Soil respiration rate in summer maize field under different soil tillage and straw application

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Abstract

Demanding for food security and current situation of global warming give a high and strict request to North China Plain in food production and inhibition of agricultural carbon emission. To explore the effective way to decrease CO_2 emission and remain high grain yield, in 2012 summer maize growing season from a long term project in North China Plain, soil organic carbon, soil CO_2-C evolution rate, soil temperature, grain yield, and ratio of soil respiration to grain yield in different soil tillage and straw application treatments were invested. The results showed that in 0-20 cm soil layer, the organic carbon in no tillage was significantly higher than that in conventional tillage. Both in no tillage and conventional tillage, straw application could enhance the soil organic carbon concentrations at maturity. The mean soil CO_2-C evolution rate in no tillage was significantly lower than that in conventional tillage; however, straw application could significantly increase soil CO_2-C evolution rate, no matter in no tillage or conventional tillage. This result was mainly due to the changes in soil organic carbon, soil total porosity, and soil temperature. No tillage and straw application result in a significantly increase in grain yield and ratio of soil respiration to grain yield of summer maize. The result obtained in field crop conditions support the idea that both no tillage and straw application affect CO_2 emissions in North China Plain.

Keywords: soil CO_2–C evolution rate, no tillage, summer maize, soil respiration to grain yield ratio, soil organic carbon

Introduction

North China Plain is one of the most important agricultural regions in China; its food production accounts for approximately 1/5 of the total national food production. In this region, summer maize is a most important crop (Shen et al, 2012). As for summer maize planting, conventional tillage, such as furrow plowing and rotary plowing is widely adopted, which aggressively disturbs the topsoil every year. In the short term, these tillage systems create a good soil physical environment for crop growth and development. However, in the long term, the soil structure is degraded and soil organic matter mineralization is increased, which induces soil organic matter content depletion, soil compaction, and soil erosion. All of these processes degrade well-structured soil and is not conductive to the sustainable development of agriculture. Hence, in recent years, with combine harvesters have been widely used, adoption of conservation tillage system, such as no tillage, has been widely accepted in North China Plain.

In recent years, with the rapid expansion of the conservation tillage areas to be adopted, many results indicated that conservation tillage improves economic performance and energy use efficiency. Fabrizzi et al (2005) reported that no tillage showed higher soil water storage during the critical growth stage in maize, and most of the wheat growing season. In the northern region of Northeast China, Chen et al (2011) reported that no tillage decreased surface runoff and increased soil water storage, which boosted soybean grain yield on the sloping farmland. These studies clearly showed that conservation tillage compared to conventional tillage could minimize soil water consumption and soil erosion. Other studies showed that conservation tillage could affect soil temperature and physical properties significantly. In the Lower Gangetic Plain of eastern India, conventional tillage and organic mulches were responsible for higher soil temperature in 0.0-0.2 m depth compared with no tillage and bare soil condition (Sarkar et al, 2007), similar result was tested by Sarkar and Singh (2007). No tillage improved soil water-holding capacity via decreasing soil bulk density, increasing soil porosity, and promoting the formation of soil water-stable aggregates (Yu et al, 2011).

Concerns about rising atmospheric CO_2 levels have prompted much interest in recent years (Ben and Allison, 2010). Indeed, though fossil fuel combustion has been the major cause of increasing CO_2 in the atmosphere, land modifications have been a significant contributor (John et al, 2007). Fluxes of CO_2 from agricultural soils are the result of complex interactions between climatic parameters and soil biological, chemical, and physical properties (David

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et al, 2009). Tillage systems could affect soil properties significantly and hence affect CO_2 emissions. Soil respiration is a major component of CO_2-exchange between soil and atmosphere, account for more than 2/3 of the respiration capacity for the global ecological community (Zhang et al, 2012). Farmland ecosystem is a major component of the global ecological community, tillage system, and planting crops have great intervene on carbon cycling. Furthermore, in the global, approximately 10% of the land is used for planting crops. Hence, it is very urgent to conduct studies on soil respiration in farmland ecosystem, these research results may provide important message for evaluating of terrestrial ecosystem carbon balance.

