Soil & Tillage Research 165 (2017) 128–136

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Increased cropping intensity improves crop residue inputs to the soil and aggregate-associated soil organic carbon stocks

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ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form 10 August 2016
Accepted 11 August 2016
Available online xxx

Keywords:
Mollisol
Vertisol
Cropping rotations
Soil aggregations
SOC stocks
Croplands

ABSTRACT

Many South American agroecosystems are based mainly on soybean [*Glycine max* (L.) Merr.] as a sole crop in the year, which has increased concerns regarding soil conservation and ecosystems sustainability. The increase in cropping intensity (CI) has been suggested as a strategy to improve crop residue inputs, which in turn, may increase soil aggregation and soil organic C (SOC) storage, while maintaining or even increasing total sequence yields. Our objective was to evaluate the relationships between CI and crop residue input with SOC storage and soil aggregation in two contrasting northeastern Argentinean Pampas soils under no-till. Two parallel experiments were established in a Mollisol and a Vertisol evaluating six cropping sequences, starting from soybean monoculture and increasing the number of crops per year and crop diversity. Crop residue inputs to the soil (aboveground biomass, belowground biomass and total biomass), grain yield, the amount of macroaggregates (MA), SOC stored inside macroagregates (SOC_{MA}) and total SOC stocks were measured in both soils two years after the beginning of cropping sequences, at three soil depths. Soil organic C stocks, MA and SOC_{MA} were all positively related with CI in both soils at 0–5 cm depth. All soil variables were lowest in simple rotations (soybean monoculture) and increased in more complex rotations (double cropping with cereals and legumes), although differences were significant ($P < 0.05$) only in the top soil (0–5 cm depth). Grain yields and crop residues followed a similar pattern being higher in rotations that included maize (with yields expressed as grain mass or as glucose equivalent mass) and lower in soybean monocultures. The highest protein yields were obtained in sequences with wheat and soybean double cropping. Increases in CI under no-till seem to be a useful strategy to improved residue inputs, soil aggregates and SOC stocks. Our results provide valuable evidence for stakeholders and policy-makers to improve SOC sequestration and soil health in agroecosystems of humid temperate croplands.

1. Introduction

Soil organic carbon (SOC) losses have been associated with intensive tillage, crop monocultures and long fallow periods in the crop sequences (Franzluebbers et al., 1994; Studdert and Echeverría, 2000; Sherrod et al., 2003; Novelli et al., 2011). The lack of crop rotations, even under no-till, could lead to both SOC and productivity losses if C inputs to the soil from addition of crop residues are lower than C outputs by decomposition or erosion (Pittelkow et al., 2015). These losses may be exacerbated if agriculture is conducted on lands with low productivity and high proneness to soil degradation, a frequent situation in many agroecosystems of South America (Calviño and Monzón, 2009; Paruelo et al., 2006; Nosetto et al., 2012; Wingeyer et al., 2015).

Increased concerns regarding soil conservation and ecosystems sustainability favored a rapid adoption of no-till in southern Brazil and Argentina. The success of no-till in this region became an important reference for its widespread adoption throughout South America. Currently, NT is being used on 70%–90% of the grain crop area in Paraguay, Brazil, Argentina, Bolivia, and Uruguay (Wingeyer et al., 2015). However, despite of the extended use of no-till in this region, there is a lack of defined rotation. In fact, soybean is currently cultivated under no-till as a sole crop in the year in 67% of South American croplands (Wingeyer et al., 2015).

Compared with cereals, soybean returns less crop residue with a low C:N ratios to the soil (Wright and Hons, 2004). It has been

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http://dx.doi.org/10.1016/j.still.2016.08.008

shown that fast decomposition of soybean residues increases susceptibility to erosion under fallow periods and the rate of SOC loses, particularly in soils with a high soybean cropping frequency (Novelli et al., 2011).

Increasing cropping intensity (CI) is a reliable alternative to restore diversity to currently simplified crop sequences and to potentially reduce agricultural pressure on natural lands (Doré et al., 2011). Cropping intensity may be defined as the length of the period with actively growing (green) crops in a sequence, on a yearly-basis (Boserup, 1965; Caviglia and Andrade, 2010). High CI maintains continuous crop roots and soil biota activity (Acosta-Martínez et al., 2007), enhances the amount and frequency of residue inputs (Franzluebbers et al., 1994; Caviglia et al., 2011), and reduces raindrop impacts on the soil by providing continuous protection via crop canopies or crop residues (Wischmeier and Smith, 1978; Shaver et al., 2003).

In several environments, increased CI has been useful to increase SOC storage (Wood et al., 1990, 1991; Franzluebbers et al., 1994; Peterson et al., 1998; Bowman et al., 1999; Sherrod et al., 2003; Álvaro-Fuentes et al., 2009; Luo et al., 2010) and improve other soil physical properties such as water infiltration and retention, bulk density, and the formation and stabilization of soil aggregates (Shaver et al., 2003; Álvaro-Fuentes et al., 2008). Stable soil aggregates are critical for sustainable agroecosystems, due to their influence on several soil biological and physical processes such as root growth and water and air movement that, in turn, directly affect crop productivity (Kasper et al., 2009). Furthermore, soil aggregation is an important process for SOC preservation and storage, because binding of soil particles and organic matter imposes a physical barrier between decomposers and SOC (Chung et al., 2009).

