

Original Research

Short Term Effects of Preceding Crops and Tillage Methods on Soil CO₂ Fluxes in the Cropland of the North China Plain

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Received: 25 June 2021

Accepted: 21 October 2021

Abstract

The influence of tillage method and crop rotation on soil respiration (SR) has been widely studied. However, very few studies have investigated the combined effects of different preceding crop types and tillage methods on SR rates of the same crop in the following season. In this study, two tillage methods including no-till (NT) and conventional tillage (CT) and three preceding crops (maize, peanut and soybean) were selected to study their combined effects on SR. The results showed that (1) for the same preceding crop, the total amount of soil respiration (TSR) of NT treatment was significantly higher than that of CT treatment; (2) under the same tillage method, preceding maize treatment generally had higher SR rates than other preceding crop treatments; (3) the temperature sensitivity (Q_{10}) values of preceding soybean crops were significantly lower than that of preceding maize and peanut crops under CT treatment, but the values of preceding soybean crops were higher than that of preceding maize and peanut crops under CT treatment, and the difference between preceding soybean and peanut crop was significant. Overall, the results indicated that NT method and preceding maize potentially increased SR by changing soil temperature and soil water content in our study area, further studies should strengthen to reveal the microbiological mechanism under different tillage methods and preceding crops.

Keywords: no-till, North China Plain, preceding crop, Q_{10} , soil respiration

Introduction

Soil respiration (SR), which produces approximately 80 to 100 Pg CO₂-C annually, plays an important role

in the global carbon (C) cycle [1-2]. Soil respiration is impacted by several factors including soil temperature and moisture, quantity and quality of soil organic matter (SOM), land use and human disturbance which affect soil properties (biological, chemical and physical). Generally, soil water availability can have both direct and indirect effects on SR through regulation of soil temperature, moreover, the effect of soil moisture on

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SR is regulated primarily by oxygen concentrations under high soil moisture conditions [3]. Soil respiration is not sensitive to temperature below 5°C, but is more sensitive at higher temperatures [4]. The stability and composition of SOM was the main factor controlling SR rates and soil enzyme activities under optimized conditions [5]. Human activities significantly affect soil respiration but the extent varies among different regions [6].

Agricultural land represents about 40-50% of the total land of the planet, and is likely to increase in the future due to increasing food demand for rapidly growing populations [7]. Agricultural practices contribute about 25% of total anthropogenic carbon dioxide emission, meanwhile, the various agricultural practices also deeply change soil physicochemical characteristics and then influence SR and C storage in cropland soils [8]. Release of CO₂ from cropland soils to atmosphere due to agriculture practices plays an important role in the global C cycle [9].

Conservation practices, including no-tillage (NT) and crop rotation, play important role in controlling soil erosion, enhancing crop productivity and improving soil fertility and microbial activities [8-11]. Tillage methods can directly change soil bulk density, soil water content, carbon availability, and all of them can affect the microbial activities that in turn, affect the soil respiration [11-13]. The effect of different tillage methods on SR is contradictory [14-15]. Most researches have reported that conventional tillage (CT) accelerated soil disturbance, weakened the stability of soil aggregates and promoted SR [14, 16-18]. However, others have reported no significant difference in SR under different tillage methods [19] or even increased SR under NT treatment [13, 20]. Since the effect of different soil tillage methods on SR has not been established yet, further investigations are essential.

Crop rotation has been another method to improve soil fertility and microbial communities [11, 21], and there have been many studies focus on the effect of crop rotation on SR emissions [22-24]. However, the study on the effect of different preceding crops on SR rates of the same crop in the following season was scarce [12].