Soil respiration rates are controlled by several factors, including soil organic matter, soil temperature, soil physical parameters, and soil moisture (Jarecki and Lal, 2006; Raich and Tufekcioglu, 2000). In addition, CO_2 emissions are affected by soil practices such as tillage and residue management (Osozawa and Hasegawa, 1995). However, relatively few studies have been conducted to evaluate the effects of no tillage on CO_2 emissions under no tillage management in North China Plain. Therefore, the objectives of this study were to determine i) soil respiration rate, ii) soil organic matter, and iii) soil physical parameters for no tillage system in North China Plain.

Materials and Methods

Experimental site

The field trial was established in 2003 as the long-term project in North China Plain, which is one of the most important regions of agricultural production in China. The region covers an area of 1.445 million km^2, amounting to 15% of the national. A major crop in this region is summer maize. In the region, long-term average annual precipitation ranges from 500 to 650 mm. Mean annual temperature is 12.9°C, and mean annual accumulated temperature of greater than 0°C is 4731°C. The total yearly sunshine duration is 2627.1 h, and the non-frost period is 195 d. The experiment was conducted at the Agronomy Station of Shandong Agricultural University (36°10’19”N, 117°9’03”E), which located in North China Plain on a brown loam soil. Soil nutrient contents of soil organic matter was 13.6 g kg^{-1}, total N was 1.3 g kg^{-1}, total P was 0.56 g kg^{-1}, rapidly available N was 91.6 mg kg^{-1}, and rapidly available P was 15.1 mg kg^{-1}. The investigations for the current experiment were performed in 2012 summer maize growing season. In the summer maize growing seasons, the level of N, P_2O_5, and K_2O were applied at a rate of 120, 120, and 100 kg hm^{-2} as a base fertilizer, and 120 kg hm^{-2} of N was used as topdressing in the jointing stage.

Experimental design

The summer maize variety used in the experiment was “Zhengdan 958”. The seeding and harvested time of the summer maize was on June 17th and October 3rd, 2012, respectively. At the five-leaf stage, the plant was fixed at the rate of 6.75×10^5 plants hm^{-2}. The experiment was conducted in 2012 summer maize growing season, according to a split plot design with tillage as main plot factor and straw management as subplot factor, was carried out in a randomized complete block design with 3 replicates, the size of each tillage plot was 4×5 m. The experiment included 2 soil tillage systems: no tillage (N) and conventional tillage (C). Each tillage system involved 2 straw managements: straw application and no straw application. As for straw application treatment, 0.6 kg m^{-2} wheat residue was added to the soil before maize was sown. In the no tillage treatment, winter wheat straw was mulched on the soil surface, which was chopped into 3–5 cm pieces; in the conventional tillage, winter wheat straw was incorporated into the soil with a moldboard plow. The conventional tillage plots were moldboard plowed to a depth of 20 cm and disked twice prior to planting. A no tillage planter was used to plant summer maize in all treatments.

Measurements

After summer maize harvest, soil samples were collected with a soil sampler. Five random locations were chosen in each treatments and samples taken from every 10 cm of the top 40 cm soil depth. Samples were then air-dried in the shed. The collected samples were ground and sieved through a 10 mesh screen. The soil organic carbon concentration was determined by the Graham Colorimetric method (Graham, 1948).

Rate of CO_2-C evolution was measured using a LI-8100 soil CO_2 flux system (LI-COR Inc, Lincon, NE, USA) with static chambers for gas sampling made of polyvinyl (PVC) pipe at seeding, bell, flowering, filling, and maturity stages of summer maize. The gas chambers bottom base comprised of 15.7 cm high and 25 cm in diameter. The chambers were inserted

Table 1 - Percentage of soil organic carbon at maturity of summer maize in 2012.

