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Tillage, seasonal and depths effects on soil microbial properties in black soil of Northeast China

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ABSTRACT

Tillage practice can alter the content and distribution of soil organic matter by burying crop residue and soil disturbance, which would impact soil microbial properties. The objective of the present study was to evaluate the effects of tillage practices (no tillage, NT; ridge tillage, RT; mouldboard plow, MP) and sampling date (April, June, September) on soil microbial properties at different soil depths. Soil core samples were taken at 0–5, 5–10 and 10–20 cm depths from a long-term tillage experiment site (initiated in 2001) in black soils in northeast China. Microbial biomass and extractable organic C were determined using by chloroform-fumigation-extraction method. Microbial abundance and community structure were determined using the phospholipid fatty acid (PLFA) method. Principal response curve (PRC) analysis revealed the magnitude of the effect of sampling date on the PLFA relative abundance decreased with depth within the tilled layer, whereas increased with depth for tillage practice. Microbial biomass carbon, abundance and the F/B ratio varied with the variation in available substrates at the 0–5 cm depths. NT and RT improved microbial abundance (total, fungal and bacterial abundance) in the 0–5 cm depth soil, but they did not contribute to a higher F/B ratio in the 0–5 cm depth soil, and had a lower F/B ratio than MP in the deeper soils below 5 cm depth. These results demonstrated that long-term conservation tillage practice has potential for improving microbial properties in surface soil, but may not cause a shift of microbial community structure in Northeast China.

1. Introduction

Soil microorganisms play an important role in biogeochemical cycling, which underpin and shape the effectiveness and mechanisms of utilizing soil organic matter (Bowles et al., 2014; Huang et al., 2014). Tillage is a major factor in altering soil physical and chemical characteristics, which in turn modify microbial activity and community structure (Jiang et al., 2011). It has been broadly proven that intensive tillage practices decrease microbial biomass by decreasing or reversing carbon accumulation and breaking down soil structure (Frey et al., 1999; Liang et al., 2011; Lupwayi et al., 2012; Wright et al., 2008). In contrast, the globally recommended practice of conservation tillage has been shown to increase microbial biomass and activity (Jacobs et al., 2010; Triplett and Dick, 2008; Wang et al., 2011). Most studies found that conservation tillage management caused accumulation of soil microbial biomass and shifts of soil microbial community from bacteria-dominated to fungi-dominated in surface soil compared with conventional tillage (Frey et al., 1999; Minoshima et al., 2007). However, in several other studies, tillage did not alter the soil microbial community structure, which may be highly influenced by nutrient availability, temporal factors and spatial scale (Helgason et al., 2009; Wardle and Zackrisson, 2005). It has been reported that time may dominate tillage management effects on soil microbial community, as seasonal crop growth regulates the quantity, quality and spatial distribution of organic matter (Spedding et al., 2004). Hence, to differentiate the effects of tillage and time will provide an insight of soil biological processes. A large number of publications exist dealing with tillage effects on microbial properties. Temporal/seasonal variations and spatial effects were also considered in several studies so far. However, there are only few studies dealing with these three factors in combination.

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The Black soil region of Northeast China is well known for its natural high soil organic matter content and crop productivity. However, conventional tillage which includes mouldboard plow (MP), has caused the loss of soil organic carbon and the severe soil degradation of soil structure in this region (Liu et al., 2010). Conservation tillage, including no tillage (NT) and ridge tillage (RT), may be a viable strategy to curb or reverse soil degradation (Feng et al., 2010). Much of the tillage research in this region has focused on physical and chemical processes under contrasting tillage systems, and found that conservation tillage increased the soil water content, soil macroporosity and soil organic carbon content and decreased soil bulk density (Chen et al., 2014). However, little information is available on the temporal dimension of soil biological properties at different soil depths. Principal response curve (PRC) analysis is a suitable method to assess the structure of soil microbial community and investigate changes of soil microbial community composition over time (Moser et al., 2007).

The objective of the present study was to determine the impact of long-term tillage practice on microbial properties of black soil at different depths and different sampling dates. We hypothesized that (1) compared with MP, conservation tillage (NT and RT) will positively affect microbial properties and will cause a shift in microbial community structure and (2) the temporal variability of soil microbial properties reacts differently at different soil depths.

2. Materials and methods

2.1. Experimental site

The tillage experiment was initiated in fall 2001 at Experimental Station (44°12′N, 125°33′E) of Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, in Dehui County, Jilin Province, China. The altitude is about 177 m. The climate is a temperate continental monsoon. The mean annual temperature is 4.4 °C, with the coldest month in January (−19.5 °C) and the warmest month in July (24.5 °C). The mean annual precipitation is 520 mm and more than 70% of the annual occurs from June to August. The soil is classified as black soil (Typic Hapludoll, USDA Soil Taxonomy) with a clay loam texture (the average soil texture is 36.0% clay, 24.5% silt and 39.5% sand). The site had been used for producing monoculture maize (*Zea mays* L.) with conventional tillage management more than 10 years prior to 2001. More detailed information about physical and chemical properties of the experimental site are given by Liang et al. (2007).