To date, the effects of decreasing the time in fallow by increasing CI on soil productivity, soil aggregation and SOC storage have been explored more intensively in semiarid regions than in humid temperate regions (Farahani et al., 1998; Bowman et al., 1999; Sherrod et al., 2003; Shaver et al., 2003; Blanco-Canqui et al., 2010; Mikha et al., 2010). In humid temperate regions with a long growing season, as the northeastern Argentinean Pampas, fallow periods may be sensibly shortened by including two crops in a year (double cropping), adding a winter crop or a cover crop to traditional summer crops. These intensification alternatives may increase grain yields and residue inputs per unit area and year (Caviglia et al., 2011, 2013; Monzón et al., 2014). However, knowledge on how the relationship between crop residue input and SOC storage are affected by CI in this region is still lacking, particularly under different soil types. In fact, the typical northeastern Argentinean Pampas soils (Mollisols and Vertisols), have shown different responses between SOC and aggregate stabilization (Novelli et al., 2013), suggesting that CI effects may be different in these two soils type.

Our objective was to evaluate the relationships between CI and crop residue input with SOC storage and soil aggregation in two contrasting northeastern Argentinean Pampas soils under no-till. We hypothesized that, increased CI: i) improves residue input, which would in turn increase soil aggregation and SOC stocks, maintaining or even increasing total crop yields and; ii) affects SOC storage in a Mollisol more than in a Vertisol due to the differences in the amount of crop residues returned to the soil and the mechanisms involved in SOC protection and stabilization.

2. Materials and methods

2.1. Study sites and cropping sequences

Two identical field experiments under no-till, spaced 2 km apart, were conducted from May 2008 to June 2010 in sites with contrasting soils (Mollisol and Vertisol) at the Paraná Experimental Station of National Agricultural Technology Institute (INTA) (31°50.9′ S, 60°32.3′ W), Entre Ríos province (northeastern Pampas of Argentina). The Mollisol was classified as a fine, mixed, thermic Aquic Argiudoll (Soil Survey Staff, 2010) of the Tezanos Pinto Series, with 45 g sand, 679 g silt and 276 g clay kg^{-1} in the Ap horizon (0–17 cm depth) (Plan Mapa de Suelos, 1998). The Vertisol was classified as fine, smectitic, thermic Typic Hapluderts (Soil Survey Staff, 2010) of the Febre Series, with 56 g sand, 542 g silt and 402 g clay kg^{-1} in the Ap horizon (0–18 cm depth) (Plan Mapa de Suelos, 1998). Both experimental sites were cropped with maize before the beginning of the experiments and had been under no-till management for at least 15 yr in a fixed rotation wheat/soybean double crop-maize (three crops in two years). Initial soil analysis (0–20 cm depth) at the beginning of the experiments (May 2008) were for the Mollisol pH = 6.2, P-bray = 20.8 mg kg^{-1}, total SOC = 2.1% and total N = 0.18% and for the Vertisol pH = 7.7, P-bray = 5.8 mg kg^{-1}, total SOC = 2.7% and total N = 0.19%. Details on monthly rainfall, mean air temperature and potential evapotranspiration (Penman-Monteith method, Allen et al., 2006), are provided in Table 1.

Table 1
Monthly rainfall (R), mean air temperature (T) and potential evapotranspiration (PET) recorded at Paraná, Argentina (31°51′ S; 60°32′ W) from 2008 to 2010.

	2008			2009			2010		
	R mm	T °C	PET mm	R mm	T °C	PET mm	R mm	T °C	PET mm
January	97	25	173	35	25	178	222	25	160
February	95	25	132	155	24	134	355	25	111
March	43	22	121	298	24	129	189	24	122
April	58	19	88	85	21	99	68	18	83
May	73	17	60	34	18	73	79	15	53
June	5	11	37	7	12	53	3	12	44
July	15	16	50	46	11	58	17	11	59
August	0	14	81	3	16	105	4	12	70
September	33	16	108	101	14	84	72	15	90
October	94	19	134	74	19	148	58	17	127
November	106	23	162	92	23	135	28	21	154
December	25	25	183	254	23	135	62	25	189

Six two-year cropping sequences which varied in CI were evaluated (Fig. 1). They were: i) soybean monoculture (S-S), ii) soybean with a previous wheat cover crop (CC) (CC/S-CC/S), iii) wheat/soybean sequential double crop, i.e. two crops in the same year (W/S-W/S), iv) two sole crop rotation with soybean followed by maize (S-M), v) soybean with maize rotation including a previous wheat CC before soybean (CC/S-M) and vi) three-crop wheat/soybean-maize (W/S-M) rotation. Treatments were established in a randomized complete block design with four replicates. Plots were 5 m wide and 30 m long. Both experimental sites had similar slopes (5.2%) and terraces for erosion control. Our work is focused on the initial effects (two year after the beginning of the experiment) of CI on total sequence yield, crop residue input, SOC stocks and soil aggregation. This is a critical period that strongly influences farmer's adoption of management strategies, such as crop rotation or the use of cover crops. However, the adoption of a new management strategy for the farmers is often more based on crop yield than on soil variables. Therefore, the improvement in soil health indices by the adoption of sequences with a higher CI should be reached maintaining or even increasing total crop yields.

The proportion of the year with actively growing (green) crops in the sequence, *i.e.* the ratio between the number of weeks with green-crop cover and the total length of the crop sequence, was used to calculate CI (Franzluebbers et al., 1994; Novelli et al., 2013). Considering a total of length of the crop sequence of 104 weeks in two years, we consider a period actively growing crops of 45 weeks