Treatments	0-10 cm	10-20 cm	20-30 cm	30-40 cm	Mean
NN	13.08±0.12 b	10.51±0.06 c	8.99±0.06 c	4.54±0.05 d	9.28±0.07 d
NS	22.03±0.15 a	16.68±0.14 a	12.52±0.09 a	6.56±0.14 c	14.45±0.13 a
CN	11.79±0.05 b	10.67±0.06 c	10.88±0.04 b	8.45±0.02 b	10.45±0.04 c
CS	13.31±0.03 b	13.24±0.10 b	12.85±0.09 a	12.97±0.03 a	13.09±0.06 b

Values followed by the same latter in the same column, do not differ significantly (LSD, $P < 0.05$) standard deviation. NN, NS, CN, and CS represent no tillage with no straw application, no tillage with straw application, conventional tillage with no straw application, and conventional tillage with straw application, respectively.

tightly into the ground without any depose of soil surface when measurement started. CO_2 was sampled and analyzed in sunny day from 9:00 a.m. to 10:00 a.m. for the above growth stages. Each measurement was taken less than 2 min. On Aug 15th, diurnal variation for 6:00 a.m. to 4:00 a.m. in the next day was measured every 2 hours. The soil respiration rate was calculated on the basis of a linear increase in chamber CO_2 concentrations overt time. Simultaneously, soil temperature, soil water content (SWC), and pH in 0-20 cm soil depth were measured by a soil temperature and electric conductivity instrument (WET brand, made in the UK). The soil bulk density was measured by the core method (Ji et al, 2013). Three soil cores were taken each plot to 20 cm depth and cut into 10 cm increments. The soil core samples were oven dried at 105°C for 48 h for the bulk density determinations. Soil total porosity and capillary porosity in 0-20 cm were determined by the Dyck and Kachanoski method (2011).

Grain yield was measured at maturity on an area of 8 m^2 corresponding to the central rows of each plot. Ratio of soil respiration to grain yield (CO_2-C kg hm^{-2}) was obtained with the relationship of grain yield / Cumulative CO_2-C evolution at maturity stage.

Statistical analysis

The data was statistically analyzed using analysis of variance (ANOVA). ANOVA was performed at α = 0.05 level of significance to determine if significant differences existed among different regimes. For determining significant effects, multiple comparisons were made using the least significant difference (LSD) test at α = 0.05.

Results and Discussion

Soil organic carbon

Tillage and straw application during the summer maize growing season could affect the soil organic carbon significantly (Table 1). With straw application, the soil organic carbon in the 40 cm soil profiles increased significantly by 5.17% and 2.64%, as compared to NN and CN treatments, respectively. However, the effect of tillage and straw application was different at each soil layer. In 0-10 cm soil layer, the soil organic carbon in NS was significantly higher than those in NN, CN, and CS by 8.95%, 10.24%, and 8.72%, respectively; in 10-20 cm soil layer, the highest soil organic carbon was found in NS, followed by CS and CN, and the lowest was found in NN, which was 10.51%; in 20-30 cm soil layer, there was not significant difference was found between NS and CS, but they were all significantly higher than those in NN and CN; in 30-40 cm soil layer, the highest soil organic carbon was found in CS, which was significantly higher than those in CN, NS, and NN. Hence, straw application could increase soil organic carbon both in no tillage and conventional tillage systems; however, in 0-20 cm soil layer, the soil organic carbon in no tillage was significantly higher than that in conventional tillage, but this was reversed below the 20 cm soil layer.

