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Soil acidification and basic cation use efficiency in an integrated no-till crop–livestock system under different grazing intensities

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ABSTRACT

Under integrated crop–livestock production system (ICLS), the animal acts as a catalyzer, modifying and accelerating fluxes by ingesting forage nutrients (grazing) and returning them to the soil as urine and dung in a continuous process whose magnitude and direction depend on grazing intensity. Thus, ICLS may change soil acidification processes and rates. The objective of this research was to verify the influence of grazing intensities on soil acidification through measurements of the soil chemical attributes in the soil profile and the efficiency of basic cation use in a soybean–beef cattle integration system nine years after surface liming under long-term no-till conditions in southern Brazil. An experiment established in 2001 in a Rhodic Hapludox with soybean (summer) and a mix of black oat + Italian ryegrass (winter) succession was used. Treatments consisted of different grazing intensities during the winter season: intensive grazing (IG), moderate grazing (MG), and no-grazing (NG). The experiment was set up in a randomized complete blocks design with three replicates. To evaluate soil chemical attributes, soil was sampled up to 40 cm, in May 2010, nine years after lime application. To quantify basic cations budgets and efficiencies, the inputs and outputs of calcium, magnesium, and potassium, as well as their initial and final exchangeable soil stocks were evaluated. Areas under grazed treatments, regardless of the intensity (IG or MG), presented lower soil acidification. Calcium and magnesium budgets were negative under NG and positive under MG. Potassium budgets were always negative, regardless of the management system, due to soybean grain harvest exportation and non-productive outputs. The soybean–beef cattle integrated system, with either IG or MG, was more efficient in calcium and magnesium utilization to produce protein; however, grazing does not affect potassium use efficiency.

1. Introduction

Acid soils represent approximately four billion ha worldwide (30–40% of arable land), which are predominant in tropical and subtropical regions (Von Uexküll and Mutert, 1995). Despite having acidic soils, these regions have lately experienced significant development in agricultural systems because of a significant increase in food demand and commodity prices (Gilbert and Morgan, 2010). To obtain high yields in agricultural systems, acidic soils require many inputs (e.g., lime and fertilizers), which has created a conflict between food production models (systems) and food security and sustainability (FAO, 2012). In many places, the use of inputs has been unbridled, which has led to economic and environmental losses (Schmieman and Van Ierland, 1999; Guo et al., 2010). The search for sustainable food production systems that optimize the use of inputs rather than achieving short-term yield increases is imperative (Lal and Pierce, 1991). The ultimate goal to be measured in the long term is for food production systems to achieve nutrient surpluses (positive budgets) over time (Urquiaga et al., 1999). According to Fixen (2011), nutrient budgets define the direction of soil fertility and agroecosystem's efficiency, functioning as a critical sustainability indicator.

No-tillage (NT) systems have long been considered an efficient strategy for sustainable agriculture in agroecosystems; in Brazil, NT systems account for more than 32 million ha for food production (FEBRAPDP, 2012). The soil in most of these areas only remains with crops that cover the soil and produces green manure ("cover crops") during some period of the year. Most of these cover crops present high grazing potential (forage species). Therefore, the introduction of animals into these areas produces an

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integrated crop–livestock system (ICLS) that can provide a more resilient and sustainable option for food production (Russelle et al., 2007).

Through grazing, animals act as catalyzers that modify and accelerate the flow of nutrients by ingesting plant biomass and returning 70–95% of the plant nutrients to soil as urine and dung (Russelle, 1997), which is a continuous process whose magnitude and direction depend on the grazing intensity (Anghinoni et al., 2013). Such a process can contribute to a decrease in non-productive losses from leaching or surface runoff because there is synergism between root growth and partial leaf thinning by grazing that stimulates resprouting (Moraes et al., 2013), resulting in continuous growth and demands for nutrient absorption. Therefore, modifying grazing intensity in ICLS can alter soil acidification processes and rates by affecting the chemical attributes in the soil profile over time.

There are three major pathways for soil acidification in agroecosystems: animal-induced, plant-induced and soil-induced. There is a concern regarding the acidification effects of animal manure, especially urine, and under intensive grazing systems, where urine can contribute to a cycle of approximately 180 kg N ha^{-1} $year^{-1}$ (Ledgard et al., 1982). In a single urination, such a rate may be as high as 200–600 kg N ha^{-1} in the urine patch (Black, 1992), with a fast downward flux through the soil macropores and leaches beyond the root uptake zone (Haynes and Williams, 1993). In this process, if the urine-N has gone through nitrification, which produces two H^+ for each N molecule that is nitrified, then soil acidification will occur (Bolan and Hedley, 2003).

