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Tillage effect on soil organic carbon, microbial biomass carbon and crop yield in spring wheat-field pea rotation

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ABSTRACT

This research was conducted to assess the influence of long-term tillage system on soil organic carbon, microbial biomass carbon, root biomass and crop yield in spring wheat-field pea rotation fields in a rainfed semi-arid environment from 2013 through 2015. The treatments were; conventional tillage with stubble removed (T); no-till with stubble removed (NT); no-till with stubble retained (NTS) and conventional tillage with stubble incorporated (TS) arranged in a randomised complete block design with three replicates. The soil organic carbon in NTS increased by 16% and 14% over T and NT. Compared with the T and NT, NTS increased soil microbial biomass carbon by 42% and 38% in 0–30 cm depth, respectively. Root biomass was significantly increased in NTS by 47% and 54% over T and NT, respectively. Across the three years, NTS had an average grain yield of 53% and 41% higher than T and NT, respectively. Compared with NTS, T and NT decreased root biomass by 54% and 48%, respectively. In view of the limited and erratic biomass production in this region, integration of no-till with straw mulching is recommended for soil fertility improvement, environmental quality and sustainable crop production.

Keywords: soil organic matter; straw recycling; carbon sequestration; crop productivity

Soil carbon (C) sequestration was suggested as a strategy to mitigate greenhouse gas emissions and improve soil quality (Bhattacharyya et al. 2009). Options for increasing carbon sequestration and reducing carbon emission from agricultural systems include the adoption of conservation tillage practices (Johnson et al. 2007). However, the potential for any mitigation by conservation tillage needs to be considered together with its impact on crop yields as climate change and global food security are intrinsically related (Huang et al. 2008).

Soil organic carbon (SOC) is an important indicator of soil quality, agronomic sustainability and environmental quality because of its impact on soil properties (Sharma et al. 2008). Higher C stocks in agricultural soils can be achieved through the return of plant residues into soil (Hobbs et al. 2008). Several studies have shown that no-till (NT) results in greater SOC sequestration because of the improved soil aggregation which protects it from mineralization compared to conventional tillage (CT). West and Post (2002) examined global data on CT and NT soils and concluded that changing from CT to NT can sequester an average of 0.57 t C/ha/year. Avoiding tillage in crop production can also impact on crop yields and ultimately food security (Huang et al. 2008). Hence, it is relevant to adopt soil and crop management systems that

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increases soil organic carbon and microbial biomass carbon and stabilize yields.

The soil microbial biomass is involved in decomposition of organic materials; it indicates changes in soil chemical and physical properties resulting from soil management and environmental stresses in agricultural ecosystems (Jordan et al. 1995). Soil microbial biomass therefore determines the nutrient availability and productivity of agroecosystems through releases of plant-available nutrients. Net primary productivity also provides inputs of carbon in ecosystem and determines the amount of photosynthetically fixed carbon that can potentially be sequestered in soil organic matter (Bolinder et al. 2007). The effect of tillage on soil quality is well studied (Tarkalson et al. 2006, Verhulst et al. 2010), but the results varied considerably. In addition, the influence of tillage technologies on the Loess soils and crop productivity are insufficiently investigated and poorly substantiated in research. We assumed that long-term spring wheat-field pea rotation under different tillage systems would not only affect the soil organic carbon and microbial biomass but also crop productivity. The objectives of this study was to determine the effect of conservation and conventional tillage systems on soil organic carbon, soil microbial biomass and crop yield on the Western Loess Plateau of China.

MATERIAL AND METHODS

Site description. The experiment was carried out on a long-term field experiment at the Dingxi Experimental Station (35°28'N, 104°44'E, 1971 m a.s.l.) of Gansu Agricultural University, Gansu province, northwest China. The soil is sandy-loam with pH of 8.3 and low fertility soil organic carbon below 7.63 g/kg. Long-term annual rainfall at Dingxi averages 391 mm, with about 54% fallen between July and September. The daily maximum temperatures can reach up to 38°C in July, while minimum temperatures can drop to –22°C in January. Annual accumulated temperature > 10°C is 2239°C. The experiment was set up in 2001 and has been maintained without alterations.

