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Full Length Research Paper

Effect of conservation tillage on soil respiration rate and water content under wheat/maize system in North China Plain

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Conservation tillage management can improve soil moisture and reduce or increase soil CO_2 emission. Soil CO_2 flux rate, soil moisture, and the relationship between soil respiration and temperature on North China Plain throughout a 3-year period was determined. Tillage systems were rotary tillage without crop residues (CT), rotary tillage with crop residues incorporated into the soil in winter, and no-tillage with crop residues used as mulch in summer (TW), and rotary tillage with crop residues incorporated into the soil in summer and no-tillage with crop residues used as mulch in winter (TS). Soil respiration was measured with a LI-8100 and the gravimetric method was used to identify soil water content. Soil temperature at 5 cm depth also was measured directly by Li- 8100 through a temperature sensing probe during the CO_2 measurement time. The crops were winter wheat (*Triticum aestivum* L) and summer maize (*Zea mays* L). During the wheat and maize growing period, TS reduced CO_2 emission when compared with CT and TW. For the first two years of this study, CT and TW had higher soil water content when compared with TS. Thus, this study suggests that conservation tillage can be useful for North China plain farmers; however, TW emitted CO_2 at the highest rate level, therefore further research is needed on long term effects of those three tillage practices on respiration rate and soil moisture in that area.

Key words: Crop residue, tillage, CO_2, soil water content, soil respiration, North China plain.

INTRODUCTION

Soil moisture can be improved by agricultural management practices such as utilization of crop residues and no-tillage. Impacts of conservation tillage on soil respiration, moisture, and relationship between soil respiration rate and soil temperature have been well investigated, but the findings vary by location due to difference in climate, crop residue management, cropping system, and soil type (Moraru and Rusu, 2012). Wheat

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and maize residues are easily incorporated into the soil, used as mulch, and are good sources of crop nutrients, enhancing soil fertility, and increasing yield (Alberto et al., 1996).

In North China, agricultural practices are characterized by clean plowing with all crop residues removed from the topsoil, usually by burning or use as animal fodder, leaving soil bare and unprotected by vegetation cover (Wang et al., 2007). However, crop residues contain high quantities of crop nutrients, and have high levels of organic matter rich in micronutrients (Lee, 2010). Many previous studies reported that crop residues improve soil moisture by reducing soil water evaporation and deep percolation; therefore, the use of crop residues can improve the soil properties and productivity (Mulumba and Lal, 2008).

Tillage has important implication for CO_2 emissions. Nowadays, a rapid increase of CO_2 in environment is one of the main issues because climate change could result in increased temperature and drought (Wood, 1990). Thus, tillage effect on CO_2 flux must be understood. There is need to observe and quantify CO_2 flux as impacted by agricultural management practice (Reicosky, 1997). Management practices need to be developed to reduce soil respiration and organic matter decomposition without decreasing crop yield. A known, deep tillage increases CO_2 emissions from the soil to the atmosphere (Reicosky and Archer, 2007). This indicates that the implementation of no-tillage practices can reduce soil CO_2 emission. However, there is no consensus on differences in soil CO_2 emission rates among no-tillage with crop residue use as mulch, tillage without residue residues, and tillage with residue incorporation. Some authors reported similar soil CO_2 emission rates from conservation tillage and conventional tillage (Elder and Lal, 2008), whereas Oorts et al., (2007) observed large CO_2 emissions under no-tillage. The differences in soil CO_2 emissions among tillage practices may depend on tillage practices (Oorts et al., 2007).

Soil moisture can be strongly affected by land management techniques such as tillage systems (Keesstra et al., 2012). Under agricultural production, the tillage system can lead to soil water evaporation or deep percolation. Water is one of the main factors for agricultural production in the North China, and thus storing water in the soil profile is essential for a crop to survive during periods without rainfall. However, intensive tillage systems are contributing to declining soil moisture in the North China Plain. Furthermore, soil water conservation is critical to winter wheat production, which mainly depends on soil water, because winter rainfall is limited and irregular (Xie et al., 2005). Storing soil water for improving crop yield has been supported by many studies including those conducted in the North China Plain (Wang et al., 2009). Conventional tillage leads to serious loss of water through evaporation and percolation, and therefore decreases crop yields. Thus, improving soil structure and water storage are extremely necessary in the North China Plain. Conservation tillage is considered helpful because it is one of the effective ways to improve soil structure and soil water storage, especially in an arid region like the North China Plain (Gicheru et al., 2004).

