Agriculture, Ecosystems and Environment 190 (2014) 52–59

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Soil carbon and nitrogen stocks and fractions in a long-term integrated crop–livestock system under no-tillage in southern Brazil

Joice Mari Assmann[a], Ibanor Anghinoni[a], Amanda Posselt Martins[a,*], Sérgio Ely Valadão Gigante de Andrade Costa[a], Diego Cecagno[a], Filipe Selau Carlos[a], Paulo Cesar de Faccio Carvalho[b]

[a] Department of Soil Science, Federal University of Rio Grande do Sul, Bento Gonçalves Avenue 7712, PO Box 15100, Porto Alegre 91 540-000, RS, Brazil
[b] Department of Forage Plants and Agrometeorology, Federal University of Rio Grande do Sul, Porto Alegre 91 540-000, RS, Brazil

ARTICLE INFO

Article history:
Received 19 February 2013
Received in revised form 27 November 2013
Accepted 2 December 2013
Available online 20 December 2013

Keywords:
Black oat + ryegrass
Carbon management indexes
Grazing intensities

ABSTRACT

Managing grazing stocks in integrated crop–livestock (ICL) systems under no-tillage is a key variable for reaching equilibrium in soil C and N budgets. Understanding how different plant and animal residues affect soil C and N stocks in these systems goes beyond soil dynamics since these elements are crucial for the functioning of the soil–plant–atmosphere system. The objective of this research was to determine soil C and N fractions, stocks, budgets and the carbon management index as affected by nine years of ICL with grazing intensities under no-tillage conditions. The experiment established in May 2001 in a Rhodic Hapludult (Oxisol) of southern Brazil was composed of black oat (*Avena sativa*) plus ryegrass (*Lolium multiflorum*) pasture in winter and soybean (*Glycine max*) crop in summer. Treatments were regulated by grazing pressures to maintain forage at 10, 20, 30 and 40 cm high (G10, G20, G30 and G40, respectively). Non-grazed (NG) treatment was the control. Changes in soil C and N stocks and fractions (particulate and mineral-associated) were assessed in the ninth year of the experiment. Moderate and light grazing intensities (G20, G30 and G40) resulted in similar increases in total organic C, particulate organic C, total N, and particulate organic N compared with NG treatment. Soil C additions ranged from 0.54 to 8.68 Mg ha^{-1} from NG to the other grazing treatments. The G10 led to a soil N loss of 1.17 Mg ha^{-1} due to soil organic matter degradation. The carbon management index (CMI) values, compared with native forest (NF) as a reference, indicated soil quality loss and degradation under high grazing intensity (G10). For a positive contribution to the soil system, ICL must be managed with moderate grazing intensities and adjustment of N additions through N fixation or fertilization.

1. Introduction

Integrated crop–livestock (ICL) systems have long been used for food production with positive results since the Neolithic era, when plant and animal domestication began (Carvalho et al., 2007). According to Keulen and Schiere (2004), ICL reached 2.5 billion hectares around the world, being responsible for more than 50% and 90% of cattle meat and milk production, respectively. Thus, these systems became promising alternatives for sustainable agriculture, with positive animal–plant interactions, allowing environmental benefits and economic viability (Allen et al., 2007; Balbinot Junior et al., 2009).

Benefits from ICL, if well managed, include yield optimization reaching soil quality ameliorations along time (Entz et al., 2002). Grazing not only affects nutrient dynamics but also water fluxes and microbial diversity and population (Descheemaeker et al., 2010; Chávez et al., 2011). Thus, in ICL systems, grazing modifies soil–plant–atmosphere feedbacks due to new processes and the rate in which they occur. An example of such changes is the increase in nutrient cycling (Carvalho et al., 2006) as a result of higher shoot and root biomass production due to defoliation, resprouting and tillering cycles.