The North China Plain is the second largest plain in China with an area of croplands of 1.8×10^6 ha [25]. Wheat and maize are major crops in this area, accounting for 51% and 32%, respectively, of the national yield [25]. Long term CT method and maize-wheat rotation system led to soil degeneration, soil fertility decrease in this region [26]. NT method and various crop rotations have been widely adopted in this area, but the effect of tillage method and different crop rotations on SR was unclear, especially the effect of preceding crops on SR in the following season. In the present study, we determined the effect of three preceding crops (maize, soybean and peanut) on SR rates under two tillage method (NT and CT) in winter wheat growing season. The main objectives of this study were to clarify and compare SR rates under

different preceding crops and tillage methods, and to investigate the interactive influence of preceding crop and tillage method on CO₂ emissions. This study would be helpful for agriculture strategy making to reduce SR and increase carbon storage in North China Plain.

Material and Methods

Site Description

The study was conducted in a long-term experimental site in Xizhangyi Village (35°17'N, 113°39'E) of Henan Province in the North China Plain. This area has a temperate continental monsoon climate, with a mean annual temperature of 14.6°C and mean annual precipitation of 557 mm (most falls in July and August), sunshine duration of 2058 h, and a frost-free period of 221 days. The double cropping system of winter wheat and summer maize is the dominant in this area. Winter wheat is sowed in October and harvested in the next June. The wheat residuals are smashed onto the field surface, leaving stubble of about 10 cm high. Summer maize is sowed in June and harvested in October. The soil texture is silt loam, and the basic chemical characters in the top 15 cm are as follows: organic carbon of 18.95 g kg⁻¹, total nitrogen of 0.98 g kg⁻¹ and pH of 7.85.

Experimental Design

The experiment was carried out in June 2017 after winter wheat (*Triticum aestivum* L.) harvest. Three crops, maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merrill) and peanut (*Arachis hypogaea* L.), were set as preceding crops. Every crop treatment was triplicated and each plot was 5 m wide and 100 m long. The maize, soybean and peanut were all planted on 13 June and harvested on 28 September, 2017. For maize and peanut, 750 kg/ha compound fertilizer (40% nutrient content, 28: 6: 6, N: P₂O₅: K₂O) was applied as starter fertilizer. For soybean, 375 kg/ha compound fertilizer (40% nutrient content, 28: 6: 6, N: P₂O₅: K₂O) was applied before flowering, the aboveground residues of maize, soybean and peanut were all removed after harvest, the root residues of maize and soybean stayed in soil. In each preceding crop plot, two tillage method treatments including NT and CT as subsidiary-factors were randomly set in the following winter wheat growing season. Each tillage treatment was also triplicated and each plot was 5 m wide and 10 m long. The CT practice including mouldboard plowing to about 20 cm depth, disking and harrowing before planting wheat; there was no other soil disturbance in the NT treatment except for sowing wheat in drill and applying fertilizer by side dress. The wheat was sown on 22 October, 2017 and harvested on 4 June, 2018. All the plots were irrigated two times (20 November, 2017 and 22 March, 2018) during winter wheat growing season.

There were totally 6 treatments and 18 plots: preceding maize and planting winter wheat in CT (PM-CT); preceding maize and planting winter wheat in NT (PM-NT); preceding soybean and planting winter wheat in CT (PS-CT); preceding soybean and planting winter wheat in NT (PS-NT); preceding peanut and planting winter wheat in CT (PP-CT); preceding peanut and planting winter wheat in NT (PP-NT).

SR was measured using an automated soil CO₂ flux system (LI-8100A, LI-COR, USA) equipped with a portable chamber (Model 8100-103). SR rates were calculated based on linear increase in CO₂ concentration in the chamber over time. A PVC collar (20.3 cm in diameter and 10 cm in height) was inserted into inter-row soil at depth of 8 cm in each plot three days before the first measurement. SR rates were measured from 27 October, 2017 to 2 June, 2018 with a 10 days interval. The measurement was conducted at 9-11 am which was the most suitable time for SR measurement [19, 25]. Soil temperature and moisture in 5 cm depth soil near each collar were determined simultaneously using handle thermocouple probe (Omega, USA) and frequency domain reflectometry (FDR), respectively.