A better understanding of the short-term effects of tillage systems and straw management practices on soil water, soil respiration, and the relationship between soil respiration rate and soil temperature is necessary for the further development of conservation tillage in the North China Plain. Since 2002, the Chinese government has issued a series of policies to promote the application of conservation tillage, because many researchers reported that conservation tillage reduces soil respiration, and promotes sustainability. The area under conservation tillage expanded from 0.13 million hectares in 2003, and to projected 10 million hectares in 2015. However, China still accounts for only 0.2% no-tillage or conservation tillage area worldwide (Bruinsma, 2003). In addition, due to the conflicting results of previous studies, and the specificity of results to soil type and climate, more work is needed to understand how tillage and crop management residues improve soil moisture and reduce CO_2 emission. It was hypothesized that conservation tillage would improve soil moisture and reduce CO_2 emission when compared with conventional tillage. Thus, the objectives of this study were to determine the impacts of conservation tillage on soil respiration, water content, and the relationship between soil respiration rate and soil temperature in North China Plain.

MATERIALS AND METHODS

Site description

The experimental site, managed by the Chinese Academy of Agricultural Sciences (CAAS), is located in Langfang in Hebei Province (39.53°N, 116.70°E). In this province, a rotation of winter wheat and summer maize accounts for 80% of agricultural land. The winter wheat is typically planted in early October after harvesting summer maize sown in June. January is the coldest month with an average temperature of 4.7°C, and July the hottest with an average temperature of 26.2°C. Annual precipitation is concentrated during the summer growing period from June to September. About 70 to 80% of annual precipitation occurs from June to September growing period of maize, and 20 to 30% occurs from October to June during the growing period of wheat. The amount and distribution of rainfall changes widely from year to year due to the continental monsoon climate. The soil texture is silt loam according to the FAO soil classification and the soil properties before the experiment are presented in Table 1.

Experimental design

This experiment was started from October 2012 to June 2015 and a randomized block design was used. The size of each plot was 66.56 m^2, and wheat and maize were grown in alternation. Three treatments were conducted in this experiment, and each treatment was repeated three times (Table 2). Rotary tiller without crop

Table 1. The basic soil properties before experimental design.

Property	Value
Soil organic carbon (g kg^{-1})	6.38
Total nitrogen (g kg^{-1})	0.85
Available phosphorus(mg kg^{-1})	12.75
Available potassium (mg kg^{-1})	93.7
pH	8.0

Table 2: Description of experimental design.

Treatment	Treatment details		Crop residue management	
	Winter	summer	Winter	Summer
CT	Rotary tillage	Rotary tillage	Removed	Removed
TW	Rotary tillage	No-tillage	Incorporation into soil	Use as mulch
TS	No-tillage	Rotary tillage	Use as mulch	Incorporation into soil

residues was conventional tillage (CT), but rotary tillage with straw incorporated into the soil in winter and no-tillage with crop residues used as mulch in summer (TW), and rotary tillage with straw incorporated into the soil in summer and no-tillage with crop residues used as mulch in winter (TS) were conservation tillage. Fertilizers for winter wheat were applied at the rate of N: P_2O_5:K_2O = 90: 150: 75 kgha^{-1} during sowing period and another 90:00:00 during growing period. Fertilizers for maize were applied at the rate of N:P_2O_5:K_2O 180:150:74 kgha^{-1} before tillage practice and another 60:00:00 during heading stage.

On no-tillage plots (TW or TS), maize was manually sown with hoe after all residues from the wheat/maize were cut, flattened and left on the soil surface at the rate of 6164.60 and 4408.8 kg ha^{-1} of maize and wheat straw, respectively. The crop residues were returned to the plot from which they originated. When the plots were under tillage with crop residues (TW or TS), rotary tillage was practiced at a depth of 25 cm, and all residues were mixed or incorporated into the soil at the rate of 6164.60 and 4408.8 kg ha^{-1} of maize and wheat residues, respectively.

On the plots under rotary tillage without crop residues (CT), all above-ground maize residues were removed and the maize straw was at the rate of zero per hectare, but wheat stubble corresponded with 110.25 kg ha^{-1} left before tillage practice.

Measurement

To measure soil respiration rate, a PVC tube with an inner diameter of 20 cm and a height of 13 cm, was inserted into the soil to a depth of 9 cm at the center of each plot. Before practicing tillage, the PVC was removed and reinserted at the same position after crop emergence. One day before measurement, all living plants inside and adjacent to the PVC were removed by hand to avoid above-ground plant respiration. Soil respiration was measured for up to 180 s between 8 and 11 am. Soil respiration was measured directly by using an automated soil CO_2 flux system analyzer (LI-8100, LI-COR, Inc., Lincoln, NE, USA) in units of µmolCO_2 m^{-2} s^{-1} in the field. Cumulative CO_2 was computed as follows:

$$CCO_2(kg\ ha^{-1}) = 38\ 016\sum_i^n R_i \qquad (1)$$

where Ri (µmolCO_2 m^{-2} s^{-1}) = average soil respiration, n = number of times the data on soil respiration rate were collected during wheat or maize growing period, and 38016 = a converting factor. It was hypothesized that there was no large variation of soil respiration rate during the measurement day.

