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Tillage effects on soil microbial biomass, SOM mineralization and enzyme activity in a semi-arid Calcixerepts

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ABSTRACT

Soil microbial properties are considered important indicators for assessing and comparing soil quality and degradation under tillage systems due to their early responses to environmental changes. The main objective of this study was to determine the medium-term (6 years) influence of tillage practices on soil microbial attributes in a semi-arid Calcixerepts from Central Iran with a similar plant residue input rate. The experiment was organized as a randomized complete block design with three replicates of each tillage regime. Tillage treatments consisted of moldboard and disk plows as conventional tillage (CT), and chisel and rotary plows as reduced tillage (RT) regimes over a period of six years (2005–2011). Soil microbial biomass carbon C (MBC) and nitrogen (MBN) contents, C (CMR) and N (NMR) mineralization rates; and urease, alkaline phosphatase (ALP) and catalase activities at the 0–20 cm depth were determined only in 2008, 2009 and 2011. Less disturbed soils by both chisel and rotary plows under RT had higher MBC (25–43%), MBN (7–13%), MBC/MBN (17%) and enzyme activities (urease 2.0-fold, ALP 31–53% and catalase 18–59%) when compared with more disturbed soils by moldboard and disk plows under CT. In contrast, RT soils had lower microbial turnover rate (9–17%), metabolic quotient (qCO_2, 37%), CMR (17–30%) and NMR (24–28%) than CT soils. However, the magnitude of the changes in soil MBC, MBN, CMR, NMR and catalase activity due to tillage effect were more greater during the later years of tillage implementation. The positive effect of RT practices on soil microbial biomass and enzyme activity was most likely due to improved environmental conditions, since soil organic matter (SOM) content was unaffected by tillage treatments. Soils under RT systems were characterized by a higher microbial biomass and enzyme activity, but development of less metabolically active microorganisms; most probably as a result of changes in the microbial community composition and lower microbial turnover rate. Furthermore, increased microbial enzyme production and biomass size with RT does not necessarily lead to higher microbial activity and SOM mineralization rate. It is suggested that the reduced SOM mineralization under RT is largely controlled by changes in the composition of microbial community and microbial turnover. In conclusion, microbial attributes were improved under RT after six years, and hence are regarded as early and sensitive indicators of changes in soil quality induced by tillage systems in this semi-arid environment.

1. Introduction

The type of tillage systems determines not only soil quality and degradation in agroecosystems (Liebig et al., 2004; Melero et al., 2011; Willekens et al., 2014), but also affects carbon (C) sequestration rate in the soil and subsequent CO_2 emissions (West and Post, 2002; Roldán et al., 2005). Intensive tillage practices at a large scale can result in a decline of soil organic matter (SOM) and subsequently low soil fertility and quality in arid and semi-arid ecosystems (Mrabet et al., 2001; Álvaro-Fuentes et al., 2013; Abdullah 2014).

The response of soil microorganisms and biochemical properties to tillage practices has been measured by estimating the size and activity of the microbial community and the activities of various soil enzymes (Carter, 1991). These microbial and biochemical properties are important soil indicators as they are involved in

Abbreviations: SOM, soil organic matter; OC, organic carbon; TN, total nitrogen; MBC, microbial biomass C; MBN, microbial biomass N; CMR, C mineralization rate; NMR, N mineralization rate; URE, urease; ALP, alkaline phosphatase; CAT, catalase; DP, disk plow; MP, moldboard plow; CP, chisel plow; RP, rotary plow; RT, reduced tillage; CT, conventional tillage.

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SOM decomposition, C sequestration, and nutrient cycling and availability (Sparling, 1997; Nannipieri et al., 2002). They are often considered sensitive indicators of soil quality and degradation to be assessed under intensive tillage systems and land use changes (Carter, 1991; Dilly et al., 2003b; Geisseler and Horwath, 2009; Ferreiro and Fu, 2016). Soil enzymatic activities and microbial biomass pool have been proposed as integrative indicators of soil quality (Dick, 1994; Sparling, 1997), and were shown to be affected negatively by intensive tillage and agricultural practices (Balota et al., 2004; Roldán et al., 2005; Madejón et al., 2007; Melero et al., 2011; Álvaro-Fuentes et al., 2013; Willekens et al., 2014). In particular, soil microbial biomass and activity, and enzyme activities have been shown to be more sensitive than total organic C (OC) to soil disturbance resulting from intensive tillage practices (Roldán et al., 2005; Madejón et al., 2007; Geisseler and Horwath, 2009; Laudicina et al., 2011). Excessive tillage practices may negatively affect soil microbial and biochemical attributes through (1) a reduction of SOM (both C and N) content that provides a substrate source for soil microorganisms, (2) a decline in the proportion of water-stable soil macroaggregates that provide a favorable microhabitat for soil microorganisms and (3) changes in environmental conditions such as soil moisture and temperature (Balota et al., 2003, 2004; Dilly et al., 2003b; Roldán et al., 2005).

