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Influence of Tillage Practice on Soil CO_2 Emission Rate and Soil Characteristics in a Dryland Wheat Field

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Abstract

In the present study, different tillage and straw-returning (SR) practices were evaluated at the Loess Plateau, the largest dryland region of China, to investigate the relationship between CO_2 emission and soil temperature, moisture and microbial biomass C (MB-C) in dryland wheat fields under the influence of different tillage and SR practices. The results showed that tillage had significant effects on soil CO_2 emissions. Compared with rotary tillage (RT), plough tillage (PT) significantly increased soil CO_2 emission rate, and no tillage (NT) significantly decreased the soil CO_2 emission rate throughout the wheat growing season. In addition to tillage, SR also significantly affected soil CO_2 emissions. With respect to the average soil CO_2 emission rate during wheat growing season, PT with SR and NT with SR significantly increased soil CO_2 emissions compared with PT and NT, respectively. Moreover, the soil CO_2 emission rate was positively and significantly correlated with soil temperature, and it was negatively and significantly correlated with soil moisture for the different tillage practices. However, no significant correlation was observed between the soil CO_2 emission rate and MB-C content. These results indicate that tillage and SR affect soil CO_2 emissions by regulating the temperature and moisture of soil.

Keywords: Carbon dioxide emission; Soil temperature; Soil moisture; Tillage; Dryland wheat field

Introduction

Scientific evidence suggests that since the industrial revolution, there has been a notable increase in the concentration of greenhouse gases (GHGs) in the atmosphere, including carbon dioxide (CO_2). This anthropogenic enrichment of GHGs in the atmosphere has led to an increase in the average global surface temperature with the current warming rate of 0.17°C/decade (Shafiq *et al*., 1994; IPCC, 2001; Ruddiman, 2003; Lal, 2004; Maia *et al*., 2009; Inglett *et al.,* 2012). In recent years, GHG emissions and the increase of global surface temperatures have become one of the greatest challenges for the sustainable development of human society.

CO_2 is the main component of GHGs, and agriculture is one of the main contributors of CO_2 emissions (Zhang *et al*., 2011). The emission of CO_2 from farmland not only increases the average global surface temperature but also decreases soil organic carbon (SOC), inhibits the cycles of elements such as nitrogen (N) and carbon (C) and promotes water runoff and erosion (Lal, 2004). This process can decrease soil fertility and soil moisture and can break soil structures. Thus, the reduction of CO_2 emissions and the conservation of farmland SOC are important.

China is one of the largest agricultural countries in the world and has approximately 140 million ha of agricultural land. Dry farming plays an important role in the agriculture of China. Northern China hosts a large dryland region that accounts for approximately 56% of the nation's total land area and approximately 50% of grain production (Ren *et al.*, 2010). In this region, conventional soil management practices include intensive soil cultivation, low fertiliser input, low manure input, crop residue removal and crop residue burning (Wang *et al*., 2007). These practices promote the losses of soil, nutrients, and water, and these practices also decrease the soil organic matter content and break the soil physical structure (Tang, 2004; Gomez-Rey *et al.,* 2012; Zhang *et al.,* 2012). Conservation tillage, which includes non-inversion techniques and leaving more than one-third of the soil surface covered by crop residues (Wang *et al.,* 2007), can increase the water and nutrient content in soil (Moraru and Rusu, 2010), restrict soil erosion (Franzluebbers, 2002), improve soil structure (Peng and Horn, 2008; Rusu *et al.,* 2009), and promote crop yield (Tang, 2004; Chen *et al.,* 2011). Therefore, conservation tillage practices have been quickly developed in the dryland region of Northwestern China.