To measure soil temperature at the same time as soil respiration, a dial probe soil thermometer was inserted vertically to 5 cm from the soil surface close to the PVC, but was removed after soil temperature was recorded. The relationship between soil respiration and temperature was examined using exponential regression during maize growing period, whereas during wheat growing period, the relationship was examined using polynomial regression. For maize growing period, the temperature sensitivity Q_{10} of soil respiration was calculated as:

$$Q_{10} = e^{10b} \qquad (2)$$

where b is a parameter estimated by applying exponential regression.

However, for data collected during wheat growing period, the temperature sensitivity Q_{10} of soil respiration was calculated as:

$$Q_{10} = \left(\frac{R_2}{R_1}\right)^{\frac{10}{T_2-T_1}} \qquad (3)$$

where R_2 and R_1 were consecutive soil respiration rates observed at temperature T_2 and T_1, and T_2 was higher than T_1.

To determine soil water content, three random locations in each plot of the middle block were considered. In 2013 and 2014, soil samples were collected on the same day as soil respiration at 20 cm increments from 0 to 200 cm depth, but in 2015 they were collected at 20 cm increments from 0 to 160 cm depth, because it was difficult for worker to get soil from deeper soil. The mean moisture for three locations was computed as the soil moisture level.

Statistical analysis

Mean values were calculated for each of the variables, and ANOVA was used to assess the effects of conservation and straw on soil properties, soil respiration, and yield. SAS 9.2 and 5% significance level were used for all statistical analyses.

RESULTS AND DISCUSSION

Soil respiration rate and its seasonal variation

The rate of CO_2 emission is one of the important parameters that can describe CO_2 emission from soil. Soil respiration rate varied over the growing periods of wheat and maize (Figure 1a, b, and c). During this study, the dynamic rate of soil respiration coincided with the dynamic of soil and air temperature, and the maximum soil respiration occurred in summer and the minimum in winter. During the winter growing period (Figure 1a and b) from 2013 October to 2014 March or October 2014 to March 2015, the mean soil respiration rates decreased from 2.21 or 1.89 to 1.44 or 0.94 under CT, from 5.33 or 5.05 to 1.44 or 1.24 under TW, and from 1.91 or 1.67 to 0.9 or 0.66 µmolCO_2 $m^{-2}s^{-1}$ under TS. From March to May, soil respiration rates increased under all treatments, and decreased again to reach their minimum values in June, the harvest period. During both wheat growing periods, highly significant differences were observed among treatments, with p-values ranging from less than 0.0001 to 0.037, and for both wheat years, TW had the highest soil respiration rate and TS had the lowest one. This implies that incorporating maize residues into the soil during winter wheat increased soil respiration as compared to using maize residue as mulch. Thus, the most disruptive tillage practices with maize residue incorporation released CO_2 at a higher rate.

During the maize growing period (Figure 1c), significant differences were observed among treatments except at the maturity stage and p-values ranged from 0.0016 to 0.621. On 12 of July, CT and TS emitted high rates of CO_2 because they were tilled at the beginning of the maize growing period and crop residues were incorporated into the soil. For these treatments, the highest CO_2 emission rate was recorded at the beginning of maize growing period and then, the CO_2 emission declined steadily. From 12 to 25 of July, the effects of tillage decreased, but those of microbes increased. Indeed, from 10 to 25 of July, the CO_2 emission rate decreased under CT and TS from 5.11 to 4.876 and 5.4 to 4.55 µmol CO_2 m^2s^{-1}, respectively. However, under TW, the CO_2 emission rate reached its maximum value (6.06 µmolCO_2 m^2s^{-1}) in July before decreasing. Furthermore, from July to September, TW significantly had the highest CO_2 emission rate, but on 3 October, no significant differences were observed among them. The average soil respiration was CT (3.62), TW (4.284), and (3.66) µmolCO_2 $m^{-2}s^{-1}$.

In addition, during this study (6 days for each growing period of wheat and 5 days for maize), the cumulative CO_2 emitted per hectare was 674.277 and 634.867(CT), 923.915 and 879.563 (TW) and 603.567 and 564.66 kg (TS), respectively in 2014 and 2015 during wheat growing period. During maize growing period, cumulative CO_2 emitted by hectare was 689.103 (CT), 814.3027 (TW), and 695.69 kg, therefore, TS could be a good tool to reduced CO_2 in North China.

Furthermore, it was noted that wheat showed relatively lower values of soil respiration than maize.

