Original scientific paper

Tillage, cropping system and nitrogen fertilization effects on soil organic and particulate carbon and nitrogen in a semiarid environment of Spain

Sombrero Aurora, Diez-Fraile M. Carmen, Casta Pierre, Rodríguez-Bragado Laura, De Benito Avelino

Agricultural Technological Institute of Castilla y León, Ctra. Burgos km.117 Zamadueñas Valladolid Spain

Abstract

The present study aimed to determine the impact of three tillage systems (no-tillage (NT), minimum tillage (MT) and conventional tillage (CT)), crop rotation sequences (cereal/cereal (C/C), fallow/cereal (F/C) and legume/cereal (L/C)) and fertilization rate (conventional (FC) and reduced fertilization (FR)) on soil organic and particulate organic carbon (SOC and SPOC) and soil total nitrogen (STN) and profile distribution (0-60 cm) in a semi-arid soil in Castile-Leon, a region in northern Spain. Distribution of SOC, SPOC and STN stocks differed under different tillage system and crop rotations. NT and MT had more SOC contents than CT at 0-15 cm depth, but the mean SOC stocks were similar under all tillage systems at 0-60 cm depth. SPOC and STN stocks were higher in MT and NT than CT at 0-30 and 0-60 cm depth respectively. These parameters were greater in L/C than in F/C rotations. SPOC stocks were only affected by nitrogen rate which higher amounts in reduced fertilization plots. These findings suggest that SOC, SPOC and STN can be improved if conservation tillage is used in lieu of CT practice and intensity crops as legume/cereal is imperative for increasing C and N in soils in dryland areas.

Key words: conservation tillage, crop rotation, soil organic and particulate carbon, nitrogen

Introduction

The predominant cropping system in semi-arid Castile-Leon, a region with a yearly rainfall of 400-450 mm, is conventional tillage (CT). Used to mix topsoil to recover lost nutrients, prepare the seedbed and improve weed control, CT has nonetheless been associated with losses in soil organic carbon and significant decline in soil quality (Hernanz et al., 2002). Conservation tillage systems such as no tillage (NT) or chisel ploughing (MT) have become increasingly popular in the region over the last decades because they enhance profitability by lowering machinery and other costs (Sanchez-Girón et al., 2007; Sombrero et al., 2008). They are also more environmentally fit suitable than CT, which induces the biological oxidation of SOC (Reicosky et al., 1995). In sustainable agricultural production systems, soil organic carbon (SOC) is essential for sustaining soil quality, promoting crop productivity and protecting the environment (Doran and Parking, 1994). SOC pool, a significant indicator of soil quality, has many direct and indirect effects on such quality. Increases in the SOC pool improve soil structure and tilth, counter soil erosion, raise water capacity and plant nutrient stores, provide energy for soil fauna, purify water, denature pollutants, enhance soil biodiversity, improve the crop/crop residue ratio and mitigate the effects of climate (Lal, 2007). Combining conservation tillage with intensive or continuous cropping has been proposed as a way of increasing the total store of SOC (Halvorson et al., 2002) because by minimizing soil disturbance, less intensive tillage reduces the mineralisation of organic matter, providing for a larger store of SOC than conventional tillage (Al-Kaisi and Yin, 2005). Some of the parameters involved include total SOC, soil inorganic carbon and particulate organic carbon (POC). POC, regarded to be a fraction of SOC midway between the active and slow fractions, changes rapidly in response to changes in management practices (Cambardella and Elliott, 1992; Bayer et al., 2001) and is associated with short-term nutrient availability. The objective of this study was to examine the effect of tillage, crop rotations and fertilization rate on soil organic carbon (SOC) and particulate (POC) and soil total nitrogen (STN) as well as production.