After comparing and analyzing the data, SR rate was fitted to soil temperature and soil water content, respectively, with exponential and linear functions given in Equations (1) and (2) to describe the dependence of SR on soil temperature and soil water content.

$$SR = a \times e^{bT} \quad (1)$$

$$SR = AW + B \quad (2)$$

Where T and W is soil temperature (°C) and soil water content (Vol. %), respectively; a, b, A and B are constant coefficients. The temperature sensitivity values of SR (Q_{10}) based on Equation (3) [9] was calculated as:

$$Q_{10} = \exp(10 b) \quad (3)$$

Total amount of soil respiration (TSR) in experimental period was calculated by interpolating the average CO₂ flux between two sampling dates, and computing the sum of the products of the average flux and the time between respective sampling dates for each measurement period [9, 19] as follows:

$$TSR = \sum F_{m,k} \Delta_{tk} \quad (4)$$

Where TSR is the total CO₂ emitted from soils among the study period (g C m⁻²), $F_{m,k}$ is the average CO₂ flux rate over the interval $t_{k+1} - t_k$, and $\Delta_{tk} = t_{k+1} - t_k$, which is the days between two measurements.

Statistical Analyses

The main and interactive effects of preceding crops and tillage methods on average soil temperature (AST), average soil water content (ASW) and TSR were

determined with repeated measures analysis of variance (ANOVA). The difference in AST, ASW, TSR and Q_{10} values were tested by one-way ANOVA. Two-way ANOVA was used to determine the effects of tillage methods, preceding crops and their interactions on the AST, ASW and TSR during the experimental period. All statistical analyses were performed at a significance level of 0.05 using SPSS 16.0.

Results and Discussion

SR Rates and Their Relationship with Soil Moisture and Temperature

In this study, SR emissions of all treatments showed a strong seasonal pattern, with the lowest values in early January and the highest values in beginning of experiments or late April depending on different treatments (Fig. 1). This seasonal pattern was mainly controlled by soil temperature and soil moisture [12, 27-28]. In this study, soil temperature of 5 cm depth during the monitoring period, with the lowest soil temperature in late January, and the highest soil temperature in the end of experimental period (Fig. S1). Soil water content had the similar tendency under different treatments and the changes ranged from 2.21 to 25.47 Vol.%. Soil water contents were generally lower in winter period and higher in summer period. The changes of soil water contents in spring and summer season were intensive because of the precipitation and irrigation (Fig. S2). Soil temperature explained 39-60% of SR using the exponential equation and soil moisture explained 59-85% using the linear function among different treatments. These results indicated that soil moisture and temperature are main factors affecting soil respiration in our study area, which resembled lots of previous studies [27, 29-30].

Impact of Tillage Methods on SR

Tillage methods had significant effects on SR in the present study (Fig. 1, Table 1). In same preceding crop, the SR rates under NT treatments were generally higher than that under CT treatment, and the tendency was obvious when soil temperature and soil moisture was suitable for microbial activity. The differences of TSR between CT and NT treatments were significant (Table 2). The difference of TSR between NT and CT were significant in the same preceding crop treatment (Fig. 1). Three factors contributed to this phenomenon. First, No-tillage treatment generally maintain soil temperature and moisture because of straw mulching especially in winter when the temperature and moisture were low [13]. In addition, No-tillage treatment reduce soil disturbance and take advantage of keep soil water [19]. In our study, the average soil temperature and soil moisture in NT was higher than that in CT treatment (Table 1), so NT treatment had higher amounts of TSR

