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Effect of conservation farming practices on soil organic matter and stratification in a mono-cropping system of Northern China

Zhiqiang Zhang[a], Hongjun Qiang[a], Allen D. McHugh[b], Jin He[a,*], Hongwen Li[a], Qingjie Wang[a], Zhanyuan Lu[c]

[a] Beijing Key Laboratory of Optimized Design for Modern Agricultural Equipment, College of Engineering, China Agricultural University, Beijing 100083, China
[b] International Maize and Wheat Improvement Centre (CIMMYT), Yinchuan 750002, China
[c] Inner Mongolia Academy of Agriculture and Animal Husbandry, Hohhot 010031, China

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ABSTRACT

An arid environment under long-term traditional agriculture has resulted in serious environmental and agricultural problems on a number of fragile soils with distinguishing physical and chemical properties in Northern China. Conservation agriculture is an alternative sustainable agriculture management system, which contributes to conserving soil, water and fertility, while changing vertical distribution of soil organic matter (SOM). No-tillage with straw cover (NTSC) and traditional tillage with straw removal (TTSR) in four regions of northern China (Tailai, Wuchuan, Nailin, Yaodu) were investigated to determine how tillage and soil type affected SOM stratification. SOM content, total N (TN), soil water content (SWC) and soil bulk density (ρ_d) in the 0–5, 5–15, 15–30 and 30–40 cm layers and the time since implementation of tillage treatments were evaluated. The top layer (0–5 cm) and total SOM content were markedly improved by NTSC. The influence dramatically decreased with depth in all sites. SOM content increased during the first 10 years following NTSC implementation, but the rate of increase was reduced in subsequent years. There was high positive correlation between SOM and SWC, high positive correlation between SOM and TN, and high negative correlation between SOM and bulk density. Effects of conservation measures on SOM content were expressed by a stratification ratio. The stratification ratio of SOM, in most sites, under long-term NTSC were >2. These results from northern China, suggest that long-term no-tillage with straw cover significantly improved topsoil conditions and whole of soil profile SOM and this improvement was obvious in different layers.

1. Introduction

Soil is an essential natural resource that provides several important ecosystem functions for plant growth and regulation of water flow in the environment. Soil organic carbon (SOC) and soil organic matter (SOM), which includes all soil macro biota, plant residues and microorganisms and their organic products, play an important role in soil fertility, structure and the supply of ecosystem services (Dikgwatlhe et al., 2014). According to Ito et al. (2015) tillage and cropping impacted a range of soil physical and chemical properties. Bai et al. (2009) showed that no-tillage (NT) and straw cover decreased mean bulk density (ρ_d) by 0.08 on silt loam soils. Wang et al. (2014) claimed that NT with subsoiling and straw cover reduced ρ_d in the 0–30 cm soil layer, and increased total porosity, water stable aggregates and pore size class distribution, and improved infiltration. However, soil disturbance associated with tillage and changed organic matter cycling, caused organic matter levels in the soil to decline and aggravated off-site transport of N (Lal, 2007). The promotion and application of suitable farming practices across agriculture sectors, i.e., less tillage, is vital to broadly improve SOC (Jarecki and Lal, 2003). During the last 60 years reduced and no tillage farming practices have continually improved farming and soil conditions around the world, however plow based agriculture is still widely practiced across China, with less than 4% (6.7 Mha) of the arable land converted to conservation agriculture (no-tillage, permanent organic soil cover and crop rotations) (Jat et al., 2014; FAO AQUASTAT, 2015).

Numerous authors have confirmed that soil fertility declines as organic matter runs down. Less organic matter, combined with tillage disturbance, has led to reduced aggregate stability and increased surface crusting, causing restricted infiltration, poor quality of seedbed preparation and inefficient use of rainfall.

* Corresponding author. Fax: +86 10 62737300.
E-mail address: hejin@cau.edu.cn (J. He).

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According to Alakukku et al. (2003), machinery wheel tracks and tillage operations cause compaction of sub-surface soil layers, as a result compacted soils are less permeable, have changed water holding properties and increased resistance to penetration by roots. Therefore well aggregated soil with organic carbon are of vital importance in resisting compaction forces and providing energy, substrates, and the biological diversity necessary to maintain numerous soil physical and chemical functions. Sustainable provision of ecosystem services facilitates an increase in agricultural productivity and environmental quality (Sojka and Upchurch, 1999; Lal, 2010). However, in the North China Plain this is not the case, as soil quality is poor due to excessive tillage and mono-cropping practices. According to Din (2006) this rain-fed region has minimal precipitation, low temperatures, serious soil degradation and increasing severity of sandstorms, which further results in greatly decreased SOM content.

