0.3 m. Macronutrients uptake by plant, yield components, and corn grain yield were not affected by the application method. However, the use of limestone showed viability to maximize up to 20% in corn productivity, regardless of lime rate. The results suggest that it is possible to ameliorate soil acidity and chemical properties of degraded grassland only by surface application of limestone; however, the strategy is considered effective just for soils with no physical restriction to root development.

1. Introduction

Increasing worldwide consumption of meat, grains, fibers, and bioenergy has made it necessary to expand the productive capacity of agricultural lands, including those considered to have low fertility. Tropical soils are considered as major agricultural borders (Borlaug and Dowswell, 1998), since have favorable environmental factors for agricultural activity. Recently, the consolidation of CLIS in tropical regions, including the integration of annual crop production (corn, soybeans, rice, cotton and sorghum) with meat and milk production (Carvalho et al., 2011; Loss et al., 2011; Mateus et al., 2011; Borghi et al., 2013; Crusciol et al., 2014), has confirmed the potentials of these productive soils.

It is estimated that the Brazilian cerrado region, which has native vegetation similar to that of African savannahs, could produce 250 million tons of grain and 12 million tons of meat annually (Lee et al., 2012). However, despite this high potential, approximately 50 million hectares of pasture in this region have been subjected to some level of degradation (Borghi et al., 2013). The naturally acidic conditions of tropical soils, which have been intensified by the use of nitrogenous fertilizers containing ammonia (Caires et al., 2015), have limited the agricultural potentials of these soils in many regions of the world. In most cases, the low chemical fertility of these degraded soils result from aluminum and manganese toxicity and low

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availability of exchangeable bases, such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) (Oliveira and Pavan, 1996; Caires et al., 2005; Calegari et al., 2013).

Liming is one of the most common and effective practices for reducing or neutralizing the negative effects resulting from acidity. In addition, liming is important for increasing the availability of Ca and Mg in soils (Caires et al., 1998; Soratto and Crusciol, 2008; Joris et al., 2013). Due to its low solubility, lime is usually incorporated into the soil by conventional methods (plowing and harrowing). However, these proceedings drastically changes the soil physical properties, including the soil structure and porosity (Pöttker and Ben, 1998), which are often good where perennial forage species are cultivated. (Salton et al., 2008; Cavalieri et al., 2009, 2010).

In most grain-producing areas that use no-tillage systems, soil acidity correction has only been performed via surface liming (Conyers et al., 2003; Soratto and Crusciol, 2008; Briedis et al., 2012) because preserving the soil structure is extremely important for obtaining good root development and for reducing degradation processes, such as erosion. Despite the benefits of surface application, several studies have demonstrated that the speed of the limestone reaction is slower in the subsurface when the lime is not incorporated (Pöttker and Ben, 1998; Caires at al., 2008). Soratto and Crusciol (2008) presents contradictory results because they confirm that liming affects the subsurface layers after a relatively short period. However, these results are still discordant, and the viability of surface liming for recovering degraded pastures remains unknown.

The need for limestone in agricultural systems with minimal mobilization is smaller than that in conventional systems, with greater soil mobilization (Pöttker and Ben, 1998; Caires et al., 2000). This difference is attributed to the complexation of exchangeable Al by soil organic matter, which is an intense process within conservation systems and involves the accumulation of large amounts of organic matter (van Hees et al., 2000). Knowledge of changes in soil chemical attributes and their effects on grain yield are necessary for establishing and adjusting lime requirements in CLIS. However, in areas with no physical limitations, such as compaction or erosion, and where low pasture productivity exclusively results from reduced soil chemical fertility, it is likely that reducing soil acidity by adding lime to the surface can provide results that are comparable with those obtained when using conventional methods.

The objectives of this study were to evaluate the chemical changes in the soil that were affected by the surface application or incorporation of lime and to determine the effects of these methods on plant nutrition, yield components, and corn grain yield in a degraded *Brachiaria decumbens* Stapf pasture.