In addition to these advantages, several previous studies have suggested that conservation tillage can decrease soil CO_2 emissions compared with conventional tillage (Bauer *et al.*, 2006; Li *et al*., 2007; Jiang and Xie, 2009; Zhang *et al*., 2009a). Our previous study suggested that

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tillage practices significantly affect soil CO_2 emissions in the dry land region of Northern China (Yang *et al.*, 2011). However, the mechanism of the effects is unclear. Ellert and Janzen (1999) suggested that soil CO_2 emission is strongly dependent on plant and soil microbial growth and is influenced by temperature and moisture. They also suggested that tillage practices significantly affect the soil temperature and moisture. However, the relationship between soil CO_2 emissions and soil characteristics in a dryland field subjected to different tillage practices is unclear. In the present study, different tillage and straw-returning practices were performed in the Loess Plateau region, which is the largest dryland region in China, and the soil CO_2 emission rate, temperature, moisture and microbial biomass carbon (MB-C) content were measured during the winter wheat growing season. The objective of the present study was to investigate the relationship between the CO_2 emission rate and the temperature, moisture and microbial biomass carbon content of soil in a dryland wheat field subjected to different tillage and straw-returning practices.

Materials and Methods

Study Site Description

This study was conducted during 2009 and 2010 at the Crop Specimen Farm at Northwest A and F University, Shaanxi Province, in Northwestern China. The latitude and longitude of the experimental station are 34°22' N and 108°26' E, respectively. The annual mean temperature and annual mean precipitation of the experimental station are 12.9°C and 550 mm, respectively. During the winter wheat growth stage of October 2009 to June 2010, the mean temperature and annual mean precipitation of the experimental station were 10.6°C and 298 mm, respectively. The soil of the experimental farm is Eum-Orthrosols (Chinese soil Taxonomy). The mean bulk density of the soil was 1.31 g cm^{-3}. The readily available N, P and K contents were 58.43, 18.12 and 120.64 mg kg^{-1}, respectively. The organic matter content of the 0-20 cm layer of topsoil was 12.21 g kg^{-1}, and the soil pH was 7.35.

Experiment Design

One winter wheat cultivar (Xinong, 9871) was grown in the dryland field. Seeds were sown on October 20, 2009. The plant density (seed rate) was 180 kg ha^{-1}, with a row spacing of 20 cm. The experiment was conducted with a randomised block split plot design with 3 tillage practices as the main plots and 2 straw treatments (with and without corn straw-returning) in subplots. The 3 tillage practices were plough tillage (PT), rotary tillage (RT) and no tillage (NT), and the corn straw was applied at 7000 kg hm^{-2} in dry weight. Each treatment was performed in triplicate in the field, and the plot size was 60 m^2 (6 m × 10 m). Urea (150 kg N ha^{-1}) and single superphosphate (120 kg P_2O_5 ha^{-1}) were applied before sowing, and no irrigation practice was conducted during the entire experiment.

Measurements

The CO_2 emission content was measured using a portable infrared gas analyser (LI-7500, LI-COR Inc., Lincoln, NE, USA) following the methods of Gao *et al.* (2008). The soil moisture and soil temperature were measured at the following stages: seedling (A, Nov 26), wintering (B, Jan 12), green-up (C, Mar 11), joint (D, Apr 2), flowering (E, May 6), grain filling (F, May 24), and mature (G, June 12). The soil temperatures were measured using mercury-in-glass thermometers with bent stems. The thermometer bulbs were sunk into the inter-row ground to depths of 5, 10, 15 and 20 cm. Soil temperatures were recorded daily at 8:00, 14:00 and 20:00, and the average of these 3 readings was calculated as the mean soil temperature. The soil moisture was determined gravimetrically to a depth of 100 cm at 10-cm increments in the topsoil (0–40 cm) and at 20-cm increments below the topsoil (40–100 cm). These data were collected during 09:00 to 10:00 (local time), and 5 measure points were selected in each plot. The measurement of the soil moisture involved oven-drying and was performed.

The soil MB-C was sampled at the following stages: seedling (Nov 26), wintering (Jan 12), green-up (Mar 11), joint (Apr 2), flowering (May 6) and mature (June 12). The soil MB-C was then estimated using the chloroform fumigation (12-h)–extraction method (Vance *et al*., 1987; Pandey *et al*., 2010). Briefly, the sample was treated by chloroform and 0.5 M K_2SO_4 (Pandey *et al*., 2009; Pandey and Begum, 2010), and organic C was then measured by dichromate digestion. The MB-C content was calculated by the following equation: MB-C content = 2.64Ec; where EC is the difference between estimates from fumigated and un-fumigated soils (both expressed as μg C g^{-1} oven-dried soil) (Vance *et al*. 1987; Pandey *et al*., 2010).