To sum up, the results of this study showed that TS reduced the soil CO_2 emission rate as compared to TW and CT. Previous studies showed that no-tillage with residue cover reduced CO_2 emission by reducing soil disturbance (Prior et al., 2004; Bauer et al., 2006; Curtin et al., 2000; Ussiri and Lal, 2009). These results also suggest that crop residues incorporated into soil by tillage significantly increased CO_2 emissions (case of TW during wheat growing period), which may have resulted from the abundance of carbon in maize and wheat straw, and close contact between residues and micro-organisms when residues are incorporated into the soil (Fu et al., 2000) releasing carbon to the atmosphere during straw decomposition (Nie et al., 2007). In contrast, when the residues were left as mulch on the soil surface, the contact between residue and soil organisms was restricted. This study also suggests that crop residue incorporation is not the best way to reduce CO_2 emissions, because no-tillage could reduce the crop residue decomposition rate (Li et al., 2010). Our results were different from those reported by Lee (2009). They reported that seasonal emission patterns were not much influenced by tillage; however, the results of this study corroborated with Krištof et al., (2014) and Prior et al. (2004). They reported that no tillage practice with straw used as mulch decreased CO_2 emissions by reducing soil disturbance. Thus, no-tillage with straw used as mulch can be used to reduce air pollution in an agriculture system. During the both wheat growing period, it was noted that soil respiration varied over time. The soil respiration recorded under all treatments in October could be mainly attributed to microbial activity and tillage practice, because these soil respiration rates were recorded only fifteen days after tillage, then tillage and crop residues could change soil property, such as soil aeration, the contact of soil microorganisms with substrate, the substrate distribution, and soil temperature and moisture. Tillage also could disrupt soil aggregate and transforming labile or fresh organic matter once protected by aggregate to unprotected ready organic matter exposed to microorganism activity (La Scala et al., 2008; De Gryze et al., 2006) as a result of higher soil respiration rate, was observred under TW. The lower soil respiration observed in March could be mainly attributedto air and soil temperature and less microbial activity. Indeed, from January to March, air temperatures were low and average soil temperature was recorded in March ranging from 1.85 to 2.47°C, thus during cold period, the number and activity of microorganisms fell down. In general, population and activities of soil microorganisms are the lowest in winter season. This finding was consistent with what Pietikainen et al., (2005) reported. They reported that the respiration rate at 45°C