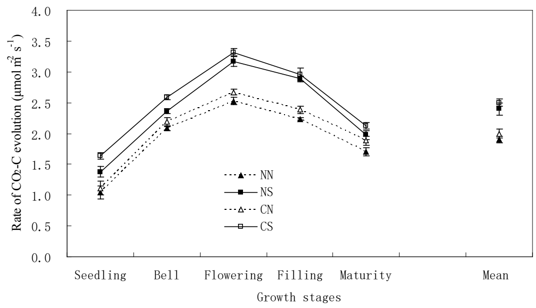

Figure 1 - Soil CO_2-C evolution rate at different growth stages during the summer maize growing season. Vertical bars are standard errors. NN, NS, CN, and CS represent no tillage with no straw application, no tillage with straw application, conventional tillage with no straw application, and conventional tillage with straw application, respectively.

Rate of CO_2-C evolution

Rate of CO_2-C evolution is a critical parameter that describes CO_2 emissions from the farmland. As shown in Figure 1, under different tillage and straw application conditions, the variation trend of rate of CO_2-C evolution in the 4 treatments is consistent, with the developing of growth stages and presenting an odd peak curve. From seeding to flowering stages, the soil CO_2-C evolution rate increased greatly, and at the flowering stage reached the maximum value, then declined rapidly. Compared with conventional tillage, the soil CO_2-C evolution rate in no tillage was significantly decreased; the mean soil CO_2-C evolution rate in NN and NS treatments were significantly lower than those in CN and CS treatments by 5.0% and 4.0% in 2012, respectively. No matter in no tillage or conventional tillage systems, applied straw could significantly increase soil CO_2-C evolution rate, compared with NN and CN treatments, the CO_2-C evolution rate in NS and CS treatments significantly increased by 26.3% and 25.0% in 2012, respectively.

Soil tillage affected soil CO_2-C evolution rate diurnal variation greatly. Figure 2 was based on the data of 15, August, 2012. Under the condition of straw application, the mean soil CO_2-C evolution rate in CS was higher than that in NS by 5.88%. The result showed that from 6:00 a.m. to 20:00 p.m., the mean soil CO_2-C evolution rate in CS and NS were 2.2 and 2.0; however, from 18:00 p.m. to 4:00 a.m., was only 1.1 and 1.0, respectively. Hence, the result indicated that the amplification of soil CO_2-C evolution rate in day time was much better than that in night time.

The result indicated that during the summer maize growing season in North China Plain, no tillage could decrease soil CO_2-C evolution rate significantly, this maybe attributed to increase soil organic carbon. Lal and Kimble (1997) considered that conservation tillage is one of the recommended management prac-

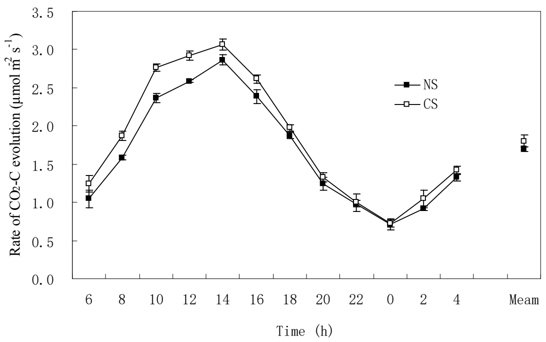

Figure 2 - Soil CO_2-C evolution rate diurnal variation on Aug 15th. Vertical bars are standard errors. NS and CS represent no tillage with straw application and conventional tillage with straw application, respectively.

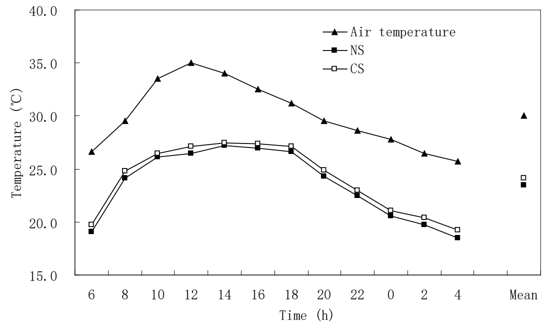

Figure 3 - Soil and air temperature diurnal variation on Aug 15th, 2012. NS and CS represent no tillage with straw application and conventional tillage with straw application, respectively.