2.2. Field experimental design

The long-term tillage experiment was established in a randomized complete block design with three tillage treatments and four replications. Each main plot was 10.4 × 20 m and each main plot was split into two 5.2 × 20 m sub-plots. Three tillage system treatments, NT, RT and MP were applied at the main plot level and two cropping systems, monoculture maize and maize-soybean (*Glycine max* Merr.) rotation were applied at the sub-plot level. Crops were planted in May and harvested in September. The soil in the NT plots was not disturbed except for planting using a no-till planter. In RT, a modified lister and scrubber were used to form and press the ridge (16 cm in height and 75 cm in wide) prior to planting, and the ridges were maintained in June of each year with a cultivator. MP included one disking (7.5–10 cm in depth) and harrowing in spring, and mouldboard ploughing (about 20 cm deep) after maize harvest in fall. Weed control under NT was achieved using broad-spectrum herbicides and weeds were removed with a manual brush hoe when necessary during growing season in RT and MP with a hoeing depth of approximately 5 cm. Following manual harvest, maize stalks in the RT and NT plots were manually cut into 30 cm pieces leaving 30–35 cm stubble and then laid on the soil surface. All aboveground maize residues were removed prior to fall ploughing in MP plots. Soybean residue was was left on the soil surface for all three tillage systems (Zhang et al., 2013).

For maize, 100 kg N ha^{-1}, 45.5 kg P ha^{-1} and 78 kg K ha^{-1} were applied each year as base fertilizer and an additional 50 kg N ha^{-1} was applied as top dressing at the V-6 growth stage (6 leaves with collars). For soybean, 40 kg N ha^{-1}, 60 kg P ha^{-1} and 80 kg K ha^{-1} were applied as base fertilizer. Base fertilizers for all plots were applied as sideband concurrently with planting.

2.3. Sample collection

Soil samples were collected for three of the four replicates in each tillage system in monoculture maize, and the maize phase of the maize–soybean rotation at three separate times: April 16 (pre-plant), June 4 (V-4 stage) and September 25 (after harvest) of 2013. Seven core samples (2.64-cm diameter, 20-cm depth) were taken from each plot. Each core sample was separated into three segments (0–5, 5–10 and 10–20 cm), and then the seven core sample segments for each of the three depths in each plot were combined into a single composite sample for each depth in each plot. Samples were stored on ice in a portable cooler during transport to the laboratory and were processed (sieved to <2 mm and freeze-dried) within 48 h. Soil temperature (T_{soil}) at 5 cm and

Table 1
Repeated-measures ANOVA results of the effects of tillage and sampling date on soil physicochemical properties.

Variation	df	MBC	EOC	TDN	SWC	T_{soil}
0–5 cm						
Tillage	2	**	ns	ns	**	ns
Time	2	***	*	***	***	***
Tillage × time	4	ns	ns	ns	ns	ns
5–10 cm						
Tillage	2	ns	*	ns	ns	ns
Time	2	***	*	**	***	***
Tillage × time	4	ns	ns	ns	ns	ns
10–20 cm						
Tillage	2	ns	ns	ns	ns	ns
Time	2	*		**	***	ns
Tillage × time	4	ns	ns	ns	ns	ns

*, **, *** indicate significant differences at P = 0.05, 0.01 and 0.001, respectively. ns represents no statistical significance at the P = 0.05 level. MBC represents microbial biomass carbon; EOC represents extractable organic carbon; TDN represents total dissolved nitrogen; SWC represents soil water content; T_{soil} represents soil temperature; *df* represents degree of freedom.

Table 2
Effect of tillage and sampling date on soil water content and temperature

Parameter		Soil water content (g g^{-1} soil)			Soil temperature (°C)		
Time	Depth	NT	RT	MP	NT	RT	MP
April	0–5 cm	0.31Aa	0.32Aa	0.27Ba	–	–	–
	5–10 cm	0.27Aa	0.29Aa	0.28Aa	–	–	–
	10–20 cm	0.27Aa	0.28Aa	0.28Aa	–	–	–
June	0–5 cm	0.18Ab	0.16ABb	0.13Bc	18.2A	18.2A	18.5A
	5–10 cm	0.22Ab	0.22Ab	0.22Ab	17.6B	17.6B	18.0A
	10–20 cm	0.23Ab	0.22Ab	0.22Ab	–	–	–
September	0–5 cm	0.19Ab	0.19Ab	0.18Ab	14.0A	14.3A	14.1A
	5–10 cm	0.21Ac	0.21Ab	0.21Ab	12.1A	13.0A	12.4A
	10–20 cm	0.22Ab	0.21Ab	0.21Ab	–	–	–

– indicates not determined. Means followed by the same upper case letter indicate no significant differences among tillage treatments; means followed by the same lower case letter indicate no significant differences among sampling dates.