Materials and methods

This study was initiated in 2004 on the Zamadueñas farm in the Spanish province of Valladolid. The soil, classified as Typic Xerofluvent, is characterised by a loamy-clay texture. In 2004 pH mean was 8.1, bulk density 1.35 g cm^3 and organic matter content 1.0 %. The mean rainfall in the area from 1985 to 2009 was 409 mm. The experimental design was a split split plot with four repetitions, with tillage system as main factor, crop rotations as sub-factor and fertilization as sub-sub factor. The tillage systems used were minimum tillage (MT) and zero or no till (NT) plus six tilled conventionally (CT) plots as a control. In 2008 and 2009, the crop sequences were: fallow-cereal (F/C), legume-cereal (L/C) and cereal-cereal (C/C). Preparatory work was conducted in early November in keeping with the respective tillage system: MT (chisel plough (10-15 cm deep), harrow, sowing and roller), NT (herbicide and sowing) and CT (mouldboard plough (25 cm deep), harrow, sowing and roller). The crops were managed in accordance with local practice, except fertilization. No crop residue was removed in any of the tillage treatments. All plots, except fallow, were fertilised, at a rate of 250 kg ha^{-1} (8-15-15 NPK). Topdressing consisting in two doses, one conventional (FC) and another taking into account the nitrogen content in the soil (FR) was applied in the subsequent tillering-stem elongation phase. The standard dose was with 300 kg ha^{-1} of NO_3NH_4 and mean recommended dose was 244 and 235 kg ha^{-1} of NO_3NH_4 (26%) kg/ha, in 2008 and 2009 respectively.

Soil properties were determined at the outset. Soil samples were taken before the preparatory work in October 2008 and 2009 at three sites on each elementary plot to obtain a composite sample per plot at depths of 0-5, 5-10, 10-15, 15-30 and 30-60 cm depth. The concentration of total C of soil was determined by dry combustion analysis using a LECO CNS analyzer. Since the parent material is calcareous, all samples were treated to remove any inorganic carbon. Soil inorganic carbon was estimated using a modified pressure-calcimeter method (Sherrod et al., 2002). Soil organic carbon (SOC) was calculated as the difference between total carbon and inorganic carbon. Soil particulate organic carbon (SPOC) was measured at 0-5, 5-10, 10-15 and 15-30 cm depth by Cambardella and Elliot (1992) method. Total N was analyzed using the Kjeldahl method (Bremner, 1965).

The SOC, SPOC, and STN stocks were quantified by measuring soil bulk density in core samples taken from each tillage system and block at the same depths. The soil samples, which were taken by hand with a 67.44 cm^3 steel cylinder, were weighted after drying at 105 ºC. Chemical values from 2008 and 2009 (Mg ha^{-1}) were calculated for each tillage and crop rotations in terms of equivalent soil mass (esm) according to the methods described by Ellert and Bettany (1995).

The statistical analysis was performed with SAS (SAS Institute Inc., 2002) analysis of variance (ANOVA) or general linear model (GLM) was performed within each depth increment for a split-plot design. Differences among treatment means were tested using Duncan's test with $p < 0.05$.

Results and discussion

Effect of tillage, crop rotation and nitrogen rate on soil organic, particulate carbon and total nitrogen concentrations, C:N ratio and distribution in the soil profile

Soil organic and particulate carbon concentrations in soil profiles under three tillage systems in two years are shown in Figure 1. SOC concentration was 5% higher in 2009 than 2008. Highly significant differences in SOC and SPOC concentrations were found between tillage systems at 0-5 cm soil layer in both years, MT and CT had significantly lower SOC and SPOC concentration than did the NT system; In 2008, NT had 1.33 times more SOC and 2.10 more SPOC than CT, and 1.14 more SOC than MT. MT, in turn, had 1.60 times more SOC and 1.63 more SPOC than CT. In 2009, SOC concentration was 1.46 and 1.15 times statistically higher in NT than CT in 0-5 and 5-10 cm soil layer, and SPOC concentration was 2.73 and 1.68 times statistically higher in NT than CT in 0-5 and 5-10 cm soil layer. These results are consistent with findings reported by Hernanz et al. (2009) who observed a higher SOC content at 10 cm in NT than CT soils in semi-arid climates. The absence of soil disturbance and the presence of crop residues on the soil surface in NT plots led to an accumulation of these parameters in the 0-5 cm layer and higher values than in tilled systems where crop residues are mechanically incorporated into the soil. When a chisel is used for primary tillage at 10-15 cm depth, the resulting redistribution of SOC and SPOC across the soil profile could explain the greater SOC and SPOC concentrations at 5-15 cm depth. In 2008, at the 15–30 and 30-60 cm depths the trend for higher SOC concentration with conservation tillage (NT and MT) reversed and CT resulted in similar values. In 2009, at the 15–30 cm depth higher SOC concentration was found in CT system than in conservation tillage (NT and MT), and the 30-60 cm depth, SOC concentration was similar in all three tillage systems. Gal et al. (2007) confirmed that NT had a substantial gain of SOC at the 0–5 and 5–15 cm depth intervals, but a substantial reduction, relative to the CT system, in the 30–50 cm depth interval.