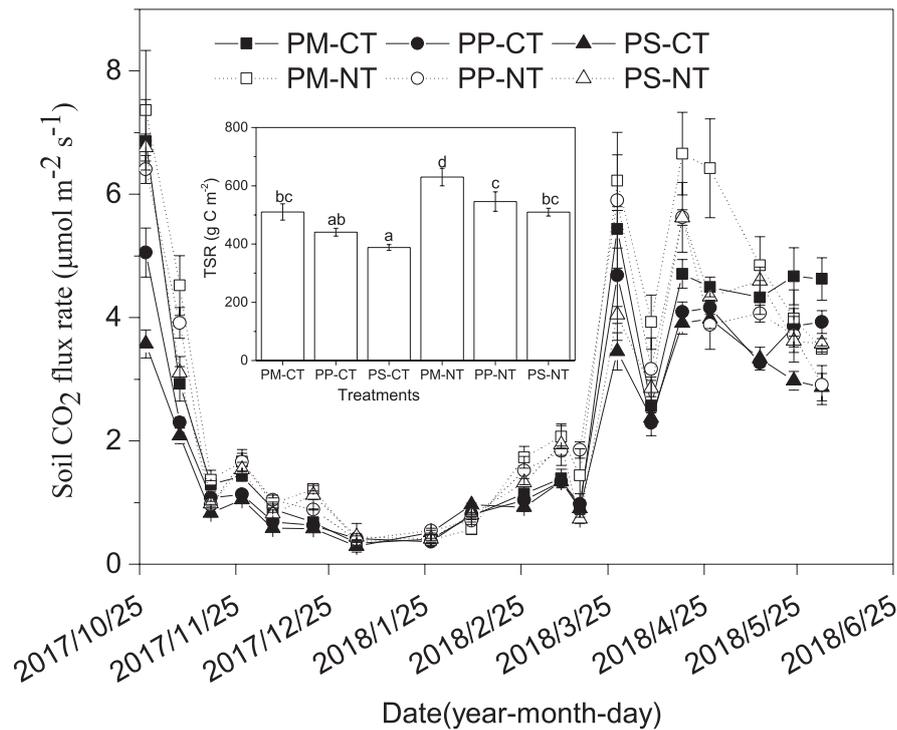


Fig. 1. Soil CO₂ fluxes and total amount of soil respiration (TSR) as affected by preceding maize, peanut and soybean crop treatments under conventional tillage (CT) and no-till (NT) treatments during experimental periods. Vertical bars represent standard errors ($n = 3$). The different lowercases indicate the difference of TSR under different tillage treatments is significant ($P < 0.05$, $n = 3$).

under same preceding crop as soil temperature and moisture were the major factors controlling SR [13, 15, 19]. Second, No-tillage treatment could increase soil organic matter and the increase of SOC stocks would result in high SR rates, although NT may decrease soil CO₂ emissions per unit of soil carbon [15, 31]. Third, No-tillage treatment had a positive effect on biomass and composition of soil microbial communities and microbial activities [11, 32] which promote SR.

Impact of Preceding Crop Types on SR

Preceding crop types also played important roles in SR (Fig. 1, Table 1). Under same tillage method

treatment, preceding maize generally had higher SR rates than other two preceding crops, and the TSR of preceding maize was higher than other two preceding treatments (Table 2). The TSR of PM-CT was significantly higher than that of PP-CT and PS-CT treatments; meanwhile, the TSR at PM-NT was significantly higher than that at PS-NT treatment (Fig. 1). Those results indicated that preceding crops also influenced soil respiration in the following season. Two factors resulted in this conclusion. First, higher root biomass and crop residue of maize than soybean and peanut leads to higher SR rates in the preceding maize crop treatment [12, 23]. The higher rates in preceding maize crop at the initial stage of experiment in CT

Table 1. Values of average soil temperature (AST), average soil moisture (ASM) and total amount of soil respiration (TSR) under different treatments during experimental periods. The different capital letters indicate the difference among various preceding crops under same tillage treatment is significant ($P < 0.05$, $n = 3$) in same column; the different lowercases indicate the difference of same preceding crops under different tillage treatments is significant ($P < 0.05$, $n = 3$) in same column.

Treatments	AST (°C)	ASW (Vol. %)	TSR (g C m ⁻²)
PM-CT	10.7(0.1)a	11.2(0.2)a	510.0(28.0)Ba
PP-CT	10.7(0.0)a	11.0(0.1)a	440.6(13.2)Aa
PS-CT	10.9(0.1)a	11.1(0.2)a	388.1(9.9)Aa
PM-NT	11.3(0.1)b	11.6(0.0)b	629.8(30.1)Bb
PP-NT	11.9(0.1)b	11.6(0.2)b	545.7(33.4)ABb
PS-NT	12.0(0.3)b	11.1(0.3)a	509.4(13.3)Ab

Table 2. Results of multivariate analysis indicating the effects of tillage methods (T), preceding crops (P) and their interactions on the average soil temperature (AST), average soil moisture (ASM) and total amount of soil respiration (TSR) during the experimental period.

