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Amelioration of soil acidity and soybean yield after surface lime reapplication to a long-term no-till integrated crop-livestock system under varying grazing intensities

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ABSTRACT

An integrated crop-livestock system (ICLS), with summer grain cropping and winter grazing of cover crops, is an option for agricultural management in subtropical areas. Despite numerous studies evaluating ICLS, there have been limited investigations of soil acidity and lime application dynamics in such systems. Because grain producers resist introducing livestock into cultivation areas due to fear of negative impacts of grazing on soybean yields and lime movement thorough the soil profile, the objective of this research is to evaluate the impacts of surface lime reapplication on the amelioration of soil acidity attributes and the yield of soybean in a long-term integrated soybean-beef cattle system under no-till under varying grazing intensities. An experiment was established in 2001 for an ICLS on a Rhodic Hapludox soil. Crop succession consisted of soybean (*Glycine max*) cultivation during summer and a mix of black-oat (*Avena strigosa*) + Italian *ryegrass* (*Lolium multiflorum*) during winter. Treatments consisted of varying grazing intensities during winter: intensive grazing, moderate grazing, and no-grazing. Lime was applied to the surface of the entire area at the beginning of the experiment, and a reapplication was performed nine years later (May of 2010) in a sub-parcel scheme (with and without lime reapplication). Soil acidity attributes (pH, base saturation and aluminum saturation) were evaluated at 12, 18, 24, and 30 months after lime reapplication, and the soybean yields of the 2010/11, 2011/12, and 2012/13 seasons were measured. As previously observed for the first surface lime application performed in the same trial area, the present study demonstrated that ICLS, regardless of grazing intensity, did not inhibit soil improvement in deeper layers after surface lime reapplication. In fact, the presence of animals helps to ameliorate soil acidity in deeper layers, compared to non-grazed areas. The soybean yield was not correlated with the soil acidity attributes and was affected by lime reapplication only under intensive grazing and drought conditions. However, when summer rainfall was lower than the expected climatological normal, soybean yields were higher in non-grazed areas.

1. Introduction

Surface lime (re)application remains a controversial topic regarding food production system management. The efficiency of this agronomic practice to correct soil acidity in the soil profile under no-tillage (NT) systems has been widely studied because the reacidification process can result in a greater increase in soil acidity in deeper soil layers compared to the upper layers (Tang and Rengel, 2003). Varying results of the effects of surface liming on the soil profile have been observed, with liming affecting soil layers to depths of only 5 cm (Rheinheimer et al., 2000; Amaral et al., 2004a) as well as soil layers of 40 cm or deeper (Oliveira and Pavan, 1996; Caires et al., 2008). According to Edmeades and Ridley, (2003) such differences exist because, in addition to the effects of the liming rate and time, several other factors affect this dynamic, such as: rainfall distribution, soil texture, structure (presence of macro and biopores), hydraulic conductivity, fauna (which mix soil layers), crop rotation and management, and residue additions, among others.

Additionally, the yield responses of crops to surface liming are not clear because the degree of impact depends on all the

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previously mentioned factors in addition to crop tolerance to acidity. In contrast to conventional tillage, under NT conditions, soil acidity attributes do not have a direct relationship with the crop responses to lime application, especially under normal rainfall conditions (Caires et al., 2001; Tissi et al., 2004). Furthermore, Brown et al. (2008) have reported that, in long-term NT systems, there is little or no crop response to liming because the decomposition of residues accumulated in the soil surface results in pH buffering and aluminum complexation.

Despite the latter, there is not a great deal of research that has examined the acidity and lime application dynamics of integrated crop-livestock systems (ICLS). In regions with acidic soils, most of the ICLS experiments only consider liming as a necessary agronomical practice for increasing crop and meat production. However, animal grazing in cropping areas modifies the fluxes and processes affecting the soil-plant-atmosphere continuum, imposing heterogeneity in the spatial distributions of nutrients impacted by selective grazing and residue (dung and urine) deposition (Anghinoni et al., 2013; Moraes et al., 2013). Thus, the dynamics associated with grazed conditions may influence the responses of soils and crops to surface liming compared to the responses of NT systems that are only used for the cultivation of cash and cover crops (non-grazed systems). However, the grazing intensity is a critical factor that influences the modifications that will occur in the system, including those related to soil chemical attributes (Carvalho et al., 2011).

When well managed, grazing stimulates root growth (Lyons and Hanselka, 2001), which can increase the volume of rhizospheric soil and organic ligand exudation (Curl and Truelove, 1986), thus increasing aluminum complexation and the mobility of lime dissolution byproducts (Ca^{2+} and Mg^{2+}) through the soil profile. Such processes are enhanced by the deposition of cattle dung (amount and distribution) (Haynes and Mokolobate, 2001; Liu and Hue, 1996), which depends on grazing intensity (Silva et al., 2014). In addition, decomposition of roots contributes to higher macroporosity and pore continuity along the soil profile (biopores) (Stirzaker et al., 1996), improving the translocation of fine lime particles from upper to deeper soil layers, thus increasing the soil pH in deeper layers (Amaral et al., 2004b). On the other hand, the impacts of cattle trampling under intensive grazing result in physical damage, increasing soil bulk density and decreasing soil macroporosity, hydraulic conductivity and infiltration rates (Bell et al., 2011). Such modifications of the soil system can slow the redistribution of lime through the soil profile. Furthermore, acidification, caused by urination (Black, 1992) and nitrogen fertilizer additions in grazed systems (Unkovich et al., 1998), inhibits the impacts of liming in deeper soil layers. Such potential negative impacts of grazing on soil improvement by surface liming and summer crop yields contribute to the ongoing resistance of grain producers to adopting ICLS.