Experimental design. The experiment consisted of spring wheat (cv. Dingxi No. 35) and field pea (cv. Yannong) rotation in the following sequence: 2013 spring wheat → 2014 field pea → 2015 spring wheat (referred to as W → P → W rotation). Four tillage system; conventional tillage with stubble removed (T); no-till with stubble removed (NT); no-till with stubble retained (NTS) and conventional tillage with stubble incorporated (TS) were arranged in a randomised complete block design with three replicates. The seedbeds for conventional tillage practices were prepared by ploughing to a depth of 10–20 cm. Ploughing was carried out immediately after harvest of the previous crop. Harrowing was conducted prior to sowing in spring. In T plots, all stubbles were removed before ploughing, whereas in TS plots, all stubbles from the previous crop were returned to the original plots immediately after threshing and then incorporated into the soil with ploughing. No ploughing was performed throughout the season in the no-till system. The crops were sown with no-till seeder. In NT plots, all the stubbles were removed at crop harvest, whereas in NTS plots, all the stubbles from the previous crop were returned to the original plots on the soil surface without incorporation. Plots were 4 m wide × 17 m long in block 1, 21 m long in blocks 2 and 3 and 20 m long in block 4. This study was conducted on blocks 1, 2 and 4. Spring wheat was sown in mid-March at a rate of 187.5 kg/ha with a line spacing of 20 cm and harvested in late July to early- August. Field pea was sown in early April at a rate of 180 kg/ha with a line spacing of 24 cm and harvested in early July each year. Nitrogen and phosphorus were applied at seeding at 105 kg/ha as urea (46% N) and at 45.9 kg P/ha as calcium superphosphate (6.1% P) for spring wheat and 20 kg N/ha and 45.9 kg P/ha for field pea. The fertilizer was applied simultaneously at sowing with the no-till seeder.

Soil and plant sampling and analysis. Measurements of total soil organic carbon and microbial biomass carbon were conducted in the 2015 cropping season in each plot from three depths: 0–5, 5–10 and 10–30 cm and composited by depth for chemical analysis. Soil samples were collected at sowing and at harvest. Soil organic carbon was determined by a modified Walkley-Black wet oxidation method (Nelson and Sommers 1982). The method of chloroform fumigation and extraction (FE) as described by (Ladd and Amato 1989) was used to determine the microbial biomass carbon. Plant stems and leaves were sampled from each plot at harvest in 2014 and 2015 cropping season for carbon and nitrogen analysis. The carbon and nitrogen content (%) were determined in the

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stem and leaf with C and N analyzer (Elementar Vario Macro Cube, Hanau, Germany). The root biomass of spring wheat and field pea were sampled from each plot at flowering using the method as described by Huang et al. (2012).

Grain yield. Spring wheat and field pea were hand harvested at maturity using sickles at 5 cm above ground and the edges 0.5 m of the plot were trimmed and discarded. The grain yields were determined on dry weight basis by oven-drying at 105°C for 45 min and dried to constant weight at 85°C.

Net primary productivity (NPP). Net primary productivity was estimated using the method of Bolinder et al. (2007). The NPP was calculated using the equation:

$$NPP = C_P + C_S + C_R + C_E \quad (1)$$

Where: NPP – total net primary productivity; C_P – plant C in the agricultural product; C_S – plant C in above-ground plant materials excluding the product; C_R – plant C in root; C_E – plant C in extra-root material, including root exudates. The C input of these fractions can be calculated if the C amount of the crop yield is known. The amount of C in the agricultural product (C_P) was calculated using grain yields for the respective crop obtained from the experiment, assuming the C concentration of all plant parts is 0.45 kg/kg and harvest index for wheat is 0.40 as indicated by (Bolinder et al. 2007).

Data analysis. Statistical analyses were performed with one-way analysis of variance (ANOVA) at $P < 0.05$ using SPSS 22.0 (IBM Corporation, Chicago, USA). Means separation was obtained by the Duncan's multiple range test.

