Soil & Tillage Research 161 (2016) 95–105

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Winter cover crops in soybean monoculture: Effects on soil organic carbon and its fractions

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ARTICLE INFO

Article history:
Received 10 November 2015
Received in revised form 22 March 2016
Accepted 6 April 2016

Keywords:
Wheat
Labile fractions
No-tillage

ABSTRACT

The current agricultural production systems in the Pampas Region have been significantly simplified by cultivating large land areas under no tillage (NT), where soybean is the predominant crop. These systems with long periods of fall-winter fallow and poor annual input of carbon (C) into the soil lead to soil degradation, thereby affecting physical and chemical properties. A 6-year cover crop study was carried out on a Typic Argiudoll under NT in the south of Santa Fe, Argentina. Various winter species were used as cover crops: wheat (W), oat (O), vetch (V), an oat + vetch mixture (O + V) and a control (Ct) treatment without a cover crop. We examined the influence of cover crops on the following soil organic C-fractions: coarse particulate organic carbon (POC_c), fine particulate organic carbon (POC_f) and mineral-associated organic carbon (MOC) from 2008 to 2011. Aboveground carbon input by the cover crops was related to the June to October rainfalls. In general, the W and O treatments supplied a higher amount of C to the soil; these gramineous species produced 22 and 86% more biomass than O + V and V. The water cost of including cover crops ranged from 13 to 93 mm compared with Ct. However, this water-use did not affect soybean yields. On average, gramineous species (pure stand or mixture) supplied more than 3.0 Mg C ha^{-1} $year^{-1}$ to the soil, whereas V supplied less than 2.0 Mg C ha^{-1} $year^{-1}$. Increase in the mean annual C-input by residues into the soil (cover crop + soybean) explained most SOC variation ($R^2 = 0.61$; $p < 0.05$). This relationship was more evident with labile soil organic fractions, both for POC_c ($R^2 = 0.91$; $p < 0.001$) and $POC_c + POC_f$ ($R^2 = 0.81$; $p < 0.001$). The stratification ratios of SOC (SI, 0–5: 10–20 cm) reflected differences among treatments, where >2.0 for W; 1.7 for O, O + V and V, and <1.5 for Ct. Soil physical fractionation by particle size showed that cover crops affected the most dynamic fraction directly associated with residue input (POC_c) at 0–5 and 5–10 cm. At 0–5 cm, the effects were observed in the most transformed fractions (MOC and POC_f) 4 years after the experiment started, whereas at 0–20 cm, differences in the labile fractions (POC_c and POC_f) were found at the end of the experiment (6 years). Although C-input by the cover crops fueled decomposition of labile soil organic fractions, concentration of surface SOC and its associated fractions (POC_c, POC_f and MOC) was modified after 6 years. This effect became noticeable during the third year when the plots under cover crops showed a higher SI than the traditional fallow.

1. Introduction

Growing concerns on global warming has spurred interest on the need to enhance atmospheric sequestration of greenhouse gases such as carbon dioxide (CO_2) on terrestrial ecosystems (Dolman et al., 2003). Some forms of CO_2 sequestration include the use of agricultural practices such as conservation tillage, cover crops, crop rotation and fertilization (Sainju et al., 2003).

Production systems involving large summer crop areas –mainly soybean (*Glycine max* L. Merr.)– under no tillage (NT) have experienced unfavorable changes in the Pampas Region over the last 15 years. These agricultural systems typically include long periods of fall-winter fallow with low annual carbon (C) input into the soil (2–3 Mg C ha^{-1} $year^{-1}$) (Restovich et al., 2005), thereby promoting microbial activity and decomposition of soil organic

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http://dx.doi.org/10.1016/j.still.2016.04.006

matter (SOM) (Huggins et al., 2007). These effects deteriorate the physical and chemical fertility of soil (Andriulo and Cordone, 1998; Lavado, 2006). Considering the strong prevalence of soybean as the main crop in these production systems, absence of a soil cover is becoming a limiting factor. Sustainability of agricultural systems can be achieved by enhancing the C-balance through from higher plant biomass production. In this sense, cover crops are an agricultural tool that can supply significant amounts of C-rich residues to the soil, thus modifying the quantity and quality of SOM (Franzluebbers, 2005; Restovich et al., 2011) and improving soil productivity (Sainju et al., 2003). In the Pampas Region, cover crops have been recommended for agricultural systems such as soybean monoculture, where crop residue production me be insufficient for proper soil cover and protection (Novelli et al., 2011). Furthermore, Muller et al. (2008) found that soybean in Vertisolls favored soil loss by erosion, whereas inclusion of cover crops reduced it. Ding et al. (2006) demonstrated that cover crops increased SOM content, especially labile fractions. In soybean monoculture, inclusion of triticale helped to maintain SOM levels, which proved to be higher than the uncovered treatment (Álvarez et al., 2006). Several winter gramineous species such as, rye (*Secale cereale* L.), at (*Avena sativa* L.), barley (*Hordeum vulgare* L.), triticale *Triticosecale* Wittmack and ryegrass (*Lolium multiflorum* Lam.) are used as cover crops to maintain or improve soil organic carbon (SOC) levels (Álvarez et al., 2006). Even though changes in SOC rarely occur in the short term (3–4 years), the fractions most likely to be affected are the labile soil organic fractions associated to crop residues in early stages of decomposition and to coarser structural fractions of soil (coarse particulate organic carbon, POC_c) (Christensen, 2001). The POC is the most active SOC fraction and it is used as a soil quality indicator in the short term because it is sensitive to management-induced changes (Rovira et al., 2010; Duval et al., 2013). Also, these labile fractions have proven to be reliable indicators of changes in crop sequences (Salvo et al., 2010) and may show early soil changes resulting from the inclusion of cover crops.