Statistical Analysis

SPSS 16.0 (SPSS Inc., Chicago, IL) was used for statistical analysis. The data were tested according to the least significant difference at $P_{0.05}$ ($LSD_{0.05}$).

Results

Yield and Yield Component Factors

The different tillage practices significantly affected the grain yield of wheat. The NT+NS (no corn straw-returning) treatment had the greatest grain yield and was significantly higher than that of the PT+SR, PT+NS, RT+SR and RT+NS treatments. Moreover, the grain yield resulting from the NT+SR treatment was higher than that of the PT+SR, PT+NS, RT+SR and RT+NS treatments. These results indicate that no tillage significantly promoted the grain yield of wheat in the present study (Table 1).

The tillage practices had different effects on the yield component factors. Compared with PT and RT, NT significantly decreased the panicles per m^2, but NT significantly increased the spikelets per panicle and grain weight. There were no significant differences in the yield and yield component factors when comparing PT and RT.

Unlike tillage practices, straw-returning had no significant effect on the grain yield and yield component factors. Moreover, there were no significant differences in the yield and yield component factors when comparing SR and NS under the same tillage practice.

CO_2 Emissions

The CO_2 emissions of all treatments fluctuated during the wheat growing season (Fig. 1). The highest CO_2 emission rate (the average rate of all treatments was 465.48 mg m^{-2} h^{-1}) was observed at sowing (Oct 20). The CO_2 emission rate then decreased and reached the lowest rate (the average rate of all treatments was 326.16 mg m^{-2} h^{-1}) during the wintering period (Jan 12). After the wintering period, the CO_2 emission rate increased and reached another peak (the average rate of all treatments was 417.96 mg m^{-2} h^{-1}) at the joint stage (Apr 2), and fluctuations occurred during the flowering (May 6), grain filling (May 24) and mature (June 12) stages.

The tillage practices had significant effects on soil CO_2 emissions. Compared with RT, PT significantly increased the soil CO_2 emission rate, and NT significantly decreased it throughout the wheat growing season. In addition to the tillage practice, straw-returning also significantly affected the soil CO_2 emissions. The effect of straw-returning on soil CO_2 emissions was related to the tillage practice. The average soil CO_2 emission rates during the wheat growing season for the PT+SR and NT+SR treatments were significantly higher than those for the PT and NT treatments, respectively. However, no significant difference in the average soil CO_2 emission rates during the wheat growing season was observed between the RT+SR and RT treatments (Fig. 1 and Table 2).

Soil Moisture

During the wheat growing season, the soil moistures of all treatments decreased first and then increased. The highest and lowest soil moisture contents occurred at the seedling (Nov 26) and grain filling stages, respectively (Fig. 2H). In total, the soil moisture contents at the surface, middle and deep layers of NT were all higher than those of PT and RT at the same stage, which indicates that NT can increase the soil moisture better than PT and RT. However, no significant differences in the soil moisture contents were observed among the treatments (Figs. 2A-G).

Soil Temperature

During the wheat growing season, the soil temperature of all treatments decreased first and then increased. The highest and lowest soil temperatures were recording during the wintering period and the mature stage, respectively (Fig. 3H).

The tillage notably affected the soil temperature (Figs. 3A-G). The soil temperature in the 5-10-cm layer of NT was significantly higher than that of PT and RT after the green-up stage. However, the soil temperature in the

Table 1: Yield and yield components of wheat under different treatments

Tillage	Straw-returning	Spike per m^2	Spikelets per spike	1000-grain weight (g)	Grain yield (t ha^{-1})
PT	SR	518.3a	45.6b	34.5b	8.2b
	NS	501.6a	45.3b	34.7b	7.9b
RT	SR	513.7a	45.3b	36.2b	8.4b
	NS	510.3a	44.7b	36.2b	8.2b
NT	SR	435.8b	54.5a	39.8a	9.3ab
	NS	438.4b	56.2a	40.6a	10.0a
Analysis of variance	Stem returning (S)	0.98	0.02	0.33	0.01
	Tillage(T)	18.82**	19.96**	24.54**	6.64*
	S×T	0.41	0.38	0.14	0.9