Treatments	AST			ASW			TSR		
	df	F	P	df	F	P	df	F	P
T	1	62.85	<0.001	1	8.30	0.014	1	36.75	<0.001
P	2	5.45	0.021	2	1.71	0.222	2	13.84	0.001
T * P	2	1.55	0.252	2	1.68	0.227	2	0.07	0.93

Table 3. Relationship between soil respiration and soil temperature (°C) and soil moisture (Vol. %) under different treatments. The different capital letters indicate the difference among various preceding crops under same tillage treatment is significant ($P < 0.05$, $n = 3$) in same column; the different lowercases indicate the difference of same preceding crops under different tillage treatments is significant ($P < 0.05$, $n = 3$) in the same column.

Treatments	Estimated parameters						
	$y = a * e^{bT}$			Q_{10}	$y = aW + b$		
	a	b	R ²		a	b	R ²
PM-CT	1.390±0.216	0.055±0.008	0.511	1.73±0.02B	0.218±0.019	0.233±0.263	0.695
PP-CT	1.103±0.143	0.055±0.007	0.601	1.75±0.05Bb	0.219±0.144	0.175±0.011	0.825
PS-CT	1.103±0.146	0.046±0.007	0.491	1.59±0.02Aa	0.158±0.009	0.162±0.119	0.85
PM-NT	1.680±0.296	0.05±0.009	0.424	1.66±0.07AB	0.237±0.021	0.388±0.304	0.686
PP-NT	1.497±0.258	0.046±0.009	0.387	1.59±0.01Aa	0.173±0.019	0.702±0.275	0.594
PS-NT	1.244±0.218	0.053±0.009	0.480	1.73±0.05Bb	0.193±0.017	0.389±0.230	0.712

and NT treatments may be mainly caused by high root biomass of maize [12, 27]. Second, preceding crop may change microbial communities both in growing season and the following period after harvest [11-12]. Zhang et al. (2014) [11] indicated that soils with monoculture corn had higher fungal biomass than soils under corn-soybean rotation regardless of tillage treatment, which can partly explain the high SR rates under Preceding maize crop. Benitez et al. (2017) [21] suggested that the preceding crop in a rotation affected the microbial community by colonizing the maize rhizosphere, and influenced maize seeding growth, which could affect SR in the following season.

The Q_{10} Values under Tillage Methods and Preceding Crop Types

The Q_{10} values ranged from 1.59 to 1.75 in different treatments in this study. These Q_{10} values in this study were similar to the range of values (1.3-3.2) reported in temperate climate [25, 33]. Under CT treatment, The Q_{10} values under preceding soybean were significantly lower than that under other two preceding crops, however, there was contrary result under NT treatment (Table 3). Interestingly, the Q_{10} value of preceding soybean was lower than that of maize and peanut under CT treatment. However, the Q_{10} value of preceding soybean was higher than that of maize and

peanut under NT treatment. At the same time, NT majorly decreased the Q_{10} values of preceding maize and peanut, but increased the Q_{10} values of preceding soybean. Those results indicated that tillage method had various influence on Q_{10} values of different preceding crop. Generally, Q_{10} values usually reduced when temperature and moisture became higher [34-35]. In our study, the NT treatment increased soil temperature and moisture, and may be the reason lead to decreasing the Q_{10} values. However, the Q_{10} value of preceding soybean was significant higher in NT than that in CT. The reasons may be that preceding soybean change microbial activities and its more temperature sensitive in NT environment [11, 36]. The specific mechanism should be investigated in further studies. Those results indicated that there are interactive effects between tillage methods and preceding crop types on Q_{10} values.