Smart and Bradford (1999) stated that wind and water erosion were reduced, and water content in the soil profile is increased, if plant residue were maintained as an organic mulch on the soil surface. The presence of organic mulch reduces evaporation and it insulates the soil surface against temperature extremes (Zribi et al., 2015). The retention of standing stubble and mulch also alleviates soil compaction and there is typically an increase in infiltration rates that results in decreased off site movement of fertilizers, herbicides and pesticides (Brendan et al., 2010). Riley (2014) found that reduced tillage increased porosity at 4–8 cm depth and decreased it slightly at 24–28 cm, altered soil moisture-holding capacity and increased aggregate stability, and thought that changes in bulk density and total porosity were mostly attributable to changes in the stratification of SOM. Soil aggregates are important for SOM retention and they protect against C oxidisation (Haile et al., 2008; Six et al., 2000). Ochoa et al. (2009) concluded that the increase in surface soil water-stable macroaggregates was related to the hydrolysable organic carbon with longer years under no-tillage which contributed to the buildup of SOM in soil macroaggregates. Huang et al. (2010) concluded that NT facilitated soil particle aggregation by stimulating C accumulation within microaggregates, which acted upon the soil to form macroaggregates. This shift of SOC to within microaggregates is essential for long-term C sequestration in soil.

In all these soil physical and chemical attributes carbon, either indirectly or directly, plays a significant role. According to Dalgliesh and Foale (1998) under undisturbed vegetation organic carbon can range from 1 to 3% (soil and region specific), however after continuous cropping for more than 60 years organic carbon levels drop to far below 1%, which is accompanied by significant loss in soil structure. The level of organic C in the soil is a function of incorporation of new plant material and the rate of oxidation, which the latter is dependent on soil temperature, moisture and exposure to the atmosphere (Dalgliesh and Foale, 1998). Under conventional farming in Northern China the retention of plant material in the field is reduced due to harvested product removal, competing demands for straw and residue burning. Additionally cultivation during residue incorporation exposes a much larger surface area of soil aggregates to the atmosphere increasing the rate of C oxidation and the loss of N and valuable soil moisture. Adopting conservation farming practices can reverse soil degradation by halting the rundown of soil organic matter as demonstrated in an analysis of 17 experiments by Kern and Johnson (1993), who concluded that by changing from conventional tillage (CT) to no tillage sequestered C in the top 8 cm of the soil, a lesser amount at a depth of 8–15 cm, but with no significant amount below 15 cm.

This stratification of SOM at different depths (soil horizon distribution) is common in many natural ecosystems such as: managed grasslands and forests, as well as when degraded cropland is restored with conservation farming practices (Franzluebbers, 2002). Changes in SOC, as influenced by soil disturbance, are expected to be more noticeable under long-term, rather than short-term practices. Kern and Johnson (1993) concluded the duration of C sequestration to be between 10 and 20 years. Paustian et al. (1997) compared 39 paired tillage experiments, ranging in duration from 5 to 20 years, and estimated that NT resulted in an average soil C increase of 285 $g\,m^{-2}$ with respect to CT. West and Post (2002) reported that a change from CT to NT can sequester an average $57 \pm 14\,g\,C\,m^{-2}\,year^{-1}$, and based on regression analyses indicate that, within 5–20 years, C sequestration rates can be expected to; have a delayed response, reach peak

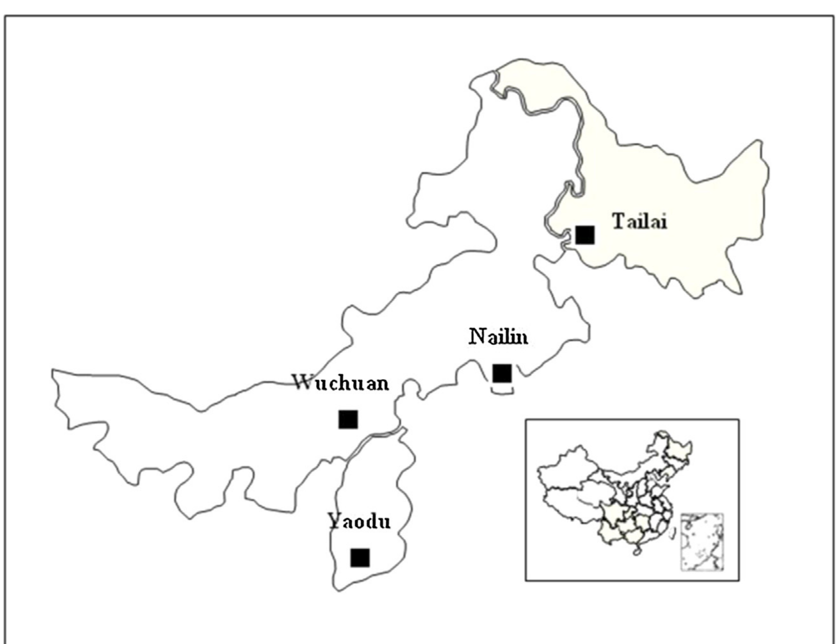

Fig. 1. The study areas and sampling locations of the four sites in Heilongjiang, Inner Mongolia Autonomous Region and Shanxi Provinces of PR China.