Table 2: Average soil CO_2 emission rates of different treatments during the wheat growing season

Tillage	Straw-returning	CO_2 emission rate (mg m^{-2} h^{-1})	Analysis of variance	
PT	SR	432.00a	Stem returning (S)	52.60**
	NS	416.88b		
RT	SR	393.12c	Tillage (T)	746.77**
	NS	389.88c		
NT	SR	368.28d	S×T	7.08**
	NS	358.56e		

Values within a column followed by different letters are significantly different at P=0.05

** Values within a column are significantly different at the 0.01 probability level

The following abbreviations are used: PT, plough tillage; RT, rotary tillage; NT, no tillage; SR, corn straw-returning; and NS, no corn straw-returning

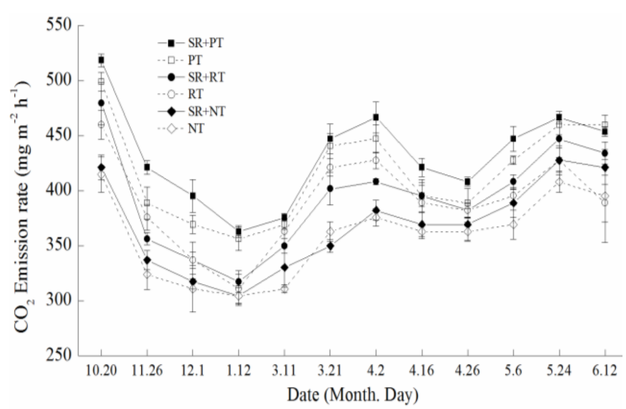

Fig. 1: Effects of tillage practice and straw-returning on the soil CO_2 emission rate in a dryland wheat field. The following abbreviations are used: PT, plough tillage; RT, rotary tillage; NT, no tillage; SR, corn straw-returning; and NS, no corn straw-returning. Vertical bars represent the standard error of the mean (n=3)

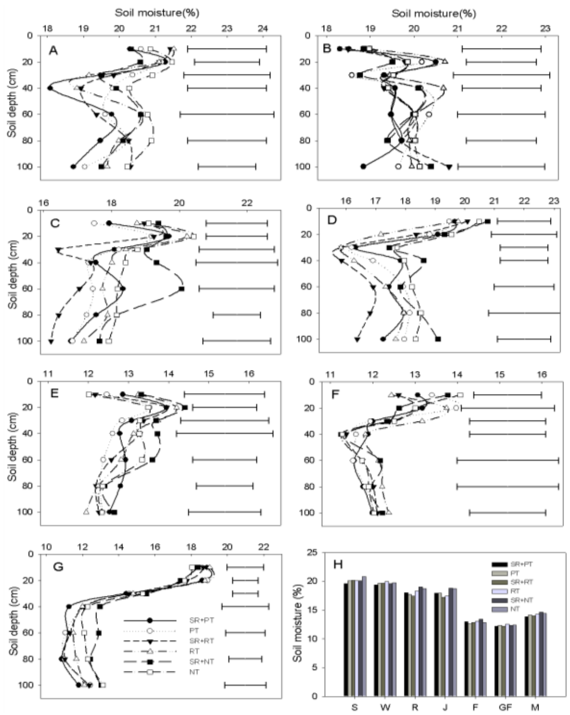

Fig. 2: Effects of tillage practice and straw-returning on the soil moisture at the following stages: seedling (A, Nov 26), wintering period (B, Jan 12), green-up (C, Mar 11), joint (D, Apr 2), flowering (E, May 6), grain filling (F, May 24), and mature (G, June 12). H) Changes in soil moisture during the wheat growing season (S, W, R, J, F, GF, and M represent seedling, wintering period, green-up, joint, flowering, grain filling and mature stages, respectively). The following abbreviations are used: PT, plough tillage; RT, rotary tillage; NT, no tillage; SR, corn straw-returning; and NS, no corn straw-returning. Vertical bars represent the LSD at P = 0.05