tices for increasing soil organic carbon pool in agricultural ecosystems. The higher soil organic carbon concentration in 0-40 cm soil layer of no tillage is attributed to soil-straw interaction which caused lower rates of mineralization. These results are according with other results which also reported a higher soil organic carbon concentration under no tillage than under conventional tillage and minimal tillage (Halvorson et al, 2002; Sainju et al, 2006; David and Rattan, 2009). Conventional tillage caused progressive homogenization of soil organic carbon concentrations in the plow layers by distributing crops straw mechanically throughout the tillage zone.

Soil temperature

With the increasing in the air temperature, the soil temperature at a depth of 20 cm also increased (Figure 3). Although the soil temperature was considerably higher in CS treatment than that in NS treatment, compared to the effect of air temperature, the increase in soil temperature exhibited a hysteretic effect. The highest value in air temperature was found at 12:00; however, the highest value in NS and CS were obtained at 14:00. The effect of soil tillage on the soil temperature was not consistent: from 8:00 a.m. to 18:00 p.m., the mean soil temperature in CS was higher than that in NS by 0.4°C; however, from 20:00 p.m. to 6:00 a.m. in the next day, the mean soil temperature in CS was higher than that in NS by 0.6 °C. Hence, the effect of tillage on the soil temperature was much better at night than in daytime.

No matter under the conditions of conventional tillage or no tillage, straw application could increase soil respiration rate, this result was consistent with Guan et al (2011). However, Sun et al (2009) showed that compared with conventional tillage, conservation tillage decreased soil respiration, with the best effects of no tillage with straw application. This may be caused by the following two reasons. Firstly, many results showed that straw application could decrease soil temperature (Li et al, 2008; Zhang et al, 2008). The more the amount of straw application increased, the more the soil temperature decreased. Under the condition of full of soil moisture, there was positive correlation between soil respiration rate and soil temperature (Tang et al, 2008). Secondly, Straw application could increase soil moisture content. Under the condition of full of soil moisture, both the activities of summer maize root and aerobic microorganisms could be restrained. As a result, the decomposition rate of soil organic matter decreased. Hence, the soil respiration rate declined.

Soil physical parameters at maturity

Straw application under different soil tillage conditions have a significant effect on soil bulk density, soil total porosity, and capillary porosity (Table 2). The soil bulk density was significantly higher in NN and CN, as compared with NS and CS. The highest soil total porosity was observed in CS, followed by NS and NN, and the lowest was found in CN. As for capillary porosity, the highest value was found in NS, followed by NN and CS, and the lowest was found in CN. There were not any significant differences in pH value between any treatments.

Relationship between soil CO_2-C evolution rate and

Table 2 - Soil physical parameters at maturity of summer maize in 0-20 cm soil depth.

Treatments	Soil bulk density (g cm^{-3})	Soil total porosity (%)	Capillary porosity (%)	pH value
NN	1.30 a	46.71d	33.55 b	7.13 a
NS	1.25 b	57.93 b	37.97 a	7.08 a
CN	1.27 b	51.45 c	30.21 c	7.19 a
CS	1.16 c	63.53 a	32.32 bc	7.26 a

Values followed by the same latter in the same column, do not differ significantly (LSD, $P < 0.05$) standard deviation. NN, NS, CN, and CS represent no tillage with no straw application, no tillage with straw application, conventional tillage with no straw application, and conventional tillage with straw application, respectively.

Table 3 - Correlation analysis of soil CO_2-C evolution rate and soil physical parameters.