Production systems that use grass species under no-tillage conditions are capable of maintaining or even increasing soil organic matter (SOM) content in the superficial layers (Diekow et al., 2005; Loss et al., 2009; Batlle-Bayer et al., 2010). The higher pasture root production under grazing conditions (D'andréa et al., 2004) enables higher soil C accumulation, becoming, thus, an important C sink (Nicoloso et al., 2008). Pasture management according to stocking rates results in different residue (plant and animal) additions and, thus, nutrient recycling, affecting soil C and N (Nicoloso et al., 2006; Lopes et al., 2008; Carvalho et al., 2010).

* Corresponding author. Tel.: +55 5133087420; fax: +55 5133086852.
E-mail address: amandaposselt@gmail.com (A.P. Martins).

0167-8809/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2013.12.003

Decreases in soil C and N stocks in pastures under long-term high grazing intensity have been observed by many researchers (Cui et al., 2005; Han et al., 2008; Steffens et al., 2008). Ingram et al. (2008) noted that high grazing intensity under mixed pasture results in soil C losses of approximately 30% in the 0 to 60 cm layer. They explained such behavior as a consequence of changes in plant morphological characteristics and biomass production and in surface soil organic matter accumulation, becoming more vulnerable to C losses. He et al. (2011) observed decreases in soil C and N stocks at 0 to 10 and 10 to 30 cm layers with an increase in sheep grazing intensity under temperate climate in northern China; however, adequate grazing management results in soil C and N stock increases.

Nicoloso et al. (2008) verified that Italian ryegrass (*Lolium multiflorum*) + black oat (*Avena sativa*) mixed pastures without fertilization and a 28-day grazing interval during winter with corn cropping during summer contribute to increases in residue production and, thus, in SOM accumulation in a Rhodic Paleudult soil in Rio Grande do Sul state, Brazil. On the other hand, after four years of ICL under high grazing frequency (14-day interval) and soybean (*Glycine max*) cropping during summer, soil C stocks decreased due to low residue addition.

Long-term ICL under no-tillage with different grazing intensities can affect nutrient dynamics, especially C and N, since grazing itself promotes modifications in biotic and abiotic conditions (Shariff et al., 1994). Animal residues, due to their labilities, influence soil nutrient concentration and microbial community (Mcnaughton, 1992; Chávez et al., 2011). Thus, the particulate soil organic matter fraction, regarded as the most suitable fraction for evaluating soil management impacts on soil quality, and, an important attribute related to soil C and N budgets (Conceição et al., 2005), must be approached. According to Franzluebbers and Stuedemann (2008), after three years of ICL under no-tillage conditions, C and N stocks and fractions were not affected by cattle grazing, resulting in total N stocks of approximately 3.88 and 4.14 Mg ha^{-1} for grazed and non-grazed areas, respectively, during winter.

The carbon management index (CMI) is a discerning tool for evaluating the impact of long-term management systems on the soil–plant–atmosphere equilibrium (Diekow et al., 2005). Evaluating a long-term ICL system, Souza et al. (2009) highlighted the importance of this tool on soil management quality by observing much lower value (65) for high grazing intensities in ICL in relation to no grazing (reference), indicating soil organic matter degradation.

Therefore, under ICL conditions, different soil C and N stocks, fractions, budgets and CMI values are expected, especially for the particulate fraction, which is more susceptible to soil management. The objective of this research was to determine soil C and N fractions, stocks, budgets and the CMI as affected by nine years of ICL with grazing intensities under no-tillage conditions.

2. Material and methods

2.1. Experimental site

The experimental area of approximately 22 ha was split into experimental plots ranging from 1.0 to 2.5 ha for treatments of different pasture sward heights of 10, 20, 30, and 40 cm (G10, G20, G30 and G40, respectively) and no-grazing (NG), representing grazing intensities, distributed in a randomized block design with three replicates. The grazing heights were controlled every 14 days by the sward stick method (Bircham, 1981) to control steer grazing. Continuous grazing was used and grazing cycles began when pasture reached 1500 kg ha^{-1} of dry matter (DM) production. Usually, the grazing cycles were from mid-July to mid-November. Steers of approximately 12 months of age were used. After grazing, the pasture was desiccated with glyphosate and soybean was sown and harvested in April–May of each year.