RESULTS AND DISCUSSION

Soil organic carbon. NTS increased SOC in 0–5, 5–10 and 10–30 cm by 19, 25 and 7% compared to T at sowing, respectively (Table 1). Similar values at harvest were 28, 12 and 8%, respectively. Treatment T and NT recorded the lowest SOC at both sampling times. The SOC declined with increased sampling depth, irrespective of the treatment. The lack of substantial organic matter stratification in the no-till systems could be attributed to the ability of the plants to produce extensive root mass in the volume of soil near the surface (Huang et al. 2012) and nutrient redistribution through biological processes and water percolation (Grove et al. 2007) to overcome nutrient stratification. Tillage brings crop residues closer to microbes thereby increasing organic matter decomposition (Lal 2004). Adopting conservation tillage avoids rapid decomposition of soil organic matter and can lead to higher C stocks. Baker et

Table 1. Soil chemical properties in spring wheat–field pea rotation under different tillage treatments

Treatment	At sowing			At harvest		
	0–5 cm	5–10 cm	10–30 cm	0–5 cm	5–10 cm	10–30 cm
Soil organic carbon (g/kg)						
T	9.23 ± 0.22^{c}	8.80 ± 0.35^{b}	8.66 ± 0.15^{a}	9.27 ± 0.01^{b}	9.12 ± 0.12^{b}	8.21 ± 0.08^{b}
NT	9.59 ± 0.73^{c}	10.20 ± 0.38^{ab}	9.07 ± 0.60^{a}	9.43 ± 0.08^{b}	9.25 ± 0.20^{b}	8.41 ± 0.09^{b}
NTS	11.03 ± 0.12^{a}	11.01 ± 0.68^{a}	9.24 ± 0.59^{a}	11.86 ± 0.12^{a}	10.23 ± 0.19^{a}	8.84 ± 0.12^{a}
TS	10.69 ± 0.08^{ab}	10.60 ± 0.34^{ab}	9.43 ± 0.18^{a}	8.09 ± 0.02^{c}	9.40 ± 0.13^{b}	9.10 ± 0.14^{a}
Microbial biomass carbon (mg/kg soil)						
T	198.86 ± 20.25^{c}	213.16 ± 7.52^{b}	161.85 ± 14.94^{b}	160.44 ± 23.39^{b}	178.42 ± 12.82^{ab}	152.67 ± 12.73^{b}
NT	247.37 ± 5.26^{b}	185.53 ± 3.95^{b}	157.89 ± 18.23^{b}	178.38 ± 9.06^{b}	167.47 ± 17.05^{b}	180.02 ± 8.76^{ab}
NTS	315.79 ± 18.25^{a}	253.95 ± 1.32^{a}	236.84 ± 9.11^{a}	260.00 ± 17.83^{a}	235.88 ± 9.12^{a}	201.49 ± 15.34^{a}
TS	264.47 ± 9.93^{b}	281.58 ± 18.42^{a}	200.00 ± 21.05^{ab}	206.30 ± 7.95^{b}	208.05 ± 24.95^{ab}	183.37 ± 8.74^{ab}

Means values ± standard error from three replicates. Values with different letters within a column are significantly different at $P < 0.05$. T – conventional tillage with stubble removed; NT – no-till with stubble removed; NTS – no-till with stubble retained; TS – conventional tillage with stubble incorporated

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al. (2007) however reported that no-till can bring about stratification of organic carbon at the soil surface compared to the more uniform distribution of carbon in conventionally tilled soils and thus questioning the effective sequestration obtainable under conservation tillage.

Microbial biomass carbon. Table 1 summarizes the MBC content following different tillage practices. The trend observed for MBC was similar to that of soil carbon content. NTS increased MBC by 37% and 40% compared with NT and T in 0–30 cm at sowing. Similar values at harvest were 33% and 42% over NT and T, respectively. The lowest value of MBC was recorded by the T treatment. Significant ($P < 0.05$) increases were found between the treatments; the mean values recorded for the three sampling times ranged from 315.79–161.85 mg/kg at sowing and 260.00–152.67 mg/kg soil at harvest. These results are similar to other studies which indicated that no tillage generally increased MBC relative to the conventional tillage (Bausenwein et al. 2008). The minimal soil disturbance and soil cover protect the biological components of the soil and enhance nutrient availability for microbial growth.