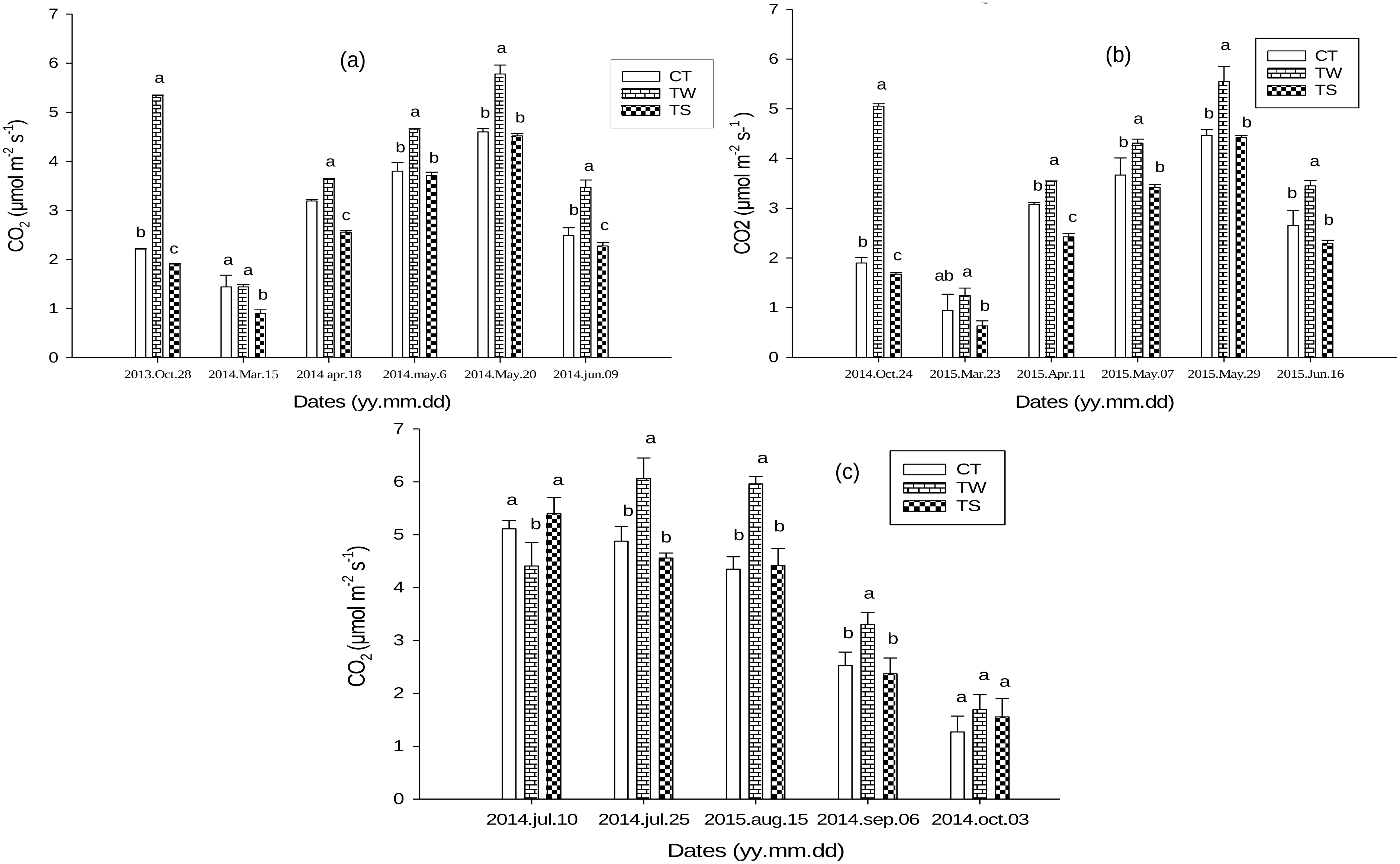


Figure 1. (a, b, and c): soil respiration rate during wheat and maize growing period (µmol m^{-2} s^{-1}). The mean (n=3) followed by the same letters are not significantly different at $p < 0.05$, CT: rotary tillage without crop residues in winter and summer; TW: rotary tillage with crop residue incorporation into soil in winter and no tillage with crop residues use as mulch in summer. TS rotary tillage with crop residue incorporation into soil in summer and no tillage with crop residues use as mulch in winter.

was around 120 times higher than at 0°C in agricultural soil. From March to May, CO_2 rate variation coincided with patterns of crop growth, because of heterotrophic (microbial) and autotrophic root respiration, this result was consistent with Yang and Cai (2006) who reported that seasonal pattern of soil respiration rate was consistent with the pattern of the cumulative rate of aerial part of soybean plant. Therefore, an increase of soil respiration recorded during that period resulted from an increase of biomass root, rhizodeposition (Franzluebbers et al., 1995). From May to June, decreased soil respiration was mainly attributed to aging phenomena, senescence.

During maize growing period, from July to August, soil respiration was high and there was no large variation of soil respiration rate under the same treatment. This could be attributed to the heavy rainfall event which occurred during that period. Indeed, during that period, a total amount of rain water of 237 mm was recorded with maximum of 8 days between two consecutive rainfall events. This result corroborated with what Morell et al. (2010) reported in a semiarid mediterranean agro-ecosystem. They reported that the CO_2 dependence on precipitation lasted for a period of time as long as the soil remained moist. From August to October, soil respiration decreased, this could be attributed to a rainfall decrease and aging phenomena.

Temperature sensitivity (Q_{10})

During wheat growth period, soil respiration rates were modeled using a polynominal function ($p < 0.05$) (Figure 2a, b, c, d, e and f). Previous studies reported that the relationship between soil respiration rate and soil temperature was exponential (Zhang et al., 2011, 2013). Our result is not consistent, because it was noted that during wheat maturity period, soil temperature was high whereas soil respiration was low. However for maize growing period (Figure 2g, h, and i), soil respiration rates exponentially increased with soil temperature ($p < 0.05$).

During the wheat growing period, soil temperature at 5 cm depth significantly correlated with CO_2 emission (CT, R^2 = 48.3 - 54.8), (TW, R^2 = 84.9 - 86.1) and % (TS, R^2 = 54.5 - 57.8) ($p < 0.05$). Thus, during the winter wheat period, the temperature explained well CO_2 rate when crop residues were incorporated into the soil. This finding is consistent with what (Zheng et al., 2009) reported.

They noted that soil temperature at 5 cm depth significant correlated with soil respiration and R^2 varied from from 0.37 to 0.83.

For wheat growing period, the Q_{10} values were separated in two groups: when the soil temperatures were less than 20°C (from 28 of October 2013 to 6 of May 2014 and 24 of October 2014 to 7 of May 2015), and the soil temperatures were higher than 20°C (from 20 of May to Jun 2014 and from 29 of May to 16 of June 2015). For both years when the soil temperatures were less than 20°C, the Q_{10} values were 2.367 and 3.012 (CT), 3.61 and 4.36 (TW), and 5.297 and 6.885 (TS), and when soil temperatures were higher than 20°C, Q_{10} values were 0.776 and 0.837 (CT), 0.863 and 0.904 (TW), and 0.855 and 0.935 (TS), thus this suggests that Q_{10} was more sensitive when soil temperature was low and the higher Q_{10} was observed under conservation tillage (TW and TS). This result corroborated with Zheng et al. (2009).