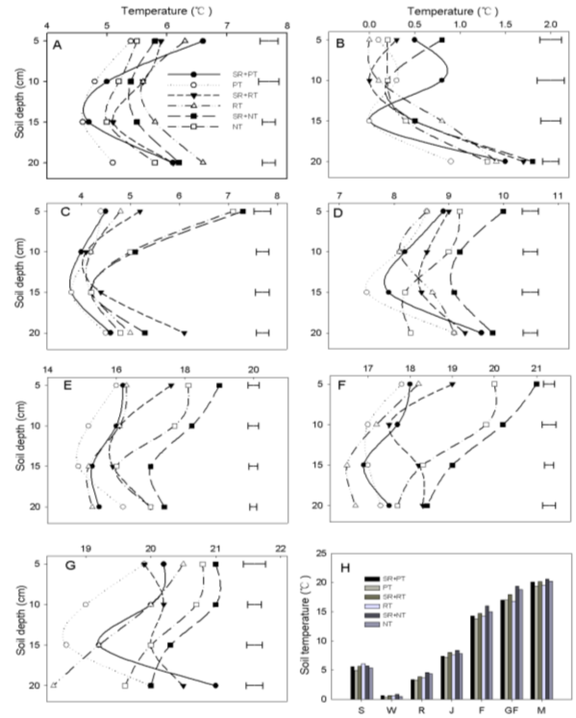

Fig. 3: Effects of tillage practice and straw-returning on the soil temperature at the following stages: seedling (A, Nov 26), wintering period (B, Jan 12), green-up (C, Mar 11), joint (D, Apr 2), flowering (E, May 6), grain filling (F, May 24), and mature (G, June 12). H) Changes in soil temperature during the wheat growing season (S, W, R, J, F, GF, M represent seedling, wintering period, green-up, joint, flowering, grain filling and mature stages, respectively). The following abbreviations are used: PT, plough tillage; RT, rotary tillage; NT, no tillage; SR, corn straw-returning; and NS, no corn straw-returning. Vertical bars represent the LSD at P = 0.05

15-20 cm layer of NT was higher than that of PT and RT after the flowering stage. Straw-returning also affected the soil temperature. After the wintering period, the soil temperature of the SR+NT, SR+PT and SR+RT treatments was higher than that of the NT, PT and RT treatments, respectively. These results demonstrated that straw-returning had a significant increasing effect on soil temperature.

Soil MB-C

During the wheat growing season, the soil MB-C content of all treatments increased first and then decreased. The highest and lowest soil MB-C contents occurred at the seedling (Nov 26) and flowering stages, respectively (Fig. 4). The tillage practice significantly affected the soil MB-C content. At the 0-10 cm depth, NT significantly increased the soil MB-C content, and the average soil MB-C content of NT during the wheat growing season was 279.92 mg kg^{-1}, which was significantly higher than that of PT (245.96 mg kg^{-1}) and RT (226.17 mg kg^{-1}). At the 10-20-cm depth, however, the average soil MB-C content of NT during the wheat growing reason was 158.13 mg kg^{-1}, which was significantly lower than that of PT (192.77 mg kg^{-1}) and RT (158.13 mg kg^{-1}). These results demonstrate that NT significantly increased the soil MB-C content at the 0-10-cm depth but that NT decreased the soil MB-C content at the 10-20-cm depth.

Straw-returning increased the soil MB-C content. With the exception of the 10-20-cm depth during the flowering stage, the soil MB-C content of the SR+NT, SR+PT and SR+RT treatments was higher than that of the NT, PT and RT treatments, respectively, during the wheat growing season.