Throughout the soil profile studied (0-60 cm depth), soil total nitrogen (STN) was 9% higher in 2009 than 2008 (Figure 1). In 2009, at 0-5 cm depth, in NT and MT systems, STN concentration was 6 and 8% higher than CT which decreased by 18 %. From 0 to 60 cm depth, STN values in conservation tillage were higher in 209 than in 2008. Highly significant differences in STN concentrations were found between tillage systems at 0-30 cm and at 0-60 cm depths in 2008 and 2009 respectively, indeed NT and NT had 30 and 24% more STN in 2008 and 68 and 60% more STN in 2009 than CT. The highest concentration of N was obtained in the plots under NT and MT when the 5–30 cm and 0-60 cm layers were considered in 2008 and 2009 respectively. These results are consistent with findings reported by López-Fandó and Pardo (2009) who found higher SOC and STN in NT than CT at 0-30 cm soil depth. On the contrary, these results differed from earlier reports to which STN was higher in the top 15 cm soil depth in NT than in CT tillage being similar at greater depths in the soil profile in a long-term experiment (Gal et al., 2007).

Soil C:N ratios ranged from 8.4 to 13.8 in 2008 and from 7.3 to 10.8 in 2009. Differences in soil C:N ratios between year might be attributed to annual variation in the input amounts of carbon as well as the different dynamics of SOC and STN contents. Total means rainfall were 456 mm and 345 mm in 2008 and 2009 respectively. The highest rainfall in 2008 led to a mean grain production of 6030 kg ha^{-1} while in 2009, the mean grain production only was 2425 kg ha^{-1}. Hence the amount of residues left on the surface was greater in 2008 which led to a larger amount of the SOC and SOC and to a smaller values of the STN and C:N ratios.

Since rotation systems in the two years studied did not affect the SOC and SPOC concentrations, these results are not presented, however, in 2008, along the profile (0-60 cm depth) SOC and SPOC concentrations were 5% and 7% higher in plots with C/C than those with F/C respectively. Martín-Rueda et al. (2007) reported no significant differences in SOC by crop rotation at any depth.