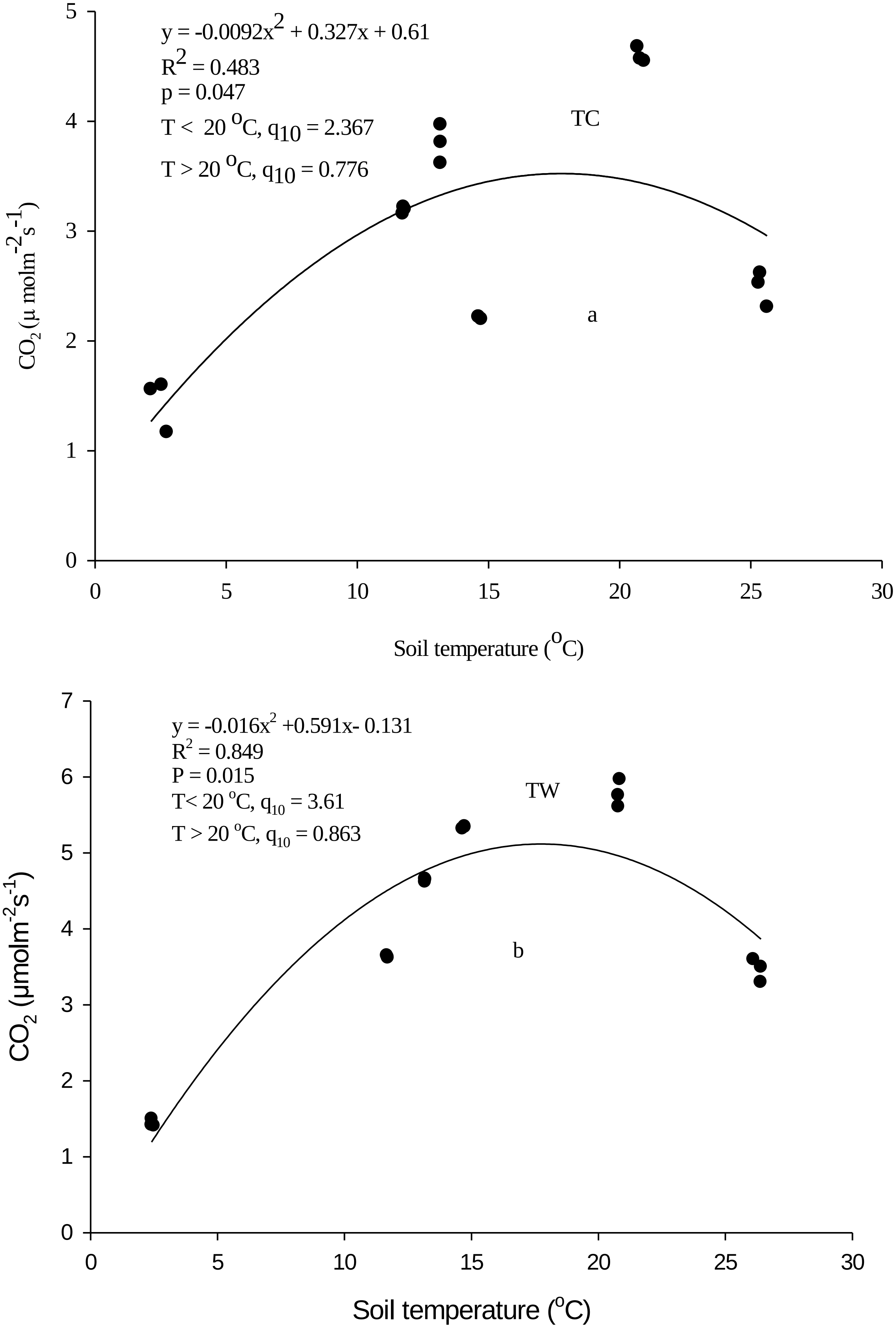
During the maize growing period, soil temperature was significantly correlated with soil respiration and R^2 was 0. 83, 0.80 and 0.76 ($p < 0.005$) under CT, TW and TS, respectively. The Q_{10} value under treatments was 2.62 (CT), 2.48 (TW), and 2.316 (TS), therefore, conservation tillage TW and TS reduced the temperature sensitivity in summer.