The experiment was established in May 2001 at Espinilho Farm (Agropecuária Cerro Coroado), located in São Miguel das Missões county in the Planalto Médio region of Rio Grande do Sul state (Brazil) (29°03′10″S latitude and 53°50′44″W longitude). The soil is a clayey Oxisol (Rhodic Hapludox—Soil Survey Staff, 1999). In the 0–20 cm layer, the amounts of clay (<0.002 mm), silt (between 0.002 and 0.02 mm) and sand (>0.02 mm) were 540, 270, and 190 g kg^{-1}, respectively. The amounts of dithionite-citrate-bicarbonate and ammonium oxalate-soluble iron were 110 and 5 g kg^{-1}, respectively (Silva Neto et al., 2008). According to these authors, kaolinite and hematite were the predominant minerals in the clay and iron oxide fractions, respectively. The climate is subtropical with a warm humid summer (Cfa), according to the Köeppen classification (Kottek et al., 2006).

Before the experiment, the area was cultivated under no-tillage for seven years with black oat during the winter and soybean during the summer. Cattle grazing in the area began in the autumn of 2000 with a black oat + Italian ryegrass mixed pasture followed by soybean cultivation. In autumn 2001, after soybean harvest, the experiment was established by seeding black oat + Italian ryegrass. After soybean harvest, the soil was sampled for physical and chemical characterization (Table 1). After grazing cycle, in the autumn of 2001, superficial broadcast liming was applied in the whole area at a rate of 4.5 Mg ha^{-1} with a total neutralization relative power (TNRP) of 62%, which is recommended to elevate the soil pH in water to 5.5 in the 0- to 10-cm layer, according to CQFS RS/SC (2004) for long-term no-tillage conditions.

2.2. Residue addition

To determine the amount of residues added to the soil in each grazing system, shoot material was sampled after each ICL cycle (soybean and pasture residual material), and shoot dry matter production was then calculated for the 10-year trial period. Pasture was sampled at the end of each grazing cycle before desiccation using an iron frame with an area of 0.25 cm^2. Root dry matter production was determined by Conte et al. (2007) and Souza et al. (2008) in the 0 to 10 cm soil layer using an auger with a diameter of 6.5 cm (2007 and 2006). The samples were dispersed in water and passed through a 1-mm sieve mesh for root-to-soil separation.

Manure dry matter production for each treatment was sampled in two-year periods at the end of August and October in 2009 and 2010. Ten manure pats were randomly sampled per parcel, and manure dry matter production was obtained using data gathered by Silva (2012), which monitored (GPS) manure distribution and accumulation during the grazing cycle.

Soybean shoot dry matter was sampled in 2009, 2010, and 2011 when plants achieved the full pod reproductive stage (R4). Soybean plants were sampled at 10 points per meter (linear) in each parcel. During flowering (R2), roots were evaluated to a 20-cm depth. Soil monoliths (0.2 × 0.2 × 0.2 m) were sampled in soybean rows and roots were washed and dried at 55 ± 5 °C until reaching constant weight. The same procedure was used for all dry matter estimations.

After drying, C additions via plant residues were calculated as a function of shoot dry matter added to the soil (pasture + soybean), considering an average C concentration of approximately 45% (Schlesinger, 1991) in soybean grains, soybean shoots, pasture shoots and manure. The average N content for pasture residue, soybean residue, pasture roots, soybean roots and soybean grain contribution were 19.3, 43.3, 10.0, 19.7, and 55.9 g kg^{-1}, respectively. For manure + urine N, the average manure N content was 24.7 g kg^{-1}. Urine N was a result of subtracting manure N and animal tissue N from the N intake (animal consumption was measured