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Effects of agricultural management on chemical and biochemical properties of a semiarid soil from central Spain

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A B S T R A C T

Long-term agricultural management may change soil C sequestration and alter soil C and N dynamics. The objective of this study was to investigate the impact of several tillage regimes with different intensity on C and N stocks in a Calcic Haploxeralf with a leguminous/cereal rotation under semiarid conditions after 15, 18 and 21 years of management. Seven chemical and biochemical properties (total C, total N, δ ^{13}C, δ ^{15}N, FDA hydrolysis, β-glucosidase and urease activities) were measured in a soil (0–5 cm, 5–10 cm, 10–20 cm, 20–30 cm) under the following agricultural management: fallow (F), no-tillage (NT), zone-tillage subsoiling with a paraplow (ZT), conventional tillage with mouldboard plow (CT), minimum tillage with chisel plow after NT (MTN) or CT (MTC). The results showed that soil reached a steady state of organic matter sequestration 15 years after starting the experiment and that C and N stocks varied greatly with agricultural management, particularly in the top 0–10 cm, and followed the order: F $\approx$ NT $\approx$ ZT > MTN $\approx$ MTC > CT. Fallow and less intensively cultivated soils (NT, ZT) exhibited strong vertical gradients of most properties analyzed (total C, total N, FDA hydrolysis, urease and β-glucosidase activities) with values decreasing with depth, followed by minimum tillage treatments (MTN, MTC) whereas similar values along soil profile were observed in CT treatment. No significant differences in soil δ ^{13}C values were detected among plots with different land use or tillage systems; however, the δ ^{15}N values suggested that, although tillage system did not affect significantly N-cycling processes, a change from "open" to "closed" N cycling occurred when cultivated soils were set aside.

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1. Introduction

Soil physical, chemical and biological properties and processes are strongly influenced by soil organic matter (SOM) content, which is a key attribute in soil quality and productivity (Gregorich et al., 1994) and plays an important role in the global C budget through sequestration of atmospheric C (Lal, 2001). Assessment of SOM is therefore a valuable step to identify the overall soil quality and the sustainability of land management. In agricultural soils, conventional tillage may cause a substantial decrease of SOM content and labile pools of nutrients (Elliott, 1986; Karlen et al., 1994; Wander and Bollero, 1999). Conservation tillage minimizes soil disturbance and maintains crop residues on the soil surface, reducing their decomposition and leading to organic matter accumulation in the upper soil layer (Balesdent et al., 2000). Although the adoption of conservation practices may temporarily reduce plant available N through increased N immobilization

(Doran, 1987), conservation tillage improves N availability to plants in the long-term (Rice et al., 1986) by increasing soil N retention and labile N pool (Franzluebbers et al., 1994; McCarty and Meisinger, 1997) in the upper soil layers. Consequently, the change of tillage methods to reduced- or no-tillage practices is recommended to sequester organic C and hence to reduce the net emission of greenhouse gases (Lal, 2001).

Short- and medium-term variations in SOM following a change in soil management or land use are less well understood because they are difficult to measure by conventional methods. Stable isotopes measurements at natural abundance levels are a powerful research tool in environmental sciences (Handley and Scrimgeour, 1997; Robinson, 2001; Yakir and Sternberg, 2000). In the case of soils, δ ^{13}C has been usefully employed to monitor long-term intensive land use effects on SOM (Kalbitz et al., 2000) and δ ^{15}N values reflect the net effect of biotic and abiotic environment on N-cycling processes (Dawson et al., 2002), being influenced by the quantity and quality of SOM inputs, N sources and isotopic fractionation during N transformations (Nadelhoffer and Fry, 1988). Likewise, the measurement of biochemical properties such as those related with mass and activity of soil microbial

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communities is recommended to detect SOM changes due to land-use and soil management over short and medium time scale (Madejon et al., 2007; Sparling, 1998). To this respect, studies of diverse authors have shown that the biochemical properties were more sensitive than total organic C and N for assessing the impact of different tillage practices on soil quality (Bergstrom et al., 1998; Biederbeck et al., 1994; Carter, 1986; Díaz-Raviña et al., 2005; Madejon et al., 2007, 2009; Melero et al., 2012; Saffigna et al., 1989).

The aim of present work was to evaluate whether changes in SOM (including δ ^{13}C and δ ^{15}N values) and soil biochemical properties (FDA hydrolysis and β-glucosidase and urease activities) could be detected after 15–21 years under six management systems: conventional tillage (CT), minimum tillage after CT (MTC), minimum tillage after no tillage (MTN), no-tillage with paraplow (ZT), no tillage (NT) and fallow soil (F).

2. Materials and methods

2.1. Site description and experimental design

The study was done in a long-term tillage experiment established at the CSIC Experimental Station (Toledo, Central Spain). The site is 450 m asl (latitude 40°3′, longitude 4°26′) on a loamy sand Calcic Haploxeralf (Soil Survey Staff, 2010). The area has a semiarid continental climate with minimum and maximum average temperatures of 6 °C in winter and 23 °C in summer. The annual precipitation averages 428 mm, of which 28% in spring, 10% in summer, 26% in autumn and 36% in winter. The aridity index, i.e. the ratio of annual mean precipitation to annual mean evapotranspiration, is 0.564 reflecting a semiarid climate which is typical of steppes and Mediterranean countries.

