CHANGES IN SOIL CARBON STORAGE IN LONG-TERM ROTATION AND TILLAGE TRIALS IN CENTRAL SPAIN

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1. Abstract

The long-term quantitation of soil organic carbon (SOC) in relation to different types of soil and climate and under various soil management options, is of great importance in identifying the pathways of C sequestration in soils. This research presents results of SOC storage in a Calcic Haploxeralf located in the semi-arid central Spain, after 19 years of a series of continuous tillage and rotation combinations. The split-plot design included two tillage treatments: conventional tillage (CT) and no-tillage (NT). The crop rotations include (1) barley (*Hordeum vulgare* L. cv. "Aramir") and vetch (*Vicia sativa* L.) (B─V), (2) barley and sunflower (*Helianthus annus* L.) (B─S) and (3) barley monoculture (B). With regard to tillage systems, the values for the total SOC storage in the 0-30 cm soil layer showed that the amount of SOC in the NT plots was 2.3 Mg ha^{-1} greater than that in CT plots. Differences between rotation treatments showed that B resulted in less SOC storage (2.9 Mg ha^{-1}) than did the other two rotations (4.8 Mg ha^{-1} and 4.4 Mg ha^{-1} for B─V and B─S respectively). There were significant tillage-rotation interactions: after 19 years, the lowest values of SOC were observed in CT / B plots (2.5 Mg ha^{-1}). The application of NT in combination with sunflower or vetch increased SOC to 4.8 and 5.4 Mg ha^{-1} respectively. Comparing the CT / B with the CT / B─V treatment, the C storage increased from 2.5 to 2.9 Mg ha^{-1}. This represents an increase of 0.4 Mg ha^{-1} in 19 years *i.e.,* a SOC sequestration rate of 21 kg C ha^{-1} yr^{-1} strictly due to a rotation effect. The overall gain in SOC stored in NT / B─V treatment as compared to the CT / B─V combination was 2.6 Mg ha^{-1} (137 kg ha^{-1} yr^{-1}). The obtained results confirm that agricultural practices, such as tillage intensity and rotation, may counteract the declining in C sequestration in semiarid soils, alleviating the trend towards increasing CO_2 concentrations in the atmosphere. When continuously practiced, NT results in higher SOC storage than when CT is applied; it can be considered as an effective technology for removing C from the atmosphere and sequestering it into the soil.

2. Introduction

The pool of SOC plays a key role in the global C cycle and has a large impact on the greenhouse effect (Lal *et al.,* 1995; Mosier, 1998; Rosenzweig and Hillel, 2000). The levels of SOC can be managed to increase the terrestrial C pool and provide a sink for atmospheric CO_2 (Halvorson *et al.* 2005; Al-Kaisi and Grote, 2007). The potential of different ecoregions of the world to sequester C is climatic dependent, being high in temperate regions where crop growth conditions are favourable. Due to the droughts, arid and semiarid regions have lower capacity to sequester C per unit area basis, but due to the large extent of such areas the total capacity may be important. Cropping practices relevant to C sequestration include tillage methods and crop rotations.

Soil tillage practices are of particular significance to the soil C status because they affect C dynamics directly and indirectly. Tillage practices, which invert or considerably disturb the surface soil, reduce SOC (Lal, 1984; 1989). Conversely, long-term NT or reduced tillage systems have shown to increase SOC content of the soil surface layer as a result of various interacting factors, such as increase residue return, less mixing and soil disturbance, higher soil moisture content, reduced surface soil temperature, proliferation of root growth and biological activity, and decreased risks of soil erosion (Lal, 1989; Blevins and Frie, 1993).

Over the past two decades, conservation tillage has evolved primarily for erosion control. Recent concern for global climate change, however, reemphasizes the importance of conservation tillage, and how it can be implemented in many soils to help reduce soil C losses and hence increase soil C sequestration. While tillage and cultivation generally result in loss of soil C and N (Mann, 1986), conservation tillage has proved to have the potential for converting many soils from sources to sinks of atmospheric C (Kern & Johnson, 1993). Lal *et al.* (1998) stimated that widespread adoption of conservation tillage on some 400 million ha of cropland by the year 2020 may lead to total C sequestration of 1500 to 4900 Mg.