The content of SOC is determined by the relationship between C-input into the soil (k_1 A) and C-losses (k_2 SOC); the temporal variation ($\delta C/\delta t$) is represented by the equation $\delta C/\delta t = -k_2 SOC + k_1 A$, where A is the annual C-input into the soil (residues + roots) (Mg ha^{-1} $year^{-1}$), SOC is the stock of total organic carbon in soil (Mg ha^{-1}), k_1 and k_2 represented the conversion rates of C added in SOC and the rate of decomposition of SOC, respectively. Therefore, long-term fallow cropping systems (soybean monoculture) reduce carbon input (A), whereas cover crops increase it significantly.

The role of cover crops in summer crop yields of the Pampas Region has been studied by many researchers (Restovich et al., 2012; Capurro et al., 2013; Vanzolini et al., 2013). However, little is known about their impact on soil properties, especially on SOC and its labile organic fractions (Salvagiotti et al., 2013; Scianca et al., 2013).

Taking into account that soils under soybean monoculture supply N-rich organic materials, we hypothesize that C-input by cover crops under soybean monoculture will be rapidly degraded, thus affecting labile soil organic fractions in the long term.

The aim of this study was (i) to evaluate the effect of winter cover crop species on the balance and dynamics of soil organic carbon and its fractions, and (ii) to determine the impact of the quantity and quality of cover crop dry matter on soybean crop yields.

2. Materials and methods

2.1. Study site

The field research was carried out in a 30-ha area with 6 years of soybean monoculture and more than 40 years of continuous agriculture. The site is located in the province of Santa Fe, Argentina (32°57′21″ S, 61°18′18″ W). The area is characterized by monsoon rainfall, 70% occurring mainly from October to March. The mean annual precipitation is 1019 mm and the average temperature is 17.5 °C (1957–2005).

At the beginning of the experiment, the soil had been under NT for the last 10 years. Crop rotation basically consisted of soybean monoculture (*Glycine max* L. Merr.), which remained under chemical fallow in fall and winter. Classified as a Typic Argiudoll (Soil Survey Staff, 2010), the soil is deep, well-drained, with a silt loam texture in the surface horizons (Horizons A). Table 1 shows the main characteristics of the study site.

2.2. Experimental design and treatments

A soybean monoculture with different winter cover crops was started in June 2006. The cover crops used for the experiment were wheat (W) (*Triticum aestivum* L.), oat (O) (*Avena sativa* L.), vetch (V) (*Vicia sativa* L.), an oat + vetch mixture (O + V) and a control treatment (Ct) (without a cover crop) that was kept weed-free with herbicide applications.

The experiment was established on 500 m^2 (50 m × 10 m) plots in a randomized block design with five treatments and three replications. A soil with its natural vegetation was also evaluated (Ref). With a history of over 50 years without anthropogenic intervention, this soil was covered with gramineous plants, notably Stipa genus, bermudagrass (*Cynodon dactylon* L.) and johnsongrass (*Sorghum halepense* L.). The Ref is located about 250 m from the trial and provides a point of reference for the impact of crop production on soil properties. Therefore, this soil was used as an equilibrium reference among the organic fractions at different depths.

Table 1
Soil physical and chemical characteristics at the start of trial (2006).

Horizons	Thickness cm	Sand g kg^{-1}	Silt	Clay	Texture	BD Mg m^{-3}	FC mm	PWP	PAW	SOC g kg^{-1}
A	25	102	699	199	Silt loam	1.33	96	51	45	16.6
B22	25	–	–	–	–	1.38	106	67	39	–
B23	20	–	–	–	–	1.35	82	51	32	–
B3	25	–	–	–	–	1.33	89	50	39	–
C1	30	–	–	–	–	1.26	92	52	40	–
C2	35	–	–	–	–	1.26	107	60	47	–
Ck	40	–	–	–	–	1.25	122	69	53	–
	200					1.31	695	400	295	

BD: bulk density; FC: field capacity; PWP: permanent wilting point; PAW: plant-available water; SOC: total organic carbon.