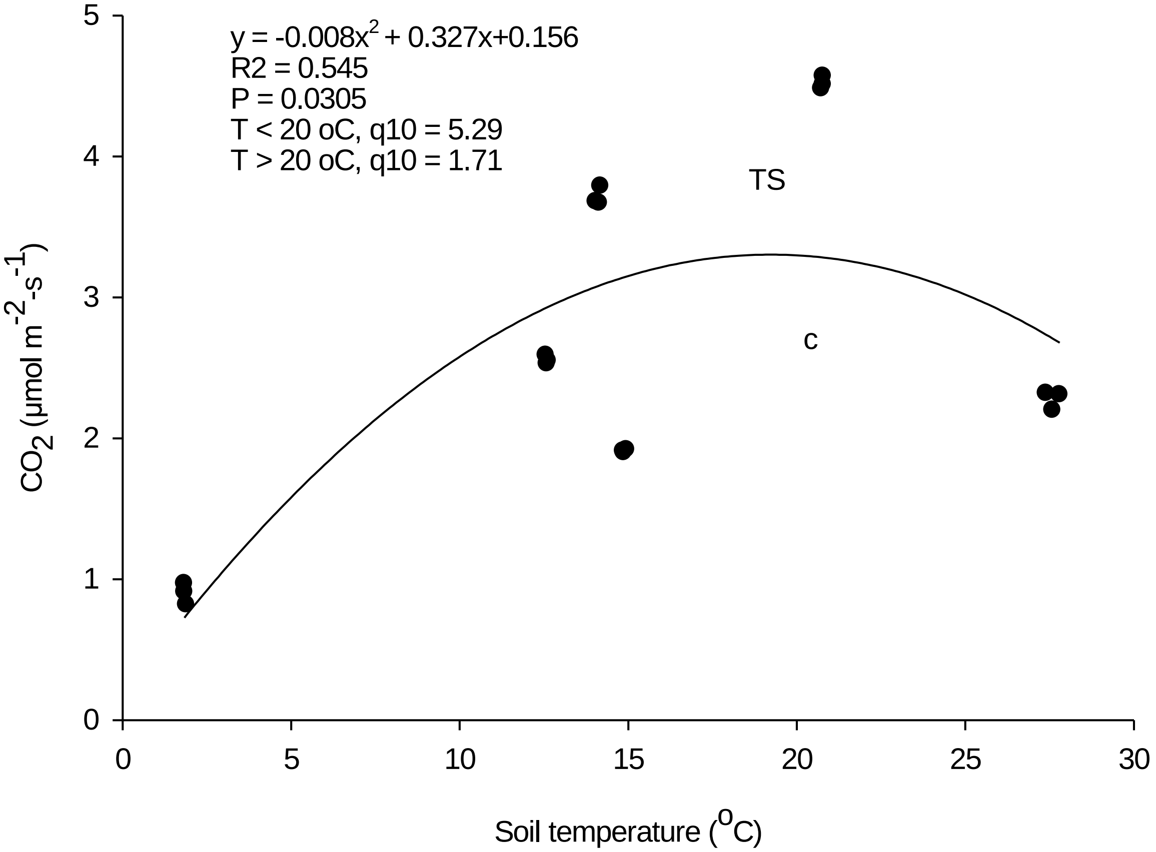
Effect of tillage on cumulative soil water content

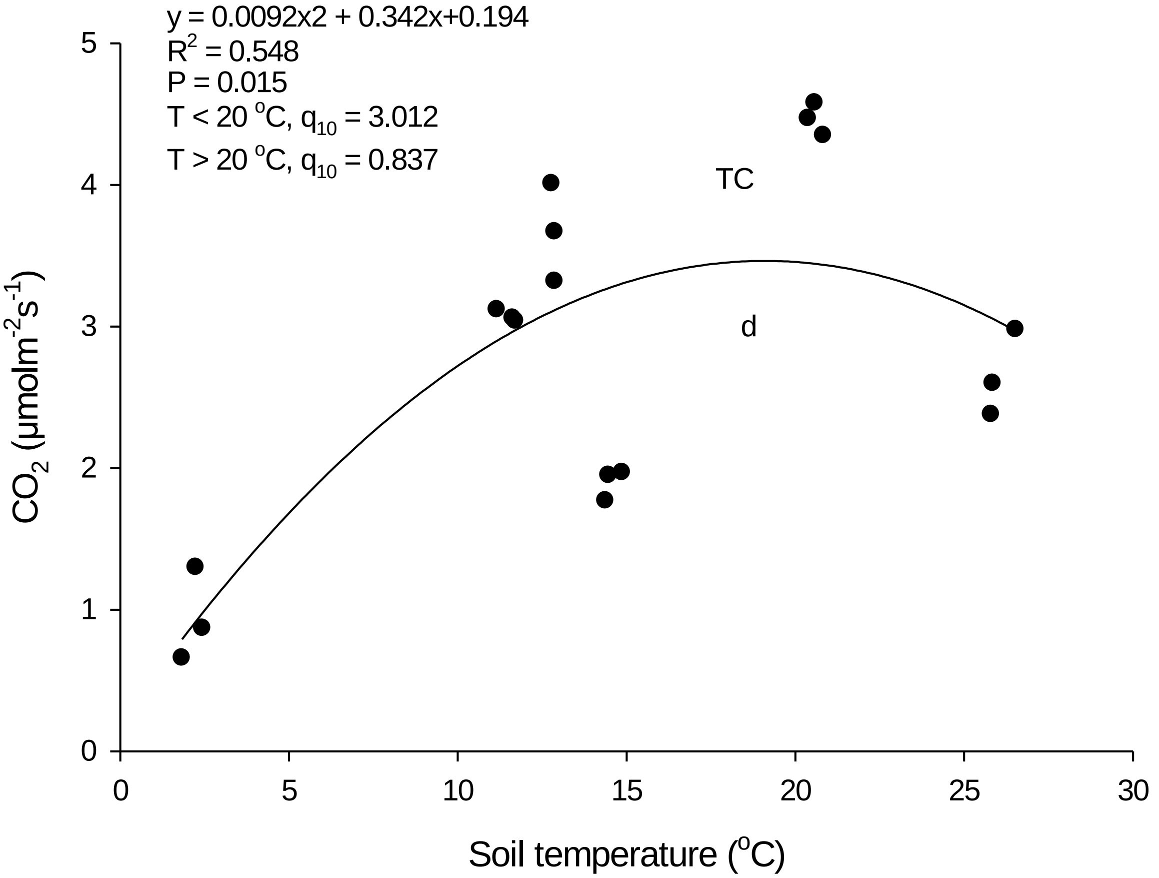
The Figure 3a and c shows the average of CSWC at 0 to 200 cm depth during the wheat and maize growing period, respectively, and Figure 3b shows CSWC at 0 to 160 cm depth. During the wheat growing period in 2013 to 2014 (Figure 3a and b), CSWC was significantly greater under TW than TS and CT ($P < 0.05$). This suggests that tillage with crop residue incorporated into the soil improves soil water content.