Stem and leaf carbon and nitrogen content (%). The C and N content is considered to be an appropriate indicator for soil organic matter quality and decomposition. Significant differences ($P < 0.05$) were observed between the treatments. Our results showed higher carbon content in the stem compared to the leaf, whilst the leaf had higher nitrogen content than the stem (Table 2). Generally, NTS had the highest carbon and nitrogen content in both study years and this was followed closely by TS; the lowest carbon and nitrogen content were produced by T. Higher C and N content in the stem and leaf achieved under NTS and TS treatments suggests an enhanced soil quality as indicated by its' SOC and MBC content. This is a significant finding because the quality and quantity of plant

Table 2. Carbon and nitrogen content (%) in stem and leaf in spring wheat–field pea rotation under different tillage treatments

Treatment	Carbon		Nitrogen	
	stem	leaf	stem	leaf
2014				
T	40.65 ± 0.97^{b}	33.93 ± 1.24^{b}	0.47 ± 0.043^{b}	1.12 ± 0.03^{b}
NT	41.13 ± 0.45^{b}	34.01 ± 0.23^{b}	0.56 ± 0.043^{b}	2.01 ± 0.41^{b}
NTS	44.03 ± 0.19^{a}	37.31 ± 0.91^{a}	0.68 ± 0.01^{a}	2.90 ± 0.041^{a}
TS	42.13 ± 0.87^{b}	36.62 ± 0.55^{a}	0.66 ± 0.05^{ab}	2.47 ± 0.26^{ab}
2015				
T	43.97 ± 0.47^{c}	39.26 ± 0.23^{b}	0.51 ± 0.05^{b}	1.11 ± 0.03^{b}
NT	43.90 ± 0.83^{c}	42.51 ± 2.43^{ab}	0.56 ± 0.04^{b}	1.43 ± 0.11^{ab}
NTS	47.52 ± 0.68^{a}	46.57 ± 1.21^{a}	0.79 ± 0.07^{a}	1.98 ± 0.11^{a}
TS	46.53 ± 1.12^{ab}	45.45 ± 0.83^{a}	0.77 ± 0.03^{a}	1.88 ± 0.10^{a}

Means values ± standard error from three replicates. Values with different letters within a column are significantly different at $P < 0.05$. T – conventional tillage with stubble removed; NT – no-till with stubble removed; NTS – no-till with stubble retained; TS – conventional tillage with stubble incorporated

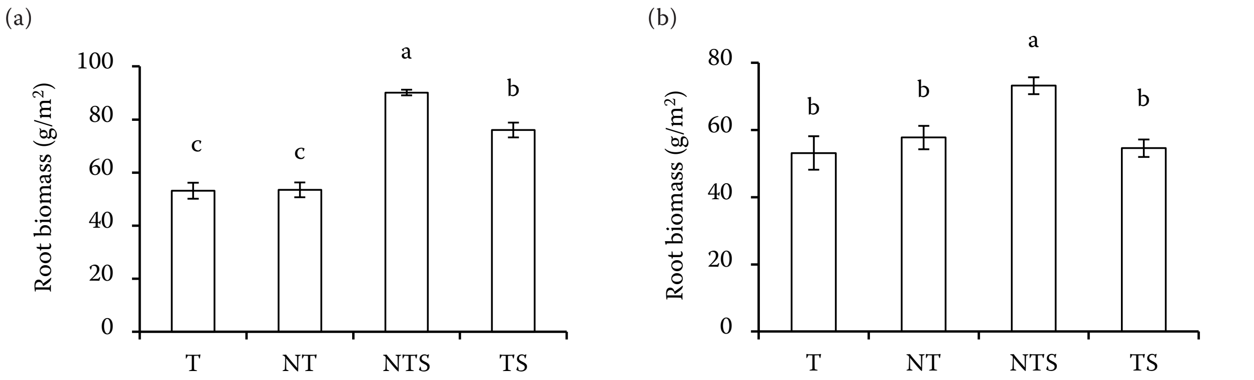

Figure 1. Root biomass in spring wheat–field pea rotation in (a) spring wheat; (b) field pea. Different letters in the figure are significantly different at $P < 0.05$. Vertical bars represent the standard error (SE). Means values ± SE from three replicates. T – conventional tillage with stubble removed; NT – no-till with stubble removed; NTS – no-till with stubble retained; TS – conventional tillage with stubble incorporated