Relationship of CO_2 Emission, Soil Moisture, Soil Temperature and Soil MB-C

Regression analysis indicated that the soil CO_2 emission

Table 3: Correlation coefficients of soil CO_2 emission with soil moisture, soil temperature and soil MB-C

	Soil temperature				Soil moisture							Soil MB-C	
	5 cm	10 cm	15 cm	20 cm	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-60 cm	60-80 cm	80-100 cm	0-10 cm	10-20 cm
CO2 emission	0.708**	0.709**	0.719**	0.672**	-0.405**	-0.565**	-0.736**	-0.739**	-0.711**	-0.666**	-0.690**	0.225	0.321

**Significant at the 0.01 probability level (for soil temperature and moisture, n = 42; for soil MB-C, n=30)

Table 4: Correlation coefficients of soil CO_2 emission rates with soil temperature at the same stage

Soil depth (cm)	A	B	C	D	E	F	G
5	0.616	-0.073	-0.941**	-0.69	-0.705	-0.688	-0.669
10	-0.453	0.763	-0.891*	-0.894*	-0.739	-0.68	-0.572
15	-0.438	-0.863*	-0.594	-0.632	-0.579	-0.476	-0.429
20	-0.082	-0.653	-0.403	-0.444	0.524	-0.429	0.793

The correlation coefficients of the soil CO_2 emission rate with soil temperature were analysed at the following stages: seedling (A, Nov 26), wintering period (B, Jan 12), green-up (C, Mar 11), joint (D, Apr 2), flowering (E, May 6), grain filling (F, May 24), mature (G, June 12). **Significant at the 0.01 probability level (n =6)

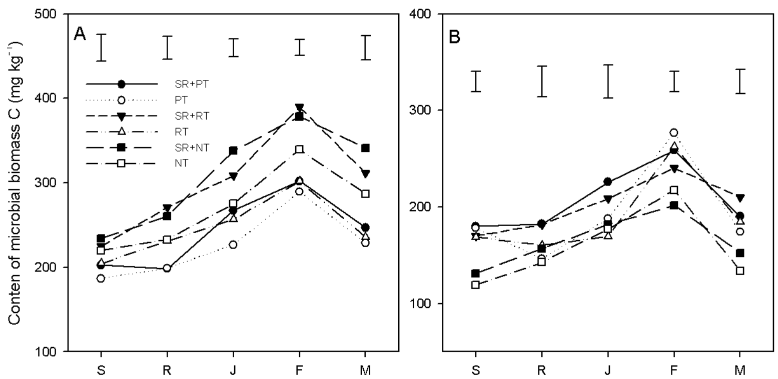

Fig. 4: Effects of tillage practice and straw-returning on the soil microbial biomass carbon at different soil layers (A, 0-10 cm; and B, 10-20 cm) and different stages as follows: seedling (S, Nov 26), wintering period (W, Jan 12), green-up (R, Mar 11), joint (J, Apr 2), flowering (F, May 6) and mature (M, June 12). The following abbreviations are used: PT, plough tillage; RT, rotary tillage; NT, no tillage; SR, corn straw-returning; and NS, no corn straw-returning. Vertical bars represent the LSD at P = 0.05

rate was positively and significantly correlated with soil temperature and that it was negatively and significantly correlated with soil moisture. However, no significant correlation was observed between the soil CO_2 emission rate and soil MB-C content (Table 3).

Discussion

In the present study, the seasonal variation of soil CO_2 emissions of the different tillage and straw practices showed a similar trend (Fig. 1). During the wheat growing season, 3 soil CO_2 emission peaks were observed at the sowing, joint, and grain filling stages. These results are similar to those reported by Zhang *et al.* (2009b). The peak at sowing may have been induced by the soil tillage, and the peaks at the joint and grain filling stages may have been induced by the soil temperature and soil moisture (Yang *et al*., 2011).

The results of the present study demonstrate that NT significantly decreased the soil CO_2 emission rate compared with PT and RT. The average soil CO_2 emission rate during the wheat growing season for NT was 358.56 mg m^{-2} h^{-1}, which was 14 and 6.5% less than the rate for PT and RT, respectively. A previous study has indicated that no tillage practice decreases CO_2 emissions by reducing soil disturbance (Ellert and Janzen, 1999; Prior *et al*., 2004), which is in agreement with the present results.

