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Carbon and nitrogen sequestration in soils under different management in the semi-arid Pampa (Argentina)

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ABSTRACT

Soil management affects distribution and the stocks of soil organic carbon and total nitrogen. The aim of this study was to evaluate the effect of different crop sequences and tillage systems on the vertical distribution and stocks of soil carbon and nitrogen. We hypothesized that no-tillage promotes surface organic carbon and total nitrogen accumulation, but does not affect the C and N stocks, when compared with reduced tillage. In addition, the incorporation of maize in the crop sequence increases total organic carbon and total nitrogen stocks. Observations were carried out in 2010 in an experiment located in the semiarid Argentine Pampa, on an Entic Haplustoll. A combination of three tillage systems (no tillage, no tillage with cover crop in winter and reduced tillage) and two crop sequences (soybean–maize and soybean monoculture) were assessed. After 15 years of management treatments, soil samples to a depth of 100 cm at seven intervals, were taken and analyzed for bulk density, organic carbon and total nitrogen. Total organic carbon stock up to a depth of 100 cm showed significant differences between soils under different tillage systems (reduced tillage < no tillage = no tillage with cover crop), the last ones having 8% more than the reduced tillage treatment. Soybean–maize had 3% more organic C up to 100 cm depth than the soybean monoculture. Total nitrogen stock was higher under no-till treatments than under reduced tillage, both at 0–50 and 0–100 cm depths. Total organic carbon stratification ratios (0–5 cm/5–10 cm) were around 1.6 under no-till and lower under reduced tillage. The stratification ratio explains less than 40% of soil carbon stock. Tillage system had a greater impact on soil carbon stock than crop sequence.

1. Introduction

Soil organic matter (SOM), a component associated to agroecosystem productivity (Bauer and Black, 1994), normally decreases through cropping, often due to the decrease in the supply of crop residues and acceleration of mineralization (Richter et al., 1990). This decline is directly associated with an increase in carbon dioxide (CO_2) production, one of the main greenhouse gases (Urquiaga et al., 2004).

Several studies have highlighted the environmental importance of soil C sequestration and its impact on climate change (Lal, 2004; Jantalia, 2005) by reducing gas emissions, especially CO_2. Soil has an important role in the production of CO_2 and other greenhouse gases.

In some regions, total organic carbon (TOC) has been lost through conversion of natural forests to agricultural production, with soil C content stabilizing at 40–60% of the original values. The value of a new equilibrium will depend upon several factors such as climate, physical and chemical soil characteristics and crop management (tillage system, crop sequence, vegetation cover and waste management) (Robertson and Paul, 2000). The Argentine Rolling Pampa has lost around one third of topsoil C content due to the agriculturization process (Alvarez, 2005). López-Bellido et al. (2010) found in a wide region of the United States that only under certain agricultural practices, soil organic carbon (SOC) has been maintained after 38 years from the start of the experiment.

According to some authors, no-tillage (NT) promotes accumulation of TOC and total nitrogen (TN) when compared with other tillage systems (Díaz Zorita, 1999; Sisti et al., 2004; Steinbach and Alvarez, 2006; Du et al., 2010), while others obtained different

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results (Alvarez et al., 1998; Costantini et al., 2006). These seemingly contradictory findings may be due to differences in experimental conditions: soil and climate conditions, historical soil management, SOM stratification, sampling depths and C and N determined in relation to soil volume instead of soil mass.

Sisti et al. (2004) found that NT as an only practice does not improve TOC and TN soil content and suggest that to increase soil TOC contents grass pastures should be included in the cropping sequence. Their elimination from the crop sequence is another factor which has negatively influenced soil C content (Andriulo et al., 2008), due to the lower C contribution of legumes compared with grasses (Alvarez and Steinbach, 2012). Cover crops (cc) can be an important tool for managing C and N dynamics in current agricultural systems (Wagger et al., 1998). Reicosky and Archer (2005) found that a desirable characteristic of including cc in the cropping sequence was N retention by avoiding potentially leachable nitrate losses. The combination of NT (no soil removal) and presence of surface crop residues under conservation practices result in accumulation of SOM in the topsoil or its stratification (Díaz Zorita and Grove, 2002). Franzluebbers (2002) proposed the use of the degree of stratification ratio of TOC as an indicator of soil quality (TOC concentration 0–5 cm/5–10 cm or 0–5 cm/10–20 cm depth), as topsoil SOM is essential for erosion control, infiltration and water conservation.

Tillage systems and machinery traffic cause changes in topsoil bulk density compared with areas of native vegetation. This determines that when calculating soil mass under both those situations, higher soil mass values can be found at a given depth, in a cropping area, due to compaction (Jantalia, 2005; Alvarez et al., 2009). Ignoring this fact when quantifying C and N stocks, can lead to misinterpretation of results (Ellert and Bettany, 1995; Neill et al., 1997). According to Du et al. (2010) it is important to increase sampling depth, to allow assessment of C input changes with depth due to different root distribution patterns, consequence of tillage practice and/or crop sequence. Sampling depths > 30 cm should be considered to be able to detect effects of conservation tillage on soil TOC and TN.