The most important plant-induced process in a long-term approach regards basic cation exportation by agricultural products (biomass or grains) (Bolan and Hedley, 2003). Overall, legume crops such as soybean (largely used in ICLS) result in higher soil acidification compared to other crops because they contribute to a higher uptake and exportation of basic cations (Ca, Mg and K) (Slattery et al., 1991). Furthermore, biological N fixation enables soybeans to become independent of soil solution N, which increases the susceptibility of N to the nitrate leaching that occurs by pairing with basic cations (Bolan and Hedley, 2003). Under ICLS, urine-nitrate enhance such processes, which might possibly lead to environmental damage when the urine/nitrate reaches surface and groundwater, and may cause a decrease in nutrient-use efficiency under such a food production system (Robertson and Vitousek, 2009). Nitrate leaching is also the main acidification process of soil-induced processes, and it is mediated by N fertilizer use (Boland and Hedley, 2003), which is a predominant agricultural practice for pasture grasses.

Most of the agricultural research in tropical and subtropical regions have focused on developing methods to identify liming requirements for soil correction and on determining the rates and application methods that result in higher crop response. Despite such efforts, few approaches have been developed to determine the processes and management practices activities that cause the return of soil acidic conditions. Little is known of the long-term effect of surface liming on ICLS under NT, its acidification processes after soil correction and how such processes affect nutrient-use efficiency. Under such a scenario, the objective of this study was to verify the influence of grazing intensities on soil acidification through measurements of soil chemical attributes along the soil profile and the efficiency of basic cation use in a soybean–beef cattle integration system under NT nine years after surface liming.

2. Materials and methods

2.1. Historical characterization and treatments of the experimental area

This experiment reports on a long-term ICLS trial that has been conducted since 2001 at the Espinilho Farm (Agropecuaria Cerro Coroado), located in Sao Miguel das Missoes in Rio Grande do Sul State, Brazil (28°57′23″S latitude and 54°21′22″W longitude).

The experimental area of approximately 22 ha is located at an altitude of 465 m in the Brazilian subtropics, which has a warm humid summer (Cfa) climate according to the Köeppen classification. The average temperature is 19 °C, and the yearly average precipitation is 1850 mm. The area is characterized by a declivity of 0.02–0.10 m m^{-1}, and the soil is a clayey Oxisol (Rhodic Hapludox - Soil Survey Staff, 1999), which is a deep, well-drained and dark-red soil with a clayey texture (540, 270 and 190 g kg^{-1} of clay, silt and sand, respectively). Kaolinite and hematite are the predominant minerals in the clay and iron oxide fractions.

The experimental area has been under NT management since 1993. Prior to the trial establishment, the soil was analyzed (November 2000) (Table 1). The cattle began grazing in June of 2001 in a black oat (*Avena strigosa* cv. Iapar 61) + Italian ryegrass (*Lolium multiflorum* "common") mixed pasture system. The soybean–beef cattle integration consisted of grazing cycles from May to November (winter season) and soybean cropping (*Glycine max* cv. Iguaçu in the first three seasons and cvs. Nidera RR in the remaining ones) from November to May (summer season). Black oat was seeded each year (45 kg ha^{-1}), and Italian ryegrass was established by natural reseeding. At the end of the winter season, the area was desiccated with glyphosate (900 g a.i. ha^{-1}) and ethylic chlorimuron (37.5 g a.i. ha^{-1}), and in December of each year, soybean was seeded in rows spaced 45 cm apart at a density of 45 seeds m^{-2}. Seed inoculation was performed as recommended (specific product), agronomic management was conducted according to the technical recommendations (use of herbicides, insecticides, fungicides), and the soybean harvest occurred every May.

Treatments consisted of grazing intensities during the winter, which were determined by the grazing pasture height, in plots ranging from 0.8 to 3.6 ha. Grazing pasture heights were 10, 20, 30 and 40 cm with an additional reference treatment (non-grazed), organized in a randomized block design with three replications. For this study, intensive grazing (IG—10 cm pasture height),

Table 1
Soil chemical attributes before no-till integrated crop–livestock system (soybean–beef cattle) establishment (November 2000).

Layer (cm)	pH (H_2O)	OM[a] (g kg^{-1})	Ca[b] ($mmol_c$ kg^{-1})	Mg[c]	Al[b]	H + Al	P[c] (mg kg^{-1})	K[c]	V[d] (%)	m[e]
0– 5	4.9	42.2	62	13	3	87	13.4	240	48	4
5–10	4.6	34.8	48	18	6	97	9.8	119	41	9
10–15	4.6	25.5	41	22	7	97	5.2	88	40	11
15–20	4.6	25.5	40	11	1	101	3.7	55	34	17

[a] Soil organic matter.
[b] Exchangeable (KCl 1 mol L^{-1}) Ca, Mg and Al.
[c] Available P and K (Mehlich-1).
[d] Base saturation.
[e] Al saturation.