The straw-returning also significantly affected the soil CO_2 emission rate. In the present study, the soil CO_2 emission rate of the SR+PT, SR+RT and SR+NT treatments was higher than that of the PT, RT, and NT treatments, respectively. These results suggest that straw-returning significantly promoted soil CO_2 emissions, which may be due to the abundance of carbon in the corn straw, because carbon may be released in the putrefaction and decomposition processes of the straw (Nie *et al*., 2007). In addition, the promoting effect of straw-returning on soil CO_2 emissions may also be attributed to increased soil microorganisms due to straw-returning because the respiration of soil microorganisms can promote soil CO_2 emissions (Yang *et al*., 2007). Wang *et al*. (2003) indicated that the soil MB-C content can be affected by the activity of soil microorganisms. The present study shows that straw-returning significantly increased the soil MB-C content (Fig. 4), which indicates that straw-returning promoted soil microorganism activity, thereby promoting soil CO_2 emissions.

Soil moisture and temperature are considered the most important factors regulating CO_2 emissions (Lotte and Sven, 1999). Soil temperature affects the metabolism of soil microorganisms and root growth, which regulates soil CO_2 emissions (Fang and Moncrieff, 2001). A positive correlation between soil temperature and soil CO_2 emissions is well described in several reviews (Lou *et al*., 2003; Reth *et al*., 2005). In the present study, the regression analysis indicates that the soil CO_2 emission rate was positively and significantly correlated with soil temperature (Table 3), in agreement with previous studies.

In addition to temperature, soil moisture also regulates soil CO_2 emissions by affecting the metabolism of soil microorganisms and root growth (Lou *et al*., 2003). However, a previous study on the relation between soil CO_2 emissions and soil moisture had different results. Simek *et al*. (2004) indicated that there is a negative correlation between soil CO_2 emissions and soil moisture. However, Zhang *et al*. (2009b) reported that soil moisture is positively correlated with soil CO_2 emissions. In addition, previous research has indicated that there is no significant correlation between soil CO_2 emissions and soil moisture (Yang *et al*., 2011). This inconsistency may be due to the differences in climate and soil characteristics (Fang and Moncrieff, 2001; Zhang *et al*., 2009b). In the present study, the regression analysis indicated that the soil CO_2 emission rate was negatively and significantly correlated with soil moisture, in agreement with the results reported by Simek *et al*. (2004). The most limiting factor of crop production in the dryland region of Northern China is water resources. The results of the present study demonstrated that increased soil moisture not only increases the crop yield but also decreases soil CO_2 emissions and conserves the SOC in the dryland region of Northern China.

In the present study, NT significantly increased soil moisture and decreased soil CO_2 emissions during the wheat growing season compared with PT and RT, which indicates that the inhibiting effect of NT on soil CO_2 emissions was related to increased soil moisture. Compared with PT and RT, however, NT also significantly increased soil temperature, which is inconsistent with the regression analysis of the present study, indicating that the soil CO_2 emission rate was positively and significantly correlated with soil temperature. For further understanding, we analysed the relation between soil CO_2 emissions and soil temperature at the same growth stage of wheat. The results demonstrate that the soil CO_2 emission rate was negatively correlated with soil temperature at the same growth stage of wheat (Table 4), which suggests that the relationship of soil CO_2 emissions and soil temperature was not only affected by tillage practice but was also affected by the climate.

In conclusion, tillage practices had significant effects on soil CO_2 emissions. Compared with RT, PT significantly increased the soil CO_2 emission rate, and NT significantly decreased the soil CO_2 emission rate throughout the wheat growing season. In addition to tillage, straw-returning also significantly affected soil CO_2 emissions. The PT + SR and NT + SR treatments significantly increased the average soil CO_2 emission rate during the wheat growing season compared with the PT and NT treatments, respectively. For all tillage practices, the soil CO_2 emission rate was positively and significantly correlated with soil temperature, and it was negatively and significantly correlated with soil moisture. However, no significant correlation was observed between soil CO_2 emissions and soil MB-C content. These results indicate that tillage and straw-returning affected soil CO_2 emissions by regulating the temperature and moisture of the soil.

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