In a previous study conducted in the same trial area, Flores et al. (2008) verified that ICLS conditions, compared to non-grazed systems, increased the liming efficiency in deeper soil layers over time. Higher values of soil pH and base saturation and lower levels of aluminum saturation were observed at 24 months after liming up to 20 cm deep in grazed areas; for non-grazed areas, the benefits of liming only reached a depth of 15 cm. However, in this study, there was not long-term effects of varying grazing intensities on soil physical attributes because surface liming was performed during the trial establishment. Furthermore, the response of the grain crop to liming was not evaluated because the area (despite treatments) was broadcast limed. Thus, the objective of the present study is to evaluate the impacts of surface lime reapplication on the amelioration of acidity attributes over the soil profile and the response of soybean yield in a long-term no-till integrated crop-livestock system under varying grazing intensities.

2. Materials and methods

This research was conducted as part of an experiment established at the Espinilho Farm (Agropecuaria Cerro Coroado) located in the Planalto region of the state of Rio Grande do Sul (Brazil) (28°57′23″S latitude and 54°21′22″W longitude). The experimental area, approximately 22 ha, is located at an altitude of 465 m in the Brazilian subtropics, with a warm humid summer (Cfa) climate according to the Köeppen classification system. The mean annual temperature is 19 °C and the mean annual precipitation is 1850 mm (data from the INMET, 2013). The area presents a declivity of 0.02–0.10 m m^{-1}. The soil is a deep, well-drained and dark-red clayey Oxisol (Rhodic Hapludox–Soil Survey Staff, 1999) (540, 270 and 190 g kg^{-1} of clay, silt and sand, respectively).

Prior to the establishment of the experiment, the area had been cultivated under NT since 1993. In November of 2000, the soil was sampled and analyzed for the chemical characterization of the 0–5, 5–10, 10–15 and 15–20 cm layers. Soil organic matter, pH, available P and K (Mehlich 1), exchangeable Ca, Mg and Al; and base and aluminum saturation values ranged from: 42 to 26 g kg^{-1}; 4.9 to 4.6; 13.4 to 3.7 mg kg^{-1}; 240 to 55 mg kg^{-1}; 62 to 40 $mmol_c$ kg^{-1}; 22 to 11 $mmol_c$ kg^{-1}; 7 to 1 $mmol_c$ kg^{-1}; 48 to 34% and 17 to 4%. The experiment started, after soil sampling, with soybean cultivation, followed by a black oat+Italian *ryegrass* mixed-pasture grazing season. Then, the cropping rotation has been conducted under an ICLS, with summer soybean cultivation from November until May and winter black oat+Italian *ryegrass* grazing from May until November.

Each year, pasture establishment occurs with black oat seeding (45 kg ha^{-1}) and Italian *ryegrass* natural reseeding. Neutered male steers aged approximately 12 months are moved into the area in the first half of July (when the forage accumulation has, approximately, reached a dry matter production of 1500 kg ha^{-1} and a 20 cm sward height) when they weigh approximately 200 kg, simulating a cattle fattening or finishing system. During the grazing season, cattle feeding was forage-based. Treatments consisted of varying grazing intensities during winter, determined by the grazing sward heights. The grazing sward heights were 10 cm (intensive grazing-IG) and 20 cm (moderate grazing-MG), as well as a non-grazed (NG) treatment, organized in a randomized block design with three replicates. A continuous grazing system was adopted (with a minimum of three remaining steers=testers). Sward heights were measured every 14 days by the Sward stick method (Bircham, 1981), which consists of a graduated-stick measurement system, with a “marker” that slides up and down to determine the height of the first forage leaf blade. In each plot, the sward heights of approximately 100 randomized readings (points) were recorded. The mean sward height is affected by the grazing intensity (stocking rates) and adding or removing steers from each plot. In the three years considered for this study, the mean stocking rates of cattle liveweight (LW) during the grazing seasons for the intensive and moderate grazing treatments, respectively, were 1182 and 917 kg LW ha^{-1} in 2010, 902 and 752 kg LW ha^{-1} in 2011, and 911 and 816 kg LW ha^{-1} in 2012.

Pasture desiccation, achieved with glyphosate (900 g a.i. ha^{-1}) and ethylic chlorimuron (37.5 g a.i. ha^{-1}) was performed after each grazing season, and in December of each year, soybean was seeded at a density of 45 seeds m^{-1} with a 45 cm row spacing. Seed inoculation followed the technical recommendations (specific product). Agronomic management was conducted according to technical recommendations (use of herbicides, insecticides, fungicides) and the soybean crop was harvested every May. A non-acidity-tolerant soybean cultivar (Nidera RR) was cropped in the three growing seasons evaluated in this study (2010/11, 2011/12 and 2012/13).