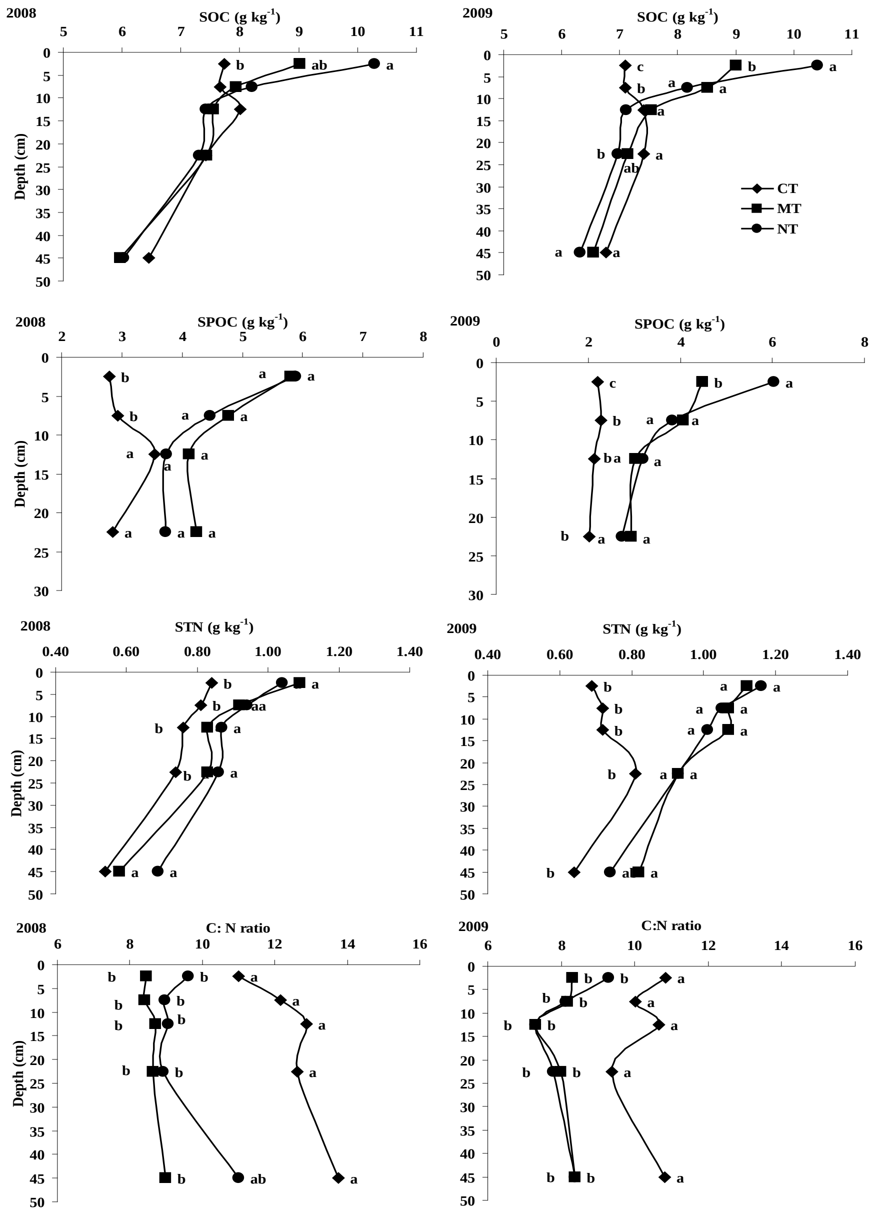

Figure 1. Vertical distribution of the soil organic and particulate carbon (SOC and SPOC) and soil total nitrogen (STN) contents and C:N ratio by tillage systems in 2008 and 2009. Lettered values mark significant differences at $p<0.05$ (Duncan's test). CT, conventional tillage; MT, minimum tillage; NT, no tillage.

Ortega et al. (2002) reported that SOC was not significantly influenced by crop rotation in NT system after 8 yr in the central Great Plains, even though continuous cropping returned greater biomass residue to the soil than other crop rotations containing fallow. In 2009, SOC and SPOC concentrations were 5% and 14% higher respectively in plots with L/C than those with C/C and F/C. Interactions of tillage systems crop rotation were significant for SPOC in 2008 and for SOC and SPOC in 2009. STN concentration was affected by crop rotation at 15-30 cm depth layer, STN was 10% higher in F/C plots than in those of L/C and C/C in 2008, while in 2009 only at 0-5 cm depth, STN values was 11% higher in L/C than C/C and F/C (data not presented). In 2008, C:N ratio was statistically different between crop rotation throughout soil profile, in L/C and C/C rotations C:N ratio was higher than in F/C.

SOC content was not affected by nitrogen rate, but the greatest concentration along the profile was found in plots with reduced fertilization (data not presented). SPOC concentration in different depths of two nitrogen rates in 2008 and 2009 years are shown in Figure 2. SPOC concentration trend was similar in the two years of study, SPOC was higher with reduced fertilization than in conventional fertilization along the profile studied, showing highly significant differences in the 0-5 cm soil layer. SPOC mean had 18% more in plots with reduced fertilization than those with conventional fertilization in both years. This indicates that SPOC changed rapidly with fertilization rate relative to SOC as suggested by several researchers (Cambardella and Elliot, 1992; Bayer et al., 2001; Sainju, 2008). Nitrogen rate did not affected STN concentration throughout soil profile in both year, however, C:N ratio only was significantly 6% higher in reduced nitrogen than conventional nitrogen at 0-5 cm depth layer in 2008. The greatest concentration along the profile was found in plots with reduced fertilization in 2008 and 2009.

