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Soil chemical properties and microbial biomass after 16 years of no-tillage farming on the Loess Plateau, China

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Abstract

Data from a 16-year field experiment conducted in Shanxi, on the Chinese Loess Plateau, were used to compare the long-term effects of no-tillage with straw cover (NTSC) and traditional tillage with straw removal (TTSR) in a winter wheat (*Triticum aestivum* L.) monoculture. Long-term no-tillage with straw cover increased SOM by 21.7% and TN by 51.0% at 0–10 cm depth and available P by 97.3% at 0–5 cm depth compared to traditional tillage. Soil microbial biomass C and N increased by 135.3% and 104.4% with NTSC compared to TTSR for 0–10 cm depth, respectively. Under NTSC, the metabolic quotient (CO_2 evolved per unit of MBC) decreased by 45.1% on average in the top 10 cm soil layer, which suggests that TTSR produced a microbial pool that was more metabolically active than under NTSC. Consequently, winter wheat yield was about 15.5% higher under NTSC than under TTSR. The data collected from our 16-year experiment show that NTSC is a more sustainable farming system which can improve soil chemical properties, microbial biomass and activity, and thus increase crop yield in the rainfed dryland farming areas of northern China. The soil processes responsible for the improved yields and soil quality, in particular soil organic matter, require further research.

Keywords: No-tillage; Soil organic matter; Total nitrogen; Available phosphorus; Soil microbial biomass; Metabolic quotient

1. Introduction

Soil organic matter (SOM) is crucial for maintaining soil quality as it stabilises soil structure against erosive forces and increases water capacity and nutrient availability. Increasing SOM on agricultural land may also provide a potential sink for atmospheric carbon (Ellert and Janzen, 1999; Reicosky et al., 1999). Long-term tillage causes severe SOM depletion in agricultural soils (Six et al., 2000) and is responsible for reducing soil organic carbon levels by up to 70% (Lal and Bruce, 1999). The different soil organic matter pools (litter, humus and living microbial biomass) that respond to management are often used as measures of soil quality (e.g. biological productivity, plant and animal health) (Doran and Parkin, 1994). These organic matter pools support plant production and influence many important physical, chemical and biological parameters of soils (Kumar and Goh, 2000). China is one of the main dryland faming countries in the world. The arid and semi-arid areas, mainly located in 16 provinces of northern China, account for 52.5% of the total national land area, i.e. 33 Mha of rainfed arable land for crop production without irrigation (Zhai and Deng, 2000). Dryland farming areas with minimal rainfall, low temperatures (short frost-free period) and high evaporation have very sensitive soils. Traditional tillage practices based on ploughing, low fertilizer or manure input, and little use of crop residue, lead to a decline in SOM and can cause soil degradation. Such degradation leads to reduced water and nutrient availability, low microbial biomass, and fragile soil

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physical structure. Consequently, yields become unstable and tend to decline and fertilizer, water, energy and labor are not used efficiently. Traditional tillage in northern China has already resulted in widespread soil degradation (Gao et al., 1999; Liu, 2004). No-tillage practices featuring residue cover and less soil disturbance have been shown to reduce runoff by 52.5% and reduce erosion by 80.2% compared to traditional tillage (Wang, 2000). Liang et al. (2007) demonstrated that no-tillage significantly increased the concentration of soil organic C in 5–20 cm soil layer by 5.6–5.9% on the clay loam soils after 3 years in the humid northeastern China. In the more arid northern China, Li et al. (2006) conducted a 4 years no-tillage experiment and showed that active C and total organic C down to 10 cm depth were up to 5% higher in no-tillage than traditional tillage systems. The application of no-tillage was also associated with increased yields and water use efficiency. Such improvement is largely due to improved soil quality. Experiments conducted by Liu (2004) in the village of Dingxing in the Hebei province showed that conservation tillage systems can increase organic matter, nitrogen, phosphorus, and potassium in the topsoil layer. Additionally, if crop residue is left in the field, this eliminates straw-burning and the labor requirements for removing straws from the fields.