The aim of this study was to evaluate the effect of different tillage systems and crop sequences on the distribution and stock of TOC and TN. We hypothesized that NT promotes surface TOC and TN accumulation, but does not affect the C and N stocks, when compared with reduced tillage. In addition, the incorporation of maize in the crop sequence increases TOC and TN stocks when compared with soybean monoculture.

2. Materials and methods

2.1. Experimental site

Measurements were carried out within the framework of a long-term experiment that started in 1995, in the INTA Manfredi Experimental Station, Córdoba, Argentina (31.5° S, 63.5° W, 292 m asl), in the semiarid Pampa. The soil is a deep, well drained, developed on silty-loam materials Entic Haplustoll (Haplic Chernozem), with an available water storage capacity of 307 mm up to 200 cm depth (Jarsun et al., 1987). Particle soil analysis of surface horizon is: clay 167 g kg^{-1}, silt 687 g kg^{-1} and sand 146 g kg^{-1} (Jarsun et al., 1987). Average rainfall in the region is 757 mm yr^{-1}, with 80% occurring during spring and summer. Average annual temperature is 16.6 °C, with an average of 9.5 °C in the coldest month and 23.4 °C in the hottest (Jarsun et al., 1987).

A 110 m × 35 m bifactorial experiment was designed. One factor was the tillage system, with the following levels: no-tillage with chemical fallow (NT), no-tillage with a triticale (*Triticosecale*) cover crop (NTcc) and reduced tillage (RT) with a disk harrow as the main tillage practice. Cropping sequence was the other factor with two levels: soybean (*Glycine max* (L)) monoculture (sy-sy) and soybean–corn (*Zea mays*) rotation (sy-mz). The combination of the different levels resulted in 6 treatments: sy-sy RT ($n = 3$), sy-mz RT ($n = 4$), sy-sy NT ($n = 3$), sy-mz NT ($n = 4$), sy-sy NTcc ($n = 3$) and sy-mz NTcc ($n = 4$).

The RT treatment included a disk harrow tillage at the end of winter and soil refinement with a vibro-cultivator before crop sowing. In the NT treatment weeds were herbicide-controlled during fallow. The cover crop (triticale) was sown after soybean to generate more surface residue cover: every year in the soybean–soybean sequence (sy-sy NTcc), and every other year (sowing the cc after soybean and a chemical fallow after the corn crop) in the soybean–maize sequence (sy-mz NTcc). The cc was killed with herbicide at the stem elongation phenological stage.

2.2. Sampling and analytical determinations

2.2.1. Total organic carbon and total nitrogen

Fifteen years after the experiment had started, two composite samples per replication were taken. Each sample consisted of 15 sub-samples, taken at 0–5, 5–10, 10–20, 20–30, 30–50, 50–70, 70–100 cm depths. TOC and TN determinations were performed with a complete-combustion auto-analyzer (LECO Corporation, St. MI, USA). Prior to the analysis, carbonate presence/absence was determined qualitatively with hydrochloric acid in each sample. When the reaction was positive, decarbonation with sulfurous acid was carried out, following Skjemstad and Baldock (2008).

2.2.2. Bulk density

Bulk density was determined by the core method (Burke et al., 1986). The core was 5 cm high and 100 cm^3 volume. Within each experimental unit two samples were taken at the following depths: 0–5, 5–10, 10–20, 20–30 cm. At deeper layers (30–50, 50–70, 70–100 cm) quintuplicate samples were taken only in two treatments because when clay content does not increase significantly greatly in depth (approximately 100 g kg^{-1}), management effect is considered minimal (Diekow et al., 2005).

2.2.3. Unit mass correction

To compare soil TOC and TN stocks (kg ha^{-1}) a correction was made to bring soil profiles to mass-equivalent up to the depth that was being evaluated (Neill et al., 1997), that can be expressed mathematically (Sisti et al., 2004, Eq. (1)).

$$C_s = \sum_{i=1}^{n-1} C_{Ti} + \left[M_{Tn} - \left(\sum_{i=1}^{n} M_{Ti} - \sum_{i=1}^{n} M_{Si} \right) \right] C_{Tn} \quad (1)$$

where C_s is total soil carbon stock (Mg ha^{-1}) to a depth where soil mass is the same as in the reference profile. $\sum_{i=1}^{n-1} C_{Ti}$ is the summed total carbon content (Mg ha^{-1}) from layer 1 (surface) to layer "$n-1$" (penultimate) of the treatment profile, "M_{Tn}" is the soil mass in the deepest layer in the treatment profile, $\sum_{i=1}^{n} M_{Ti}$ is the summed soil mass (Mg ha^{-1}) from layers 1 (surface) to "n" (deepest layer) in the soil profile of a given treatment, $\sum_{i=1}^{n} M_{Si}$ is the summed soil mass (Mg ha^{-1}) from layers 1 (surface) to "n" (deepest layer) of the reference soil profile, "C_{Tn}" is the carbon content (Mg Mg^{-1} soil) of the soil profile in the deepest layer of a given treatment.

2.2.4. Stratification ratios

The stratification ratios (S-ratio) were calculated as the ratio between TOC concentration (g kg^{-1}) at 0–5 cm and at 5–10 or 10–20 cm depth (Franzluebbers, 2002).