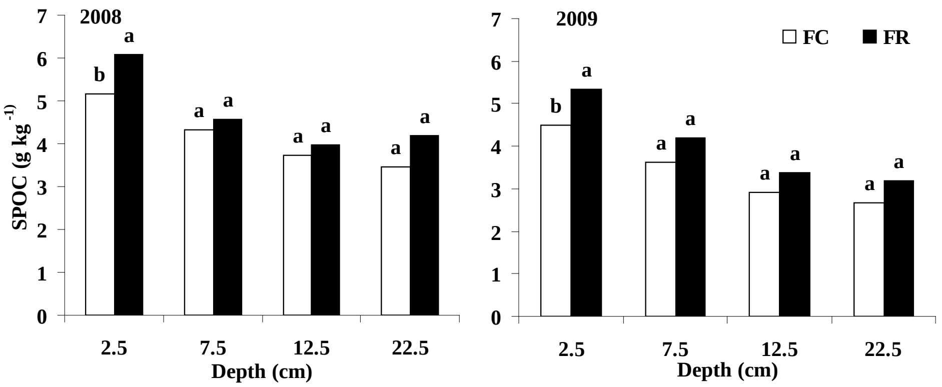

Figure 2. Soil particulate organic carbon (SPOC) concentration by nitrogen rate in different soil depths in 2008 and 2009. Lettered values mark significant differences at $p<0.05$ (Duncan's test). FC, conventional fertilization; FR, reduced fertilization.

Effect of tillage, crop rotation and nitrogen rate on soil organic, particulate carbon and total nitrogen stocks and distribution in the soil profile

In general, SOC, SPOC stocks were significantly higher in 2008 than in 2009 at 0-30 cm depth (Figure 3a). The highest rainfall in 2008 led to a mean grain production of 6030 kg ha $^{-1}$ while in 2009, the mean grain production only was 2425 kg ha $^{-1}$. Hence the amount of residues left on the surface was greater in 2008 which led to a larger amount of the SOC and SPOC in this year. There were significant differences in stocks of SOC and SPOC among the three tillage systems in 0-5 cm depth and at 0-30 cm depth respectively (Figure 3a). The amount of SOC in the 0-5 cm depth was greater in NT than in MT and greater in MT than CT. The SOC stocks were 2.08 and 2.73 Mg C ha $^{-1}$ greater in NT than CT and 0.91 and 1.65 Mg C ha $^{-1}$ in MT than CT in 2008 and 2009 respectively. At 0-15 cm depth, in 2009, SOC contents were 3.07 and 2.57 Mg C ha $^{-1}$ greater in NT and MT than CT system. Hernanz et al. (2009) observed a higher SOC content at 10 cm in NT than CT soils in semi-arid climates. In the whole soil profile (0-60 cm depth) there were no differences in stocks of SOC among the three tillage systems, SOC stocks were a mean of 74.6 and 76.3 Mg C ha $^{-1}$ in 2008 and 2009 respectively. Blanco-Canqui and Lal (2008) suggested that whereas NT practices increases soil C stocks in the top layer, they do not affect soil C contents across the 0-60 cm soil profile. The amount of SPOC throughout the soil profile studied (0-30 cm depth) was greater in NT and MT than in CT. At 0-5 cm depth, the SPOC stocks were 3.36 and 3.17 Mg C ha $^{-1}$ greater in NT than CT and 2.12 and 1.98 Mg C ha^{-1} in MT than CT in 2008 and 2009 respectively. At 0-30 cm depth, SPOC stocks were a mean of 22.6 and 22.1 Mg C ha^{-1} for conservation tillage and 15.7 and 11.5 Mg C ha^{-1} in 2008 and 2009 respectively. The STN trend was similar to the SPOC, although the amount of STN was greater in 2009 than in 2008. The amount of STN throughout the soil profile studied (0-60 cm depth) was greater in NT and MT than in CT. At 0-5 cm depth, the STN stocks were 0.20 and 0.42 Mg N ha^{-1} greater in NT than CT and 0.16 and 0.37 Mg N ha^{-1} in MT than CT in 2008 and 2009 respectively. At 0-60 cm depth, STN stocks were a mean of 0.92 and 1.76 Mg N ha^{-1} greater in NT than CT and 1.67 and 2.34 Mg N ha^{-1} in MT than CT in 2008 and 2009 respectively.