2. Materials and methods

2.1. Site description

This experiment was performed in Botucatu City (in the State of São Paulo in southeastern Brazil; 48° 23′ W, 22° 51′ S, 765 m above sea level) during two growing seasons. According to the Koppen classification system, the climate of the study area is Cwa, which is tropical with dry winters and hot and rainy summers (Lombardi and Drugowich, 1994). The rainfall and the mean maximum and minimum temperatures recorded during the experimental period are shown in Table 1 (Unicamp, 2012).

The soil is a sandy clay loam, kaolinitic, thermic Typic Haplorthox with 600, 208 and 192 $g\,kg^{-1}$ of clay, silt and sand, respectively. In our study, the soil was managed using conventional tillage (one disk plow with a working depth of 200 mm and two leveling harrows with a working depth of 100 mm) for five or more years before the trial began. The area was cultivated following its use as a *Brachiaria decumbens* Stapf. pasture without soil mobility.

Before starting the experiment, the soil chemical characteristics were determined at depths of 0–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.30 m (Table 2). These initial values were only used for comparison with the following results and were not considered in the statistical analysis. The soil pH was determined in 0.01 $mol\,L^{-1}$ $CaCl_2$ (1:2.5 soil/solution ratio). Exchangeable Al was extracted using neutral 1 $mol\,L^{-1}$ KCl with a 1:10 soil/solution ratio and determined by titration in 0.025 $mol\,L^{-1}$ NaOH (Yuan, 1959). The soil organic matter content was evaluated using the Walkley–Black method (Walkley and Black, 1934). Exchangeable basic cations (Ca^{2+}, Mg^{2+}, and K^+) and available P were extracted using an ionic resin (van Raij et al., 1986). Exchangeable Ca^{2+}, Mg^{2+} and K^+ were determined using a Shimadzu AA-6300 atomic absorption/Flame-Emission spectrophotometer. Phosphorus was determined colorimetrically (Murphy and Riley, 1962), using a FEMTO 600S spectrophotometer. Base saturation values were calculated using

Table 2
Chemical characteristics of the soil before the experiment.

Depth m	pH ($CaCl_2$)	SOM $g\,dm^{-3}$	P (resin) $mg\,dm^{-3}$	Al^{3+}	H + Al	Ca^{2+}	Mg^{2+}	K^+	BS %
				$mmol_c dm^{-3}$					
0.00–0.05	3.9	31	13	27	62	7.7	5.8	0.8	19
0.05–0.10	3.8	30	8	30	67	5.5	5.0	1.0	15
0.10–0.20	3.7	27	10	33	90	4.7	4.1	0.5	9
0.20–0.30	3.6	25	4	36	85	2.1	2.0	0.2	5
0.00–0.20	3.8	30	10	30	70	6.2	5.1	0.8	15

Table 1
Rainfall, maximum and minimum temperatures at Botucatu, São Paulo State, Brazil, during the study period and long-term average.

Climate characteristics	Month								
	Sep	Oct	Nov	Dec.	Jan.	Feb.	Mar.	Apr.	May
First season									
Monthly rain, mm	90.4	133.9	146.3	290.3	400.1	203.5	111.0	70.3	44.8
Mean max. temp., °C	25.3	27.1	27.8	28.0	27.9	28.3	28.4	25.8	22.8
Mean min. temp., °C	13.7	14.9	15.3	18.9	20.0	19.8	19.3	16.1	13.4
Second season									
Monthly rain, mm	–	–	–	183.8	220.7	227.9	162.4	12.1	10.3
Mean max. temp., °C	–	–	–	28.9	27.8	27.4	27.0	27.1	24.4
Mean min. temp., °C	–	–	–	18.7	19.1	19.0	18.6	17.0	14.1
Long-term (50-yr) avg.									
Monthly rain, mm	71.3	126.5	133.3	184.6	224.0	203.2	140.9	66.5	75.8
Mean max. temp., °C	26.2	26.7	27.2	27.2	28.1	28.0	28.0	27.0	24.0
Mean min. temp., °C	12.4	14.2	15.1	16.4	17.1	17.4	19.0	17.0	15.0