	Soil bulk density (g cm^{-3})	Soil total porosity (%)	Capillary porosity (%)	pH value	Organic carbon (%)	Air temperature (°C)	Soil temperature (°C)	SWC (%)
Soil bulk density (g cm^{-3})	1							
Soil total porosity (%)	-0.943	1						
Capillary porosity (%)	0.073	0.198	1					
pH value	-0.698	0.445	-0.755	1				
Organic carbon (%)	-0.972*	0.993**	0.08	0.55	1			
Air temperature (°C)	-0.67	0.869	0.647	-0.056	0.802	1		
Soil temperature (°C)	-0.990**	0.963*	-0.066	0.67	0.989*	0.703	1	
SWC (%)	0.661	-0.872	-0.501	-0.01	-0.817	-0.956*	-0.729	1
Soil CO_2-C evolution rate (μmol m^{-2} s^{-1})	-0.942	0.985*	0.064	0.525	0.991**	0.802	0.976*	-0.853

*, ** significant at the 0.05 and 0.01 probability levels, respectively.

soil physical parameters

The relationship between soil CO_2-C evolution rate and others soil physical parameters were investigated (Table 3). It was found that the soil total porosity, organic carbon, and soil temperature had a significant effect on the soil CO_2-C evolution rate. Correlation analysis showed that the organic carbon (r=0.991, p<0.05)>soil total porosity (r=0.985, p<0.05)>soil temperature (r=0.991, p<0.05). These results indicated that organic carbon, soil total porosity, and soil temperature, compared with other soil physical parameters, had more contribution and influence on the soil CO_2-C evolution rate during the summer maize growing season in North China Plain.

Both soil tillage and straw application could affect soil physical parameters significantly. Ji et al (2013) indicated that soil penetration resistance, bulk density, and soil moisture content were significantly affected by tillage practices. By the soil respiration system, the characteristics of soil respiration were correlated between soil respiration and soil moisture (Xie et al, 2010).

Grain yield and ratio of soil respiration to grain yield

Table 4 shows the grain yield and ratio of soil respiration to summer maize grain yield, which was obtained with the relationship of grain yield / cumulative CO_2-C evolution at maturity stage. CS resulted in the highest grain yield (7117.23 kg hm^{-2}), but it was not significantly higher than that in NS, followed by CN, and the lowest grain yield was observed in NN. This grain yield value was lower than that in CS, NS, and CN by 714.62, 631.42, and 352.77 kg hm^{-2}, respectively; furthermore, the ratio of soil respiration to grain yield in NN was only 0.24 CO_2-C kg hm^{-2}, which was significantly lower than that in CS and NS by 0.05 and 0.03 CO_2-C kg hm^{-2}. It was apparent that under the condition of straw application, CS did result in a significant increase in grain yield and ratio of soil respiration to summer maize grain yield.

Table 4 - Grain yield and ratio of soil respiration to grain yield of summer maize.

Treatments	Grain yield (kg hm^{-2})	Ratio of soil respiration to grain yield (CO_2-C kg hm^{-2})
NN	6,402.61 c	0.24 c
NS	7,034.03 a	0.27 b
CN	6,755.38 b	0.24 c
CS	7,117.23 a	0.29 a

Values followed by the same latter in the same column, each year, do not differ significantly (LSD, P < 0.05) standard deviation. NN, NS, CN, and CS represent no tillage with no straw application, no tillage with straw application, conventional tillage with no straw application, and conventional tillage with straw application, respectively.

This study clearly showed that straw application treatments had an overall greater grain yield over no straw application treatments. The difference between mulched soil and bare soil with maize plants is not due to the total water consumption, but due to the alteration of the ratio of transpiration to evapotranspiration (Li et al, 2013). The mechanism of transpiration and evapotranspiration in coordination with carbon utilization acting on grain yield of different mulching and plant density should be studied further. Now and for a fairly long time to come the risks of extreme weather phenomena are increasing along with global climate changes during the summer maize growing seasons in North China, its interaction mechanisms are still not very clear. Hence, understanding these mechanisms is not only essential for understanding the soil respiration rate characteristics with soil tillage and straw application but also provides theoretical and practical crops planting techniques in North China Plain.

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