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Impacts of 9 years of a new conservational agricultural management on soil organic carbon fractions

Wang Quanying[a], Wang Yang[b], Wang Qicun[a], Liu Jingshuang[a,*]

[a] Key Laboratory of Wet Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China
[b] Key Laboratory of Mollisols Agroecology, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China

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ABSTRACT

Labile soil organic carbon pools are widely regarded as valuable indicators of changes in soil C sequestration pools and dynamics induced by different soil management practices. The objective of this study was to evaluate how a new conservational agricultural management (NCAM), which has been proved to be an effective pattern to increase corn yield, affects soil organic C (SOC) and labile SOC pools after a 9-year experiment in Northeast China. Narrow-wide row (1.70 m wide row and 0.30 m narrow row, corn is sowed in the narrow row with two lines), no-till, residue retention, change of ridge direction, and fallow are adopted for NCAM. Soil under conventional agricultural management (CAM) was also studied to be as a comparison. Soil samples were taken from 0–20 to 20–40 cm depths. The results showed that no significant difference was found for SOC between the two managements for both depths, indicating that SOC is a too gross measurement. Soil labile organic C fractions: microbial biomass C, hot-water extractable organic C and permanganate oxidizable C ($KMnO_4$–C) contents were significantly higher under NCAM compared to CAM for both depths, reflecting the build-up of labile C pools under NCAM. In addition, of the three C fractions, $KMnO_4$–C was the most sensitive indicator of changes in SOC induced by different agricultural management regimes. Our results implied that the application of NCAM is important to soil C sequestration and improving soil quality.

1. Introduction

It is widely known that the high levels of soil organic C (SOC) are linked to the improvements of nutrient supply to crops. Thus, the enhancement of SOC in agricultural soils could not only improve soil quality but also could increase crop productivity (Lal, 2004). Soil management systems can affect SOC in the agricultural ecosystem (Plante et al., 2006). However, it is difficult to detect the changes in total SOC in the short- and medium-term because of the large background amounts of relatively stable SOC (Gregorich et al., 1994). Meanwhile, SOC is recognized to consist of various fractions varying in degree of decomposition, recalcitrance, and turnover rate. Labile SOC pools are valuable indicators of early changes in SOC stocks, and (hence) changes in soil C sequestration pools and dynamics induced by changes in soil management practices (Haynes, 2000; Weil et al., 2003). Thus, it would be useful if labile SOC fractions are identified. Additionally, since soil is a complex system, the measurement of a single labile SOC fraction does not adequately reflect management-induced changes in soil quality. Soil microbial biomass C (SMBC), hot-water extractable organic C (HWEOC) and permanganate oxidizable C ($KMnO_4$–C) have been widely recognized as labile SOC pools and important indicators of soil quality (Ghani et al., 2003; Chen et al., 2009). SMBC, as the living component of soil organic matter (SOM), has played a critical role in nutrient cycling and SOM decomposition and transformation. The hot water extraction method is thought to extract the soluble organic C which originates from soil microbial biomass, root exudates, and lysates (Ghani et al., 2003). $KMnO_4$ oxidation simulates microbial decomposition, and therefore $KMnO_4$–C partly reflects the in situ enzymatic decomposition of labile SOM (Loginow et al., 1987).

The "Jilin Corn Belt" (40°–42° N, 125°–128° E) covers an area of 60,000 km^2, and it has played a very important role in food supply in China. The sustainability of agriculture in this region could affect China's food security. Soil has been intensively used in an improper way in this area since the reclamation, especially in the latest 50 years, i.e. conventional agricultural management (CAM) (Yang et al., 2003). Under this cultivation system, tillage and residue

* Corresponding author. Tel.: +86 431 85542296; fax: +86 431 85542298.
E-mail address: liujingshuang@neigae.ac.cn (J. Liu).

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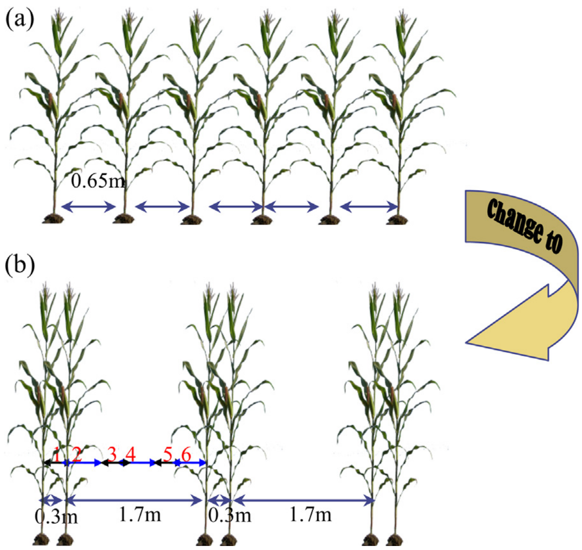