Conclusions

We studied the combined effect of preceding crop and tillage method on soil respiration in the North China Plain. Preceding maize lead to higher SR than preceding soybean and peanut crop in the winter wheat season; NT had higher SR than that of CT treatment. There is positive correlation between SR and soil temperature and moisture; the Q_{10} values may interactively change

by both preceding crops and tillage methods. Our results indicated that both preceding crop and tillage method play important roles in SR. Further studies should fully take the preceding crop into consideration to accurately evaluate SR in agroecosystems. Preceding soybean and CT treatment may be effective agricultural operations to decreasing SR in winter wheat season in this area. We just investigated the effect of preceding crop and tillage methods on soil respiration in short term in this study, carbon sequestration under different preceding crop and tillage methods should be considered since carbon sequestration is as important as carbon emissions.

Acknowledgments

This work was supported by the National Science Foundation of China (41930643), the National Key Research and Development Program of China (2016YFD0300203-3), the Key project of science and technology research of Henan Provincial Department of Education (19A180020) and the Training Project of Henan Normal University for National Science Foundation of China (2017PL10). We acknowledge the Puyang Field Scientific Observation and Research Station for Yellow River Wetland Ecosystem, Henan Province.

Conflict of Interest

The authors declare no conflict of interest.

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Supplementary Material

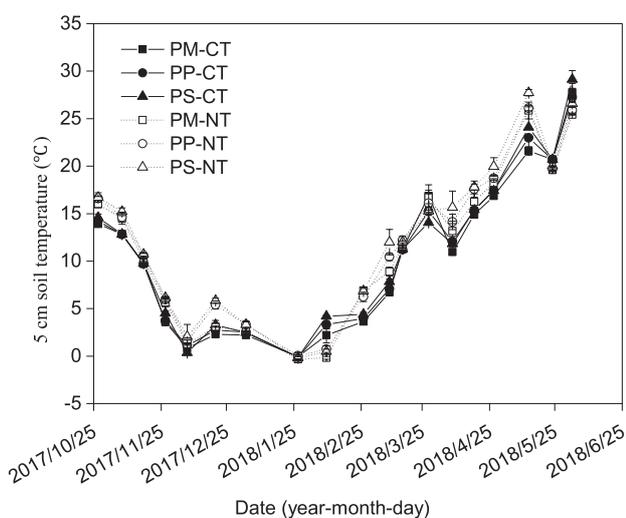


Fig. S1. 5 cm soil temperature as affected by preceding maize, peanut and soybean crop treatments under conventional tillage (CT) and no-till (NT) treatments during experimental periods. Vertical bars represent standard errors ($n = 3$).

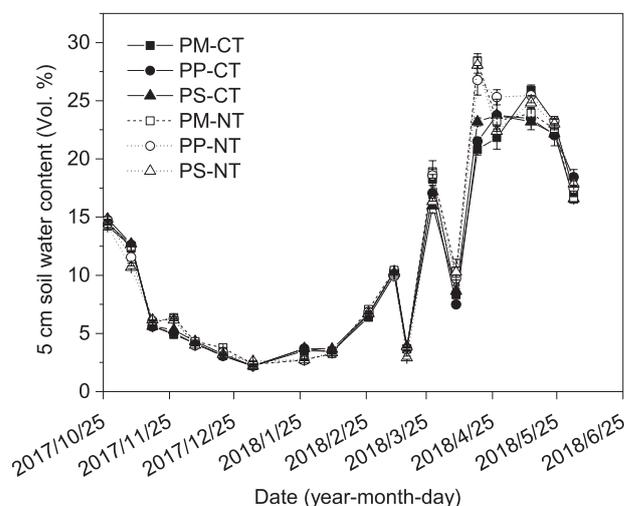


Fig. S2. Soil water content as affected by preceding maize, peanut and soybean crop treatments under conventional tillage (CT) and no-till (NT) treatments during experimental periods. Vertical bars represent standard errors ($n = 3$).