This paper presents results of SOC storage in a soil located in in Toledo (central Spain) after 19 years of maintaining various tillage and rotation combinations.

3. Methods

The field studies were carried out between 1987 and 2005 in the cereal-producing area of central Spain. The soil formation is a Calcic Haploxeralf (Soil Survey Staff, 1999). The main characteristics of the soil profile are recorded in Table 1.

The experimental site is characterized by a semiarid continental climate (minimum and maximum average annual temperatures are 6°C in the winter and 23°C in the summer, with 400 mm of average annual rainfall).

Table 1 Soil properties for Ap horizon

Particle size distribution (g 100 g^{-1})	Coarse sand (2.0–0.2 mm)	32.3
	Fine sand (0.2–0.02 mm)	40.4
	Silt (0.02–0.002 mm)	9.2
	Clay (< 0.002 mm)	18.1
Water content (g 100g^{-1})	-33 kPa	15.1
	-1500 kPa	7.9
pH (H_2O)		5.8
Organic matter (g kg^{-1})		11.7
CEC* ($cmol_c$ kg^{-1})		17.4
Bulk density (g cm^{-3})		1.3
Total N (g kg^{-1})		1.2
Available P (g kg^{-1})		84.0
Available K (g kg^{-1})		188.0

*CEC: cation exchange capacity.

The experiment was arranged in a split-plot design with the rotation as the main plot (9 × 72 m) and tillage as the split-plot (9 × 36 m). All treatments were replicated three times (three blocks). The crop rotation variable consisted of: i) B─V in a 2-year rotation, ii) B─S in a 2-year rotation, and iii) B─B monoculture. The tillage variable consisted of NT and CT. Sufficient numbers of plots were established so that each different phase of the crop rotation was present every year. A total of 4 randomly selected sites of each split-plot were sampled each year at 5 different depths to analyze a series of soil properties including SOC (Nelson and Sommers, 1982). The samples were subjected to analysis of variance (ANOVA). The least significant difference test was used to compare treatments at the $P<0.05$ level.

4. Results

Soil Organic Carbon Concentrations

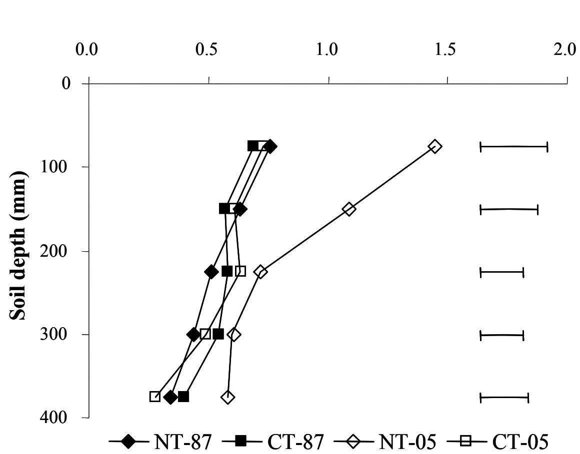

Figure 1 Comparison of tillage and time (1987 and 2005) effects on SOC concentrations at different soil depths. NT= no-tillage; CT= conventional tillage. Error bars are LSD among treatments within a soil depth at P= 0.05.

A decreasing trend in SOC with soil depth was observed for both tillage treatments (Figure 1). The largest drops in SOC from the surface to subsoil horizons, however, occurred for NT.

Significant changes between 1987 and 2005 in the amount of SOC were found for CT and NT. When NT treatment was applied, SOC clearly increased at all the different depths considered. This increase, however, was much more noticeable for the soil surface layer (0–75 mm). On the contrary, CT treatment either maintained (0–225 mm) or decreased (225–375 mm) the total amount of SOC. These results support those reported by others (Lal, 1989; Blevins and Frie, 1993).