Fig. 1. The sketches of the conventional agricultural management and the new conservational agricultural management. (a) conventional agricultural management; (b) new conservational agricultural management. Under the new conservational agricultural management, the ridge direction is the south-west 15–20 degrees, and a 2.0 m super wide row is adopted. The super wide row is combined by a wide row with a distance of 1.7 m and a narrow row with a distance of 0.3 m. The wide row is separated into five parts, with 37 cm for parts 2, 4 and 6, while 30 cm for parts 3 and 5, respectively. The corn is sown in part 1 with two lines for the first year and the rest parts are left fallow. Then, the corn is sown in parts 3 and 5 for the second year and the third year, respectively. For the fourth year, the corn is sown in part 1 again. Thus, the rotation cycle period is three years for the new conservational agricultural management.

removal practices are adopted. Consequently, this agricultural strategy has resulted in serious environmental problems, such as the decrease of SOC content (Wang et al., 2007). In order to make the corn utilize the sunlight fully during the growth and to increase crop yields in this area, we have proposed a new conservational agricultural management (NCAM). Under NCAM, narrow-wide row, no-till, residue retention, change of ridge direction, and fallow are adopted (Fig. 1; Liu et al., 2006). According to the results of a 9-year field experiment, the corn yield has increased about 15–17% under the NCAM compared to the CAM.

Because SOM is an important indicator of soil fertility and productivity, the maintenance of SOC is necessary for sustainable agroecosystems (Gregorich et al., 1994; Haynes, 2005). Many studies have indicated that various tillage systems have different effects on SOC, depending on regional climate, soil type, residue management practice, and crop rotation (Chan et al., 2002; Puget and Lal, 2005; Qin et al., 2010). Moreover, the differences in amounts of labile organic C fractions resulting from different management practices can provide valuable information about mechanisms of C sequestration (Six et al., 2002). Hence, for an improved understanding of the effects of NCAM on soil quality, researches about SOC pools are needed. The objectives of this study were to investigate the effects of NCAM (after a 9-year period) on labile SOC pools including SMBC, HWEOC, and $KMnO_4$–C, and their sensitivity to management-induced changes. For comparison, the effects of CAM, which is a dominant agricultural management in this area, on labile SOC pools were also studied.

2. Materials and methods

2.1. Site information

This study was conducted at the Agricultural Experiment Station of Black Soil (44°12′ N, 125°33′ E), Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Dehui County, Jilin Province, China. The mean annual temperature is 4.4 °C, and the mean annual precipitation is 520 mm. The soil is classified as Mollisols according to USDA Soil Taxonomy, with a mollic epipedon 0–50 cm. The average soil texture was 36.0% clay, 24.5% silt and 39.5% sand. In the spring of 2004, part of the field under CAM was converted to NCAM. The area of CAM and NCAM is 10,000 m^2, respectively. Corn is sown in April and harvested in September. After harvest, the corn straw keeps 30–35 cm stubble stand for CAM and NCAM. The CAM includes the processes of tillage and remove of crop residues. The tillage treatment is performed by a stubble cleaner, and this tool is similar to a shallow plough but undercuts and mixes only the upper soil layer (10 cm). To make the ridge direction coincidence with the direction of sunlight radiation in summer in Dehui County, the ridge direction was changed from the north-south to the south-west 20 degrees under NCAM. A "30 cm + 170 cm" narrow-wide row was adopted for the NCAM. Under NCAM, the soil is virtually left undisturbed except for the opening where the seed is placed. The residue retention is performed for NCAM, and the corn straw is just left in the narrow rows as a whole. Under the CAM, the distance between the plants is 25 cm, while the distance is 16.7 cm under NCAM. Thus, the numbers of the corn are both 6.4 plants m^{-2} for the two different managements. The corn is planted with self-made no-till planter under NCAM. The application rates of N, P and K are the same for the two managements. Each year, N, P and K fertilizers were applied to corn at 100, 45.5 and 78 kg ha^{-1} respectively as starter fertilizers. The types of these fertilizers were urea, ammonium, dibasic phosphate, and potassium sulfate. Additional, 50 kg N ha^{-1} was top dressed at the sixth leaf stage of maize. More specific information about NCAM can be found in Table 1 and Fig. 1.

2.2. Soil sampling

Soil samples were collected from two depths (0–20 and 20–40 cm) in October 2012. Three tillage rotation cycles have finished for the NCAM. Twelve soil samples were collected from each

Table 1
Planting patterns of the two agricultural managements. CAM, conventional agricultural management. NCAM, new conservational agricultural management.

	Row spacing	Row direction	Residue retention	Tillage	Rotation	Plant distance	Mean corn yield (kg hm^{-1} $year^{-1}$)		
CAM	65 cm	North–south		Without crop residues		Tillage (mixes only the upper 20 cm layer)	No	25 cm (6.4 plants m^{-2})	8500
NCAM	"30 cm + 170 cm" narrow-wide row	South–west 20 degree	Residue retention (the corn straw is just left in the narrow rows as a whole)	No till	Rotation (the rotation cycle period is three years)	16.7 cm (6.4 plants m^{-2})	11,000		