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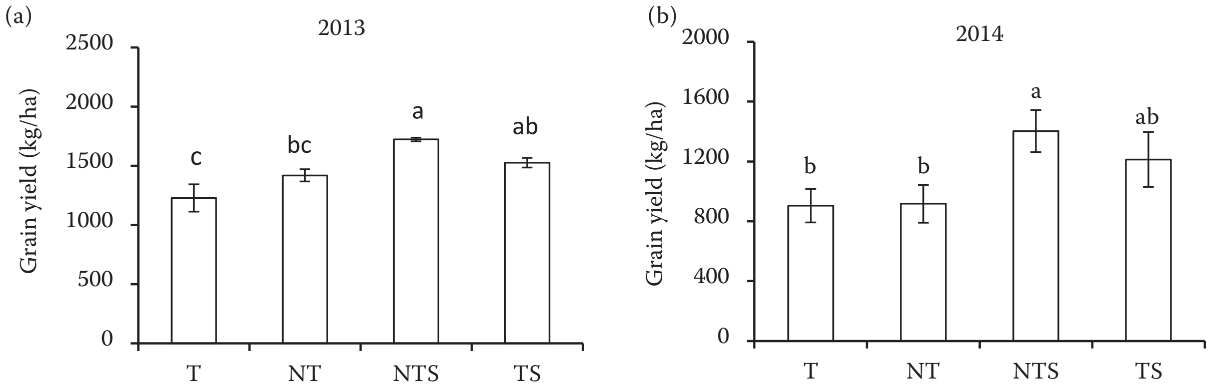
materials produced impacts plant carbon pool and sequestration of carbon (West and Post 2002).

Root biomass. Root biomass following the application of different tillage systems is presented in (Figure 1). T recorded significantly ($P > 0.05$) lower root biomass compared to the NTS treatment: this was consistent for both crops. The root biomass in NTS was higher in both spring wheat (90.12 g/m^2) and field pea (73.17 g/m^2) plots and this was followed by TS treatment. The large differences in root biomass between NTS and T were related to variations in SOC and MBC content. Huang et al. (2012) explained that higher root biomass under NTS system was due to greater availability of soil nutrients.

Grain yield. Application of different tillage systems significantly ($P < 0.05$) affected grain yield (Figure 2). NTS had the highest wheat grain yield following the application of different long-term tillage practices. The NTS treatment recorded the highest spring wheat grain yield (1722.82 kg/ha) followed by TS (1526.33 kg/ha) which were 21% and 8% higher compared to NT in 2013 (Figure 2a). In 2014, NTS increased field pea yield by 53% and 55% compared to NT and T (Figure 2b). The higher field pea yield obtained in NTS could be attributed to the significant increase in SOC in the soil surface. The concentration of SOM in the soil surface plays vital role in erosion control, conservation of nutrients and water infiltration (Yang et al. 2013) and improves crop production (Franzluebbers 2002). The trend observed for grain yield was similar in 2015. T treatment obtained the lowest grain yield throughout the sampling period. Our findings are consistent with the report by (Huang et al. 2008) at the same study site who observed that improved soil organic carbon under NTS acts as nutrient source which could contribute to higher crop productivity. The low grain yields of both spring wheat and field pea highlights the degraded nature of the Loess soil coupled with limited precipitation and high evaporation resulting in low crop yield (Liu et al. 2009).

