Agriculture, Ecosystems and Environment 190 (2014) 60–69

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Special Issue: Crop–Livestock System

Soil carbon indices as affected by 10 years of integrated crop–livestock production with different pasture grazing intensities in Southern Brazil

Francine Damian da Silva[a,*], Telmo Jorge Carneiro Amado[b], Ademir Oliveira Ferreira[b], Joice Mari Assmann[c], Ibanor Anghinoni[d], Paulo Cesar de Faccio Carvalho[d]

[a] Department of Agricultural Engeneering, Federal University of Santa Maria, Campus Universitário, Centro de Ciências Rurais, Prédio 42, 3° piso, CEP 97105-900 Santa Maria, RS, Brazil
[b] Department of Soils, Federal University of Santa Maria, Campus Universitário, Centro de Ciências Rurais, Prédio 42, 3° piso, CEP 97105-900 Santa Maria, RS, Brazil
[c] Agronomic Institute of Parana, Rodovia BR 158, km 5.517 SR, Bom Retiro, CEP 85501-097 Pato Branco, PR, Brazil
[d] Faculty of Agronomy, Federal University of Rio Grande do Sul, Av. Bento Gonçalves 7712, CEP 91540-000 Porto Alegre, RS, Brazil

ARTICLE INFO

Article history:
Received 3 March 2013
Received in revised form 28 November 2013
Accepted 2 December 2013
Available online 21 December 2013

Keywords:
Carbon management index
Resilience index
Carbon balance
No-till
Oxisol.

ABSTRACT

Brazil has the world's second-largest cattle herd and second-largest no-till grain crop area. However, these activities are not frequently integrated because there is a widespread perception that cattle have a negative effect on cropping, especially when high crop yields are a goal. This misunderstanding of the synergy between pastures, livestock and crops is linked to overgrazing at the pasture rotation phase, which causes a decline in soil quality. Few studies have investigated the effect of pasture grazing intensities on soil carbon (C) balance and soil quality in subtropical environments. This work assessed the effects of different grazing intensities (0.10, 0.20, 0.30 and 0.40 m sward height) on soil C indices and animal productivity in a clay Haplorthox. The crop–livestock system model was a soybean/ryegrass plus black oat annual rotation managed for 10 years, using a randomized complete block design with three replications. Grazing intensity affected the quantity and composition of soil C input. Under heavy grazing with limited soil C input, there was a decrease in pasture and an increase in soybean participation in total C input. Soil organic C (0–0.20 m) under different grazing intensities had a linear relationship with C stratification ratio, C management index (CMI) and C pool index. Our results suggest that integrated crop–livestock systems could act as atmospheric C sources or sinks, depending on the grazing intensity. Pastures managed at 0.20 and 0.40 m height had the best balance between CMI and animal daily gain. The best balance between CMI and live weight gain per unit area occurred in sward height of 0.20 m.

1. Introduction

Total area of pastures in Brazil is approximately 172 million hectares (MAPA, 2013), of which 70% is currently estimated in some stage of pasture degradation. The majority of livestock production is carried out with free grazing and poor pasture management, making pasture degradation one of the biggest challenges of Brazilian livestock production, which reflects directly on the system's sustainability and ecosystem quality (Euclides et al., 2010). Among the main causes of pasture degradation are inadequate pasture management (Dubeux Jr. et al., 2007), high stocking rates and unbalanced nutrient replacement (Boddey et al., 2004). Consequently, weed infestation (Dubeux Jr. et al., 2007) and a progressive decline in soil quality (Marchão et al., 2009) was observed.

Total area of grain production in Brazil is approximately 52.2 million hectares (MAPA, 2013), with no-till systems representing approximately half of this area. One of the biggest challenges of no-till agriculture in tropical and subtropical environments is providing permanent soil cover and enough carbon (C) as crop residue input to account for climate conditions that promote fast crop residue decomposition and soil organic matter turnover (Amado et al., 2006; Bolinder et al., 2007; Sá et al., 2001).

The synergy between pasture, livestock and crops in an integrated crop–livestock system (ICLS) could meet these challenges

Abbreviations: C, carbon; CMI, carbon management index; CPI, carbon pool index; CSR, carbon stratification ratio; DG, daily gain; ICLS, integrated crop–livestock system; POC, particulate organic carbon; RI, resilience index; SOC, soil organic carbon; WG, live weight gain per unit area.

* Corresponding author. Tel.: +55 55 3320 8916.
E-mail addresses: frandamian@hotmail.com (F.D.d. Silva), telmo.amado@cnpq.br (T.J.C. Amado), aoferreira1@yahoo.com.br (A.O. Ferreira), joiceassmann@hotmail.com (J.M. Assmann), ibanghi@ufrgs.br (I. Anghinoni), paulocfc@ufrgs.br (P.C.d.F. Carvalho).

0167-8809/$ – see front matter
http://dx.doi.org/10.1016/j.agee.2013.12.005

Table 1
Soil physical and chemical characterization in different sward heights in 2011.