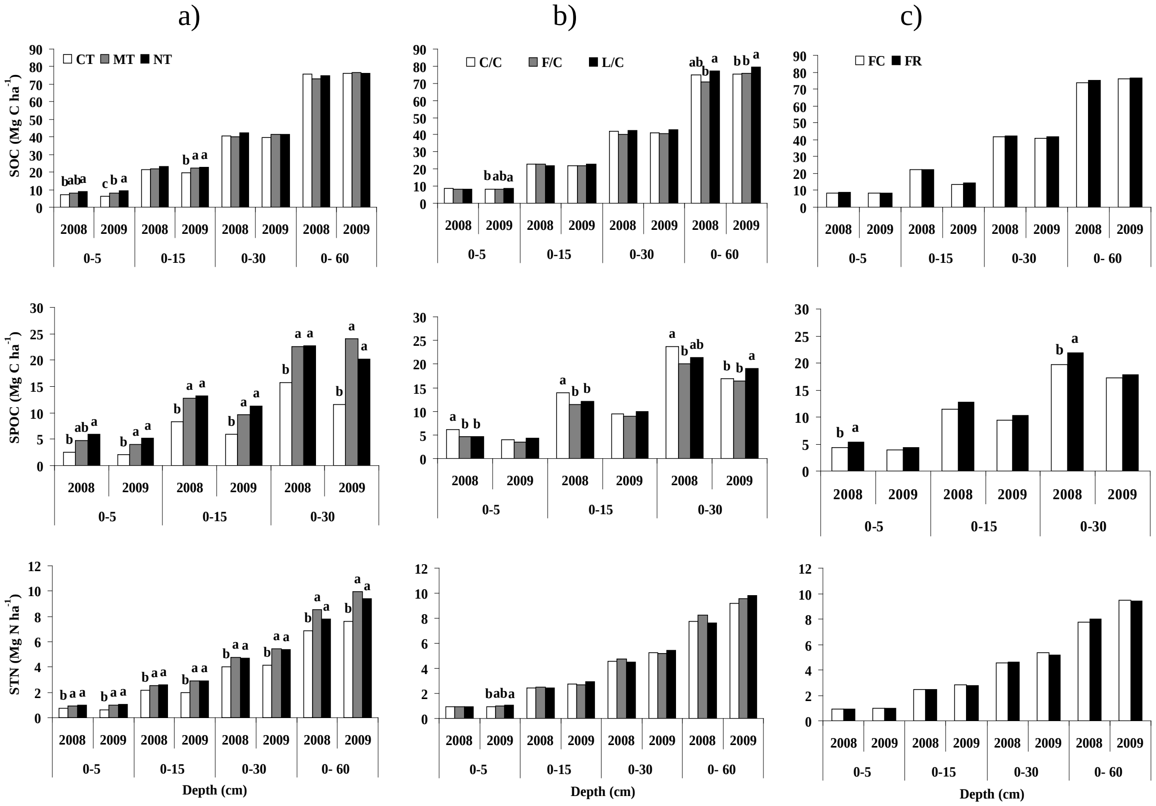

Figure 3. Soil organic, particulate carbon (SOC and SPOC) and soil total nitrogen (STN) expressed on equivalent soil mass under different tillage systems (a), crop rotation sequences (b) and nitrogen rate (c) in 2008 and 2009 years. Lettered values mark significant differences at $p<0.05$ (Duncan's test). CT, conventional tillage; MT, minimum tillage; NT, no tillage. C/C, cereal/cereal; F/C, fallow/cereal, L/C, legume/cereal. FC, conventional fertilization; FR, reduced fertilization.