Net primary productivity. It is very important to estimate the C inputs in soils to better predict and manage soil carbon dynamics. Our results showed that the highest NPP was obtained in NTS in 2013 (7685.22 kg C/ha/year), 2014 (6961.67 kg C/ha/year) and 2015 (9250.31 kg C/ha/year), respectively (Figure 3). The lowest NPP value was obtained in T; and the trend in NPP was generally similar to SOC. The increase in soil nutrients associated with conservation tillage resulted in higher accumulation of carbon and nitrogen content in the plant tissues, which could contribute to organic carbon when the straw is recycled. Our results showed that the



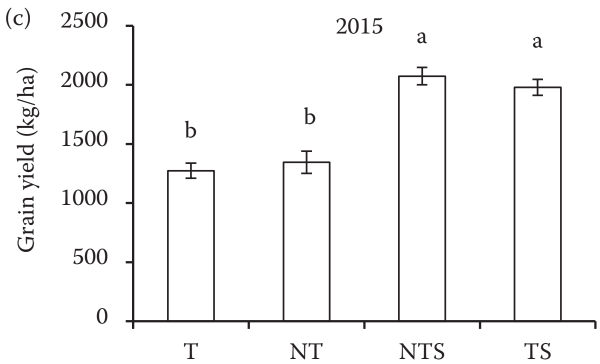


Figure 2. Grain yield in spring wheat–field pea rotation in (a) 2013; (b) 2014 and (c) 2015. Different letters in the figure are significantly different at $P < 0.05$. Vertical bars represent the standard error (SE). Means values ± SE from three replicates. T – conventional tillage with stubble removed; NT – no-till with stubble removed; NTS – no-till with stubble retained; TS – conventional tillage with stubble incorporated

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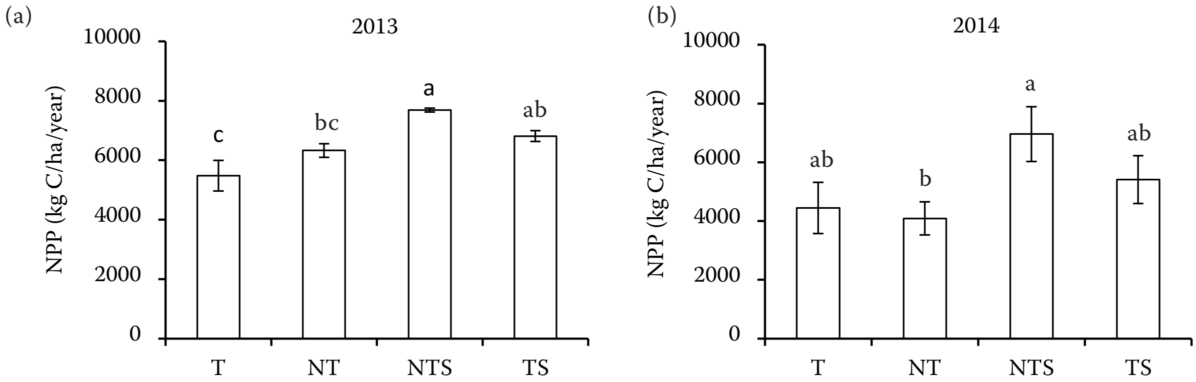

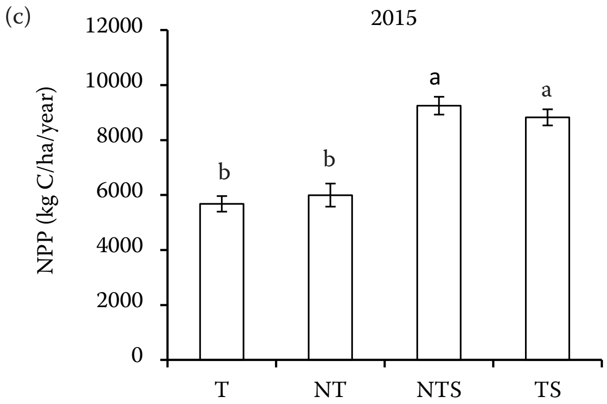

Figure 3. Net primary productivity (NPP) in spring wheat–field pea in (a) 2013; (b) 2014 and (c) 2015. Different letters in the figure are significantly different at $P < 0.05$. Vertical bars represent the standard error (SE). Means values ± SE from three replicates. T – conventional tillage with stubble removed; NT – no-till with stubble removed; NTS – no-till with stubble retained; TS – conventional tillage with stubble incorporated

application of crop residues coupled with no-till could improve soil organic carbon, soil microbial biomass, and stimulate grain yield, thus creating synergic relationship.

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