Carbon Storage in Soil Profiles

The values for the total SOC storage (Table 2) showed that, after 19 years, the amount of SOC stored in the NT plots was 2.3 Mg ha^{-1} greater than that in the CT plots. This increase was in the range of the results presented by other authors (Cihacek & Ulmer, 1998; Dick & Durkalski, 1998).

Differences among rotation treatments showed that the B monoculture resulted in significant less SOC storage than did the B─V and the B─S rotations, both showing similar results. The vegetation is a major factor affecting soil formation, and the greater amounts of residue inputs for the B─V and B─S rotations *versus* B─B monoculture has impacted SOC concentration.

Table 2 Carbon storage in the (0–300 mm) soil layer as affected by tillage systems and crop rotations. NT= no-tillage; CT= conventional tillage. B→V (barley/vetch); B→S (barley/sunflower); B→B (barley monoculture

Treatment	Bulk Density (kg m^{-3})		Mean SOC concentration (g kg^{-1})		C stored (Mg ha^{-1})	
	1987	2005	1987	2005	1987	2005
Tillage						
NT	1.58	1.68	5.7	9.38	2.70	4.73
CT	1.56	1.66	5.4	4.95	2.53	2.47
Rotation						
B→V	1.59	1.67	5.31	9.54	2.53	4.78
B→S	1.55	1.65	5.58	8.91	2.59	4.41
B→B	1.65	1.65	4.90	5.82	2.43	2.88
Rotation & tillage						
NT/B→V	1.66	1.68	5.60	10.78	2.79	5.43
NT/B→S	1.67	1.65	5.29	9.80	2.65	4.85
NT/B→B	1.66	1.65	5.00	7.14	2.49	3.53
CT/B→V	1.55	1.67	4.91	5.72	2.28	2.87
CT/B→S	1.56	1.62	5.24	5.61	2.45	2.73
CT/B→B	1.65	1.58	5.15	5.28	2.55	2.50

[a] Means followed by the same letter for each set of treatments are not significantly different at the $P \leq 0.05$ level.

Significant interactions between tillage and rotation could also be observed. After 19 years, the lowest absolute values of SOC stored in the soil were obtained with the CT/B─B combination (2.5 Mg ha^{-1}). The application of NT in combination with sunflower or vetch increased C storage to 4.8 and 5.4 Mg ha^{-1} respectively.

Comparing the CT/B─B combination with the CT/B─V treatment, the C storage increased from 2.5 to 2.9 Mg ha^{-1}. This represents an increase of 0.4 Mg ha^{-1}, which corresponds to a C sequestration rate of 21 kg C ha^{-1} yr^{-1} due strictly to a rotation effect. The overall gain in SOC stored in NT/B─V treatment as compared to the value in the CT/B─V combination was calculated to be 2.6 Mg ha^{-1} (137 kg ha^{-1} yr^{-1}) due strictly to tillage.

5. Conclusions

The results obtained confirm that agricultural practices, such as tillage intensity and rotation, may counteract the declining trend in C sequestration in semiarid soils or may even increase it over time and thus help alleviate the trend towards increasing concentrations of CO_2 in the atmosphere. No tillage, when continuously practiced, results in values of SOC storage that are greater than when conventional tillage is applied. Thus NT can be considered as an effective technology for removing C from the atmosphere and sequestring it into the soil. In addition, implementing NT practices implies that the use of conventional tillage will decline, thus reducing the oxidative loss of soil C and increasing SOC in agricultural soils. However, from the results obtained it can be inferred that, in the soil formation studied, SOC concentrations had certainly not yet achieved equilibrium in 1999 after 11 years of NT. Only additional samplings in subsequent years will be able to determine whether or not we have achieved a steady state in SOC concentrations within the soil profile.

6. References

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