There were significant differences in stocks of SOC and SPOC among crop rotations in 0-60 cm and in 0-30 cm depths (Figure 3b). In 2009, the amount of SOC in the 0-5 cm depth was 0.70 Mg C ha^{-1} greater in L/C than in C/C rotation. In the whole soil profile (0-60 cm depth), in 2008, SOC stocks were 3.86 and 2.45 Mg C ha^{-1} greater in L/C than F/C and C/C rotations and 3.84 and 4.24 Mg C ha^{-1} in L/C than F/C and C/C in 2009. These results concurred with other studies reporting the positive effect of vetch on the SOC content in soil and consequently soil quality (Katsvairo and Cox, 2000; Masri and Ryan, 2006). Bremer et al., (2008) observed that SOC can increase where reduced tillage is adopting and long fallows eliminated from cropping systems. SPOC amount was significantly different between rotations in 2008 (Figure 3b). Plots with monoculture cereal had higher SPOC content than L/C and F/C rotations throughout the study profile (0-30 cm depth). However, in 2009 the trend of SPOC was different from the previous year, SPOC content was 2.7 and 2.3 Mg C ha^{-1} greater in L/C plots than in those with F/C and C/C respectively. In general, there were not significant differences in stocks of STN among crop rotations, except at 0-5 cm depth layer, where STN values were higher for L/C than C/C and F/C in 2009. There were no differences in stocks of SOC and STN among the nitrogen rate, in 2008, SPOC only showed significant differences between nitrogen rates, reduced fertilization had 1.05 and 2.14 Mg C ha^{-1} higher amounts at 0-5 cm and 0-30 cm depth than conventional fertilization (Figure 3c). The highest rainfall in 2008 and reduced nitrogen fertilization led to a lower mineralization of soil organic carbon and consequently the amount of particulate carbon was higher. Much of the SOC lost from arable soil can be attributed to tillage, the returns of N depleted crop residue, long fallows and the excessive use of nitrogen fertilizer (Khan et al., 2007).

Conclusions

This study examined the effect of tillage systems, crop rotations and nitrogen rate on soil organic and particulate carbon and total nitrogen in a semiarid climate of Castile and Leon (Spain). NT and MT accumulated 3.07 and 2.57 Mg C ha^{-1}more SOC than CT at 0-15 cm depth, but when the whole soil profile (0-60 cm depth) was considered, similar total SOC content was measured under all tillage systems. SPOC stocks were 12.5 and 8.7 Mg C ha^{-1} higher in MT and NT than CT at 0-30 cm depth. Throughout soil profile (0-60 cm depth), STN amounts were 2.34 and 1.76 Mg N ha^{-1} greater in MT and in NT respectively than in CT. SOC and SPOC contents were significantly affected by crop rotations, L/C had 3.8 and 4.2 Mg C ha^{-1} more SOC at 0-60 cm depth and 6.7 and 11.4 Mg C ha^{-1} more SPOC than F/C at 0-30 cm in 2008 and 2009 respectively. STN stocks were not significantly affected by crop rotations nevertheless L/C had higher values than F/C. SPOC stocks were greater in reduced than conventional fertilization along the profile studied. SPOC mean had 18% more in plots with reduced fertilization than those with conventional fertilization in both years at 0-5 cm depth. Conservation tillage as NT and MT and intensity crops (avoid fallows) practices could be effective strategies to improve C and N in soils in semi-arid areas of Spain.

Acknowledgements

This study was funded by the National Agricultural and Food Research Institute (Project RTA2006-00121-C03-01).

References

Al-Kaisi, M., Yin, X. (2005): Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations. J. Environ. Qual. 34, 437–445.

Blanco-Canqui, H., Lal, R. (2008): No tillage and soil-profile carbon sequestration: An on-farm assessment. Soil Sci. Am. J. 72, 693-701.

Blanco-Canqui, H., Lal, R. (2008): No tillage and soil-profile carbon sequestration: An on-farm assessment. Soil Sci. Am. J. 72, 693-701.

Bremer, E., Janzen, H.H., McKenzie, R.H. (2008): Soil Organic Carbon after Twelve Years of Various Crop Rotations in an Aridic Boroll. Soil Sci. Soc. Am. J. 72, 970-974.

Bremner, J.M. (1965): Total Nitrogen. In: Methods of soil Analysis. (Ed. Black. C.A.).pp. 1149-1178. Agronomy. No. 9, ASA and SSSA. Madison. Wisconsin.