The studies mentioned above have shown that conservation tillage can improve soil physical properties, reduce wind and water erosion and increase soil fertility in northern China (e.g. Li et al., 2005; Luo et al., 2005; Zhou et al., 2007). However, comparatively little information is available on the changes in soil organic matter and nutrients, in particular microbial biomass for different tillage systems. A better understanding of the long-term effects of no-tillage and straw management practices on SOM, nutrients, microbial biomass and activity is also necessary for the further development of conservation tillage in dryland farming areas in China. Since 1992, the Australian Centre for International Agricultural Research (ACIAR) and the Chinese Ministry of Agriculture have conducted experimental research on conservation tillage in the Loess Plateau of Shanxi province, northern China. The objective of this research is to identify the long-term effects of no-tillage with full straw cover to traditional tillage with full straw removal on soil chemical properties and microbial biomass on a rainfed dryland farming system on the Chinese Loess Plateau.

2. Materials and methods

2.1. Site description

The study was conducted at the site of a long-term experiment (1992–2007) located in the village of Chenghuang near the city of Linfen (38°6 N, 113°E, 456 m a.s.l.) on the Loess Plateau in the south-central Shanxi province. Linfen lies in a semi-arid and warm temperate zone and has a continental climate. The mean annual temperature in the region is 10.7 °C and precipitation is about 555 mm (Fig. 1), but highly variable between years. About 65% of the annual precipitation occurs as rainfall during the summer season (June–September). The frost-free season lasts 180 days. A single crop system of winter wheat is common, with crops sown in September and harvested in June. In the experimental plots, the soil type is a Chromic Cambisol (sand 23.1%, silt 43.3%, clay 33.6%, pH 8.1) according to the FAO/UNESCO soil classification. In the top 30 cm layer, soil bulk density was 1.3 Mg m^{-3}, and total porosity was about 40%. The field capacity and wilting point were 21% and 4% by weight, respectively.

2.2. Experimental design

At the beginning of the experiment in 1992, the entire field was ploughed to a depth of 40 cm to mix soil thoroughly and ensure uniform soil conditions in each experimental plot. The experiment was designed as a randomized block with three replications. Each plot was 9 m wide and 78 m long. The two tillage systems, traditional tillage with straw removal (TTSR) and no-tillage with straw cover (NTSC), were applied to the experimental plots from 1992 to 2007. The TTSR system included spreading of fertilizer, ploughing to 15 cm depth and tillage for seedbed preparation, planting between September 20th and 30th, herbicide (2,4-D butylate) and insecticide (40% dimethoate) spraying in April, and manual harvesting between June 1st and 10th. While the majority of straw was removed, a small amount of standing stubble of 8 to 15 cm in height (0.7 t ha^{-1}) remained after the winter wheat was harvested. A fallow period followed harvest until mid-September when the soil was ploughed to 15 cm depth again. The NTSC system was applied as follows: no-tillage planting and fertilizing between September 20th and 30th, herbicide (2,4-D butylate) and insecticide (40% dimethoate) spraying in April, and harvesting between June 1st and 10th by mechanized harvester. Standing stubble of 15 to 25 cm in height was retained with all wheat straw left as mulch cover (3.8 t ha^{-1}) Properties of the winter wheat residue were showed in Table 1. A fallow period followed harvest until mid-September, with chemical weed control applied when necessary. During the experimental period of 1992–2007, for each crop cycle, 2,4-D butylate and 40% dimethoate were applied at the rate of 0.9 and 0.3 kg (a.i.) ha^{-1} using a knapsack sprayer with a flat fan nozzle. The winter wheat variety was

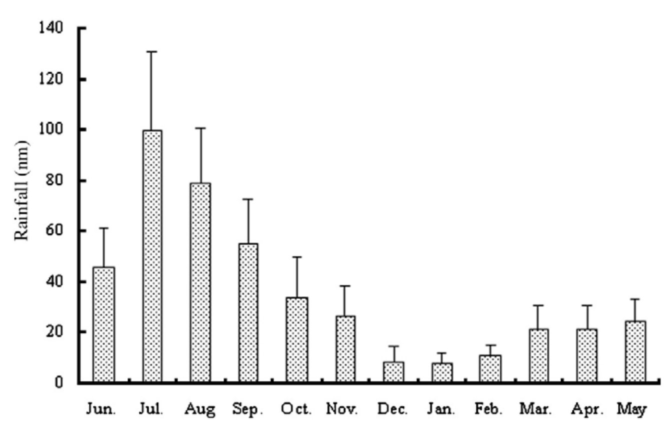

Fig. 1. Distribution of mean monthly rainfall at the experimental site from June 2002 to May 2007. Error bars represent standard deviation.