Our previous study (Kabiri et al., 2015) indicated that reduced intensity of tillage did not affect soil organic C and N stocks in a semiarid Calcixerepts. It remains, however, unknown whether microbial indicators of soil quality would show a response to different tillage systems. Therefore, the main objective of the current study was to measure soil microbial indicators (microbial biomass C and N, C and N mineralization rates, and urease, alkaline phosphatase and catalase activities) after chisel and rotary plows as non-inversion tillage or RT systems in the medium-term (6 years). Results were compared with moldboard and disk plows as inversion tillage systems that are commonly practiced in Central Iran. We hypothesized that (1) soil microbial properties would respond more rapidly to tillage treatments than SOM contents after six years and (2) the magnitude of differences in the microbial indicators of soil quality between tillage systems may vary over years of tillage treatments.

2. Materials and methods

2.1. Study location and experimental arrangement

This study was conducted at the Agricultural Research Station of Shahrekord University (32°21′14″N; 50°51′52″E; altitude 2085 m above sea level) with semi-arid climate. Kabiri et al. (2015) provided a detailed description of the study location and experimental set-up. In brief, the selected experimental site had not been ploughed for five years prior to the experiment. The annual precipitation over the six yrs. of study varied greatly from 196 (2008) to 447 (2005) mm and most of it occurred between November and February. The average annual precipitation over the experimental period was 316 mm. The annual temperature at the study location ranged from 9.8 (2006) to 11.6 (2008) °C during the experiment. Annual average temperature for the duration of the study was 11.9 °C. The experimental plots were established in 2005 on a calcareous loam soil classified as Haplic Calcisols or mesic Typic Calcixerepts. Composite soil samples were collected randomly from the 0–20 cm depth for analysis of the initial soil properties before the commencement of the experiment. The initial properties in the soil surface layer were: 290 g sand kg^{-1}, 440 g clay kg^{-1}, 260 g silt kg^{-1}, bulk density 1.61 Mg m^{-3}, pH (1:5 in water) 7.95, EC (1:5) 0.40 dS m^{-1}, 5.84 g organic carbon (OC) kg^{-1}, 0.49 g total nitrogen (TN) kg^{-1}, 12.2 mg available P kg^{-1}, 207 mg available K kg^{-1} and 350 g $CaCO_3$ kg^{-1}. Data on soil pH, bulk density, and OC and TN concentrations under tillage systems and over experimental period are shown in Table 1 (Kabiri et al., 2015).

The experiment was setup in a randomized complete block design with four tillage systems. The tillage systems were: (1) moldboard plow (MP) to a depth of 17–18 cm; (2) disk plow (DP) to a depth of 17 cm; (3) chisel plow (CP) to a depth of 14 cm, and (4) rotary plow to a soil depth of 10 cm (RP). Each tillage treatment was replicated three times (plot size 4 m × 50 m). The distance between blocks was 4 m and the distance between plots in each block was 1.5 m as buffer zone. The plant rotation started with red clover (*Trifolium pratense* L.) planted in mid-autumn (2005 and 2008) at a density of about 200 plants m^{-2}, which was followed by barley (*Hordeum vulgare* L.) planted in mid-autumn (2006, 2008 and 2010) at a density of about 350 plants m^{-2} and fallow period in the subsequent year (2007, 2009 and 2011). Approximately 25–35% of the barley top residues were left on and added to the soil surface after plant harvest in all the tillage treatments while the clover residues were fully added as green manure to the soil surface. Other agricultural practices were identical to those used by local farmers. Barley straw from previous year was hand-harvested at 25 cm after reaching physiological maturity only in 2007 and 2011, dried at 60 °C, and the weight of straw was determined. For clover, forage production from previous year was similarly measured in 2006 and 2008 using 0.5 × 0.5 m quadrates, and the remaining plant biomass was returned to the plots as green manure. Data on plant aboveground biomass are reported in Table 2.

Table 2
Straw yield of barley and clover herbage production (kg ha^{-1}) under tillage systems and over the study period (2005–2011).

Plant biomass	Tillage treatment				Harvested in year			
	Moldboard	Disk	Rotary	Chisel	2006	2007	2008	2011
Barley straw	3460	3180	2750	3100	ND	3120	ND	3130
Clover herbage	9600	10270	8800	10700	9900	ND	9800	ND

ND, not determined.

Table 1
Effect of tillage treatments and sampling years on soil pH, bulk density, the concentrations of organic carbon (OC) and total nitrogen (TN), and C/N ratios in the surface layer (0–20 cm) in a semi-arid loam soil from Iran (Kabiri et al., 2015).

Soil attribute	Tillage treatment				$LSD_{0.05}$	Sampling year			$LSD_{0.05}$
	Moldboard	Disk	Rotary	Chisel		2008	2009	2011	
pH	7.67	7.69	7.65	7.64	0.234	7.93	7.55	7.50	0.322
Bulk density (Mg m^{-3})	1.60	1.59	1.55	1.52	0.016	1.59	ND	1.54	0.020
OC (g kg^{-1})	6.97	6.93	7.00	7.18	0.273	6.03	7.37	7.67	0.176
TN (g kg^{-1})	0.75	0.70	0.65	0.72	0.099	0.53	0.72	0.88	0.100
C/N	9.9	10.6	11.0	10.4	2.070	11.7	10.6	9.02	1.391

The least significant difference (LSD) values for differences among means (n = 9 for tillage treatment and n = 12 for sampling year) are shown at $P < 0.05$.