Cambardella, C.A., Elliott, E.T. (1992): Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J., 56, 777-783.

Campbell, C.A., McConkey, B.G., Zentner, R.P., Selles, F., Curtin, D. (1996): Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Canadian Journal of Soil Science, 76(3), 395-401.

Doran, J.W., Parkin, T.B. (1994): Defining and assessing soil quality. In: Defining soil quality for a sustainable environment. S.S.S.A., 35, 3-21.

Ellert, B.H., Bettany, J.R. (1995): Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Canadian Journal of Soil Science 75, 529–538.
Gál, A., Vyn, T.J., Michéli, E., Kladivko, E.J., McFee, W.W. (2007): Soil carbon and nitrogen accumulation with long-term no-till versus moldboard plowing overestimated with tilled-zone sampling depths. Soil Tillage Res. 96, 42–51.
Halvorson, A.D, Peterson, G.A., Reule, C.A. (2002a): Tillage system and crop rotation effects on dryland crop yields and soil carbon in the central Great Plains. Agronomy J. 94, 1429-1436.
Hernanz, J.L., López, R., Navarrete, L., Sánchez-Girón, V. (2002): Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semi-arid central Spain. Soil Tillage Res. 66, 129-141.
Hernanz, J.L., Sánchez-Girón, V., Navarrete, L. (2009): Soil carbon sequestration and stratification in a cereal/leguminous crop rotation with three tillage systems in semiarid conditions. Agriculture ecosystems and environment. 133, 114-122.
Katsvairo W., Cox W.J. (2000b): Tillage X Rotation X Management interactions in corn. Agronomy J. 92, 493-500.
Khan, S.A., Mulvaney, R.L., Ellsworth, T.R., Boast, C.W. (2007): The Myth of Nitrogen Fertilization for Soil Carbon Sequestration. J. Environ. Qual. 36, 1821-1832.
Lal, R., 2007. Farming Carbon. Soil Tillage Res. 96, 1-5.
López-Fandó, C., Pardo, M.T. (2009): Changes in soil chemical characteristics with different tillage practices in a semi-arid environment. Soil Tillage Res. 104, 278–284.
Martín-Rueda, I., Muñoz-Guerra, L.M., Yunta, F., Esteban, E., Tenorio, J.L., Lucena J.J. (2007): Tillage and crop rotation effects on barley yield and soil nutrients on a Calciortidic Haploxeralf. Soil Tillage Res. 92, 1-9.
Masri Z., Ryan J. (2006): Soil aggregation and related physical properties in a Mediterranean wheat-based long-term rotation trial. *Soil Tillage Research* **87,** 146-154.
Ortega, R.A., Peterson, G.A. Westfall, D.G. (2002): Residue accumulation and changes in soil organic matter as affected by cropping intensity in no-till dryland agroecosystems. Agronnomy J. 94, 944–954.
Reicosky, D.C., Kemper, W.D., Langdale, G.W., Douglas, C.L. JR. and Rasmussen, P.E. (1995): Soil organic matter changes resulting from tillage and biomass production. Journal of Soil and Water Conservation. May-June, 253-261.
Sánchez-Girón, V. Serrano, A. Suárez, M., Hernanz, J.L., Navarrete, L. (2007): Economics of reduced tillage for cereal and legume production on rainfed farm enterprises of different sizes in semiarid conditions. Soil Tillage Res. 95, 149-161.
SAS Institute Inc. (2002): SAS/STAT User's Guide. SAS Institute Inc., Cary.
Sherrod, L.A., Dunn, G., Peterson, G.A., Kolberg R.L. (2002): Inorganic Carbon Analysis by Modified Pressure-Calcimeter Method. Soil Sci. Soc. Am. 1. 66:299-305
Sombrero, A., de Benito, A, Tenorio, J. L., Martín, D., Perez de Ciriza, J.J., Delgado, J. (2008): Economic Analysis of Crop Rotation in three Tillage Systems in Semiarid Central- Northern Spain. Italian Journal of Agronomy, 3, 261-262.
Sombrero, A., Benito, A. (2010). Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. Soil Tillage Res. 107, 64-70.