Sward heights (m)	Physical attributes (0–0.10 m)	Chemical attributes (0–0.20 m)						
	Soil bulk density ($Mg\,m^{-3}$)	pH	P [a]	K [a]	Ca [a]	Mg [a]	CEC [b]	V [c]
		H_2O	$mg\,kg^{-1}$	$mmol_c\,kg^{-1}$			$cmol_c\,kg^{-1}$	%
0.10	1.32	4.28	13.02	2.10	39.20	23.40	11.67	55.61
0.20	1.23	4.30	11.60	2.10	41.00	24.20	10.25	65.78
0.30	1.30	4.12	9.94	1.90	34.20	20.70	9.58	59.41
0.40	1.23	4.20	16.91	2.70	39.20	24.10	14.25	46.30
GF	1.08	4.03	7.22	2.20	49.50	27.00	11.50	68.44

[a] Extracted with Mehlich-I.
[b] Cation exchange capacity.
[c] Base saturation.

of animal and grain production. In this system, the pasture phase could provide permanent soil cover and crop residue input required for a no-till system. Grain crops could improve overall soil fertility, because of the need for mineral fertilizer and lime inputs, and therefore increasing pasture vigor. Livestock, by producing dung and urine, could increase soil biological activity and nutrient recycling (Dubeux Jr. et al., 2009). Integrated crop–livestock system have proven to be effective in improving soil quality, breaking the cycle of pests and diseases, decreasing weed infestation, improving cash flow by diversifying income (i.e., by producing income from meat and grain) and providing sustainability to the production system (Franzluebbers, 2007; Sulc and Tracy, 2007).

Large-scale adoption of ICLS in Southern Brazil has been limited by the misconception that livestock during the pasture phase will have a negative effect on grain yields of the crop phase, particularly under no-till, because of minimal soil disturbance. Pasture overgrazing drives a progressive decline in soil quality because limited soil C input causes a lack of mulch that could otherwise prevent soil erosion (Franzluebbers, 2013), reduce soil compaction caused by agricultural machinery traffic (Reichert et al., 2009), stimulate biological activity, compensate for the fast residue decomposition in tropical environments and prevent weed infestation with species that are difficult to control chemically, such as horseweed (*Conyza bonariensis L. Cronquist*). According to Oldeman et al. (1991), approximately half of the world's agricultural land has severe soil degradation, notably in tropical and subtropical environments. Overgrazing is among the main causes of soil degradation.

Long-term studies are essential tools for understanding the effects of soil management on soil organic C (SOC) stocks changes (Bayer et al., 2009). There are few medium and long-term studies that investigate the relationship between pasture grazing intensities and SOC stocks under no-till in tropical climates.

Soil C indices are efficient early indicators of whether a given production system is driving the ecosystem to lose soil quality (Bayer et al., 2009), even before the SOC stocks has changed. According to Islam and Weil (2000), some fractions of SOC are important indicators of soil quality. The carbon management index (CMI) is an indicator of the quality of soil management and allows for a comparison of different systems with regard to their effects on soil quality (Diekow et al., 2005). Generally, high CMI values are associated with high soil quality in grain cropping systems (Bayer et al., 2009; Blair et al., 1995). Recently, this index was used as an indicator of the effects of pasture grazing intensity on soil quality (Carvalho et al., 2010; Souza et al., 2009).

Carbon stratification ratio (CSR) is the ratio between SOC from two different soil layers, usually the topsoil and an adjacent soil layer less affected by farming operations (Franzluebbers, 2002; Franzluebbers et al., 2007). Greater CSRs are related to soil management practices that enhance soil quality (Ferreira et al., 2013; Franzluebbers, 2002).

Research on soil C balance and soil quality in ICLS in tropical and subtropical climates is still scarce. This work assessed the effects of different grazing intensities (0.10, 0.20, 0.30 and 0.40 m sward height) on soil C indices and animal productivity in a clay Haplorthox. The study was conducted over a time span of 10 years using ICLS under no-till in subtropical Southern Brazil.

2. Materials and methods

2.1. Experimental field

The experiment was established in May of 2001 at the Espinilho farm, located in São Miguel das Missões, a county with a tradition of livestock production and recent expansion into grain crop production. The geomorphological unit corresponds to the Planalto Medio region in Rio Grande do Sul State (Southern Brazil; 28° 56′S and 54° 20′W, at an altitude of 425 m above the mean sea level). Soil is classified as Rhodic Haplorthox (Oxisol), deep, well drained, with a clayey surface texture of basaltic rock (540, 270 and 190 $g\,kg^{-1}$ of clay, silt and sand, respectively, in the 0–0.20 m soil layer). Soil physical and chemical characteristics are presented in Table 1. Climate is classified as Cfa (humid subtropical) according to the Köppen system of climate classification, with a mean annual rainfall of 1850 mm and an average temperature of 19 °C. Original vegetation was composed of gallery forest (GF) and natural pastures formed by grasses, predominantly *Paspalum notatum* Fluegge.

An integrated system of crops and livestock was adopted in 2001, with soybean (*Glycine max* (L.) Merrill) as the grain cash crop during summer and mixtures of black oat (*Avena strigosa* Schreb) and Italian ryegrass (*Lolium multiflorum* Lam.) grown during winter for grazing pasture. An experimental area of approximately 22 ha was divided into 12 plots ranging from 0.9 to 3.2 ha; four pasture grazing intensities were applied by managing pasture heights at 0.10, 0.20, 0.30 and 0.40 m, distributed in a randomized complete block design with three replications. The pasture heights were monitored every 15 days by the sward stick method (Barthram, 1986). Continuous put-and-take animal stocking was used to maintain desired pasture heights, as proposed by Mott and Lucas (1952).

Crossbred beef steers, approximately 10 months old and weighing approximately 199 kg, were used. The average stocking rates were approximately 6.7, 4.7, 3.1 and 1.7 steers ha^{-1} for pasture grazing heights of 0.10, 0.20, 0.30 and 0.40 m, respectively (Fig. 1). Grazing began in the first half of July and ended in the first half of November, with animal entrance occurring when the pasture reached an average dry matter accumulation of approximately 1,800 $kg\,ha^{-1}$. Animal daily gain (kg) was obtained by the difference between the initial and the final individual live weight of the tester animals during grazing duration. Live weight gain per unit area was obtained by multiplying the daily gain by the number of animals per hectare and per day. After 45 days from pasture seeding (May), urea top dressing of 45 $kg\,N\,ha^{-1}$ was applied. Detailed