Two tillage systems were initially applied: conventional tillage with mouldboard plow (CT) and no-tillage (NT) in a randomized complete block design with nine replications (plots measured 9 m wide and 40 m long). After 7 years, three of the nine plots under NT were changed to minimum tillage with chisel plow (MTN) and other three to zone tillage with paraplowing (ZT) whereas three of the nine plots under CT were changed to minimum tillage with chisel plow (MTC). Thus, the five tillage systems applied by triplicate were: NT, ZT, MTN, MTC and CT. The crop sequence was chickpea (*Cicer arietinum* L.) cv. Gracia/barley (*Hordeum vulgare* L.) cv. Volley, selected for their suitability in the climatic conditions of a dry farming experimental site. Cultural practices were similar to those employed by local farmers, adapted to the type of soil, weed incidence, etc., and remained constant for each crop and tillage system since the study began. CT consisted of fall ploughing to an average depth of 25–30 cm, followed by one or two passes with spring tine cultivator (10–15 cm depth) for seedbed preparation. Minimum tillage (MTN and MTC) involved chisel ploughing to an average depth of 15–20 cm. The ZT subsoiler (paraplow) was applied in alternate years and set to operate at a depth of 30 cm with little disturbance of the soil surface. Chemical fertilizers were applied in the same quantity for all treatments at barley pre-sowing in a mixed form (8–15–15 N–P–K) and as a top-dressing, at the tillering stage in the form of calcium ammonium nitrate (33% N), at an average total rate of 90–60–60 kg N–P–K ha^{-1} (adjusted to supply the average uptake of the crops). Chickpea crop received at pre-sowing the same mixed fertilizer but at a lower rate (16–30–30 kg N–P–K ha^{-1}). Crop yields (barley and chickpea) were harvested after reaching physiological maturity, usually in early July.

2.2. Sampling and analysis of soil

Soil was sampled after harvest of crops at different times after the establishment of experiment (15, 18 and 21 years). Eight soil sub-samples in each plot were taken at 0–5, 5–10, 10–20 and 20–30 cm depth using an auger. The sub-samples were mixed to produce a composite sample for each treatment, layer and plot. Additionally, a control soil (F) under shrub vegetation dominated by *Retama sphaerocarpa* (L) and other plants characteristics of semiarid ecosystems (*Silene vulgaris*, *Medicago minima*, etc.) was sampled at random in an adjacent (50 m apart) agricultural soil without human disturbance during the last 30–40 years, but in this case only a composite sample for each depth was taken. Chemical analyses were performed on soil samples collected at three sampling times (*t* = 15, 18 and 21 years after the experiment setup) whereas biochemical properties were only analyzed in samples collected at *t* = 15 years. After sieving at 2 mm, the homogenized soil samples were separated in two fractions, one was air-dried and used for measurements of chemical properties and the other was stored at 4 °C for no longer than 4 weeks until analysis of biochemical properties.

Total C, total N, δ ^{13}C and δ ^{15}N were measured on finely ground (<100 μm) soil samples with an elemental analyser (Carlo Erba CNS 1508) coupled on-line with an isotopic ratio mass spectrometer (Finnigan Mat, delta C, Bremen, Germany). The following rules, some of them also recommended by Jardine and Cunjak (2005), were taken into account in isotopic analysis. We constraint the weights of samples (analyzed on duplicate) and standards such that their peaks' amplitudes were within a small range, and we adjusted to this range the peak of the internal reference injected in each analysis (CO_2 or N_2 from a pressure bottle calibrated against IAEA standards). With regard to C isotopic analysis, accuracy and precision for isotope reference materials IAEA-CH-6 and IAEA-CH-7 (included, alternately, after every tenth sample) were always within the certified values ($-10.40 \pm 0.20‰$ and $-31.80 \pm 0.20‰$, respectively). The same was true for N with isotopic standards IAEA-N1 and IAEA-N2 ($0.40 \pm 0.20‰$ and $20.3 \pm 0.20‰$, respectively).

The hydrolysis of fluorescein diacetate (FDA), an overall index of activity of heterotrophic microorganisms, and the measurement of two specific enzyme activities related with the C (β-glucosidase) and N (urease) cycles were used as indicators of soil microbial activity. Fluorescein diacetate (FDA) hydrolysis was determined as reported by Schnurer and Rosswall (1982) by incubating the soil samples with a solution of fluorescein diacetate for 1 h at 24 °C. The β-glucosidase activity was measured following the procedure of Eivazi and Tabatabai (1988), which determines the released *p*-nitrophenol after incubation of the soil samples with a 4-nitrophenyl-β-ᴅ-glucopyranoside solution for 3 h at 37 °C. The urease activity was estimated by incubating the soil samples with an aqueous urea solution and extracting the NH_4^+ produced with 1 M KCl and 0.01 M HCl followed by the colorimetric NH_4^+ determination by a modified indophenol reaction (Kandeler and Gerber, 1988).

All analyses were carried out in duplicate and the mean of both analyses was used in the statistical procedures and were expressed on the basis of oven-dried (105 °C) weight of soil (absolute values).

2.3. Statistical analysis

Data on biochemical properties, measured only 15 years after the establishment of experiment, were statistically analyzed by two-way ANOVA to determine the percentage of variation attributable to the factors tillage system (NT, ZT, MTN, MTC and CT) and soil depth. For the chemical properties, the exploratory analyses showed that soil total C, total N, δ ^{13}C and δ ^{15}N did not vary significantly among sampling dates (15, 18 and 21 years after the establishment of experiment); therefore, data of the three years were jointly analyzed by two-way ANOVA (with treatment and soil depth as factors). The Levene's test was used for verifying the equality of variances among groups. In the case of