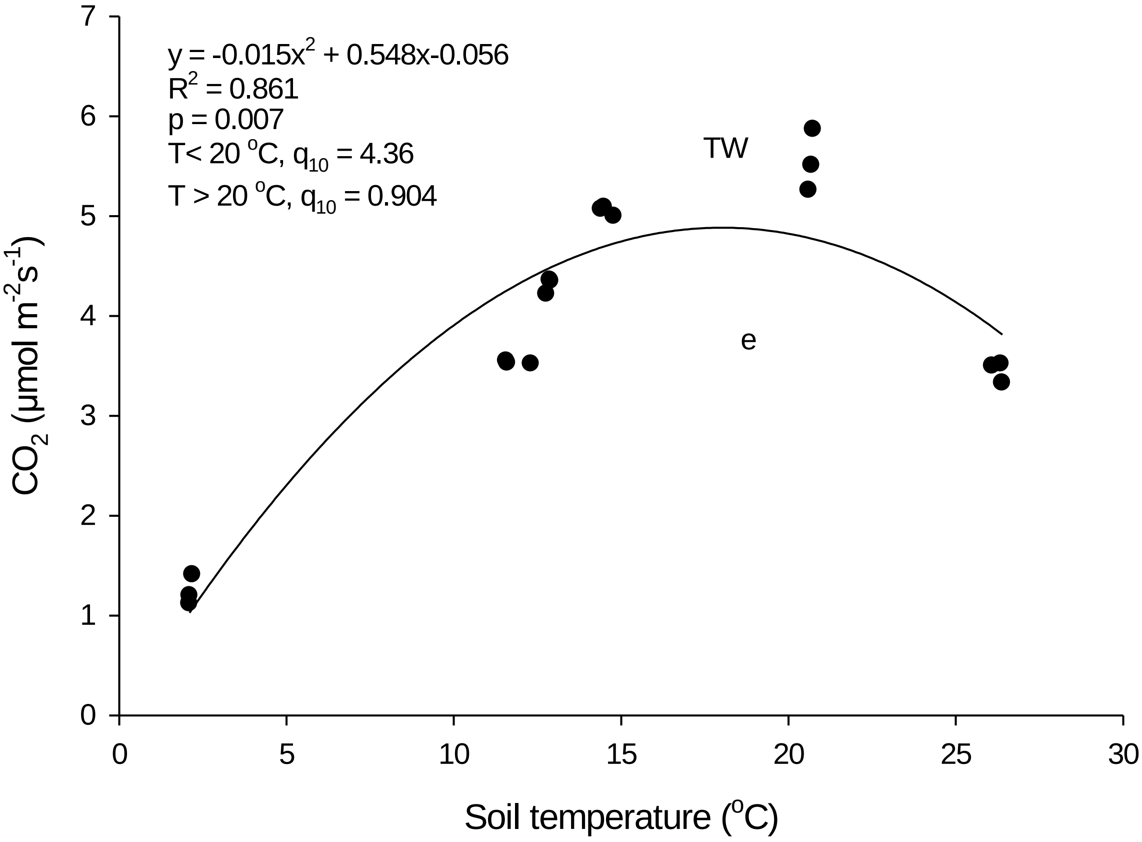
During maize growing period (Figure 3c), CSWS was significantly higher under TW at 0 to 80 cm of soil depth, and TW significantly increased CSWC by 13.94 and 39.17% when compared with TS and CT, respectively. At 80 to 200 cm depth, TW and CT significantly increased CSWC compared with TS, but no significant differences were observed between TW and CT. In addition, CT had higher CSWC when compared with TW; this suggests that during wet period, water percolation occurred under CT. From 2014 to 2015, TW and TS (Figure 3b) increased CSWC when compared with CT at 0 to 40 cm depth; there was water evaporation under CT. At 60 to 160 cm conservation tillage (TS and TW) significantly had lower CSWC when compared with CT, thus under CT there was deep percolation. At 0 to 200 cm depth, no significant differences were observed among treatments, thus soil water was distributed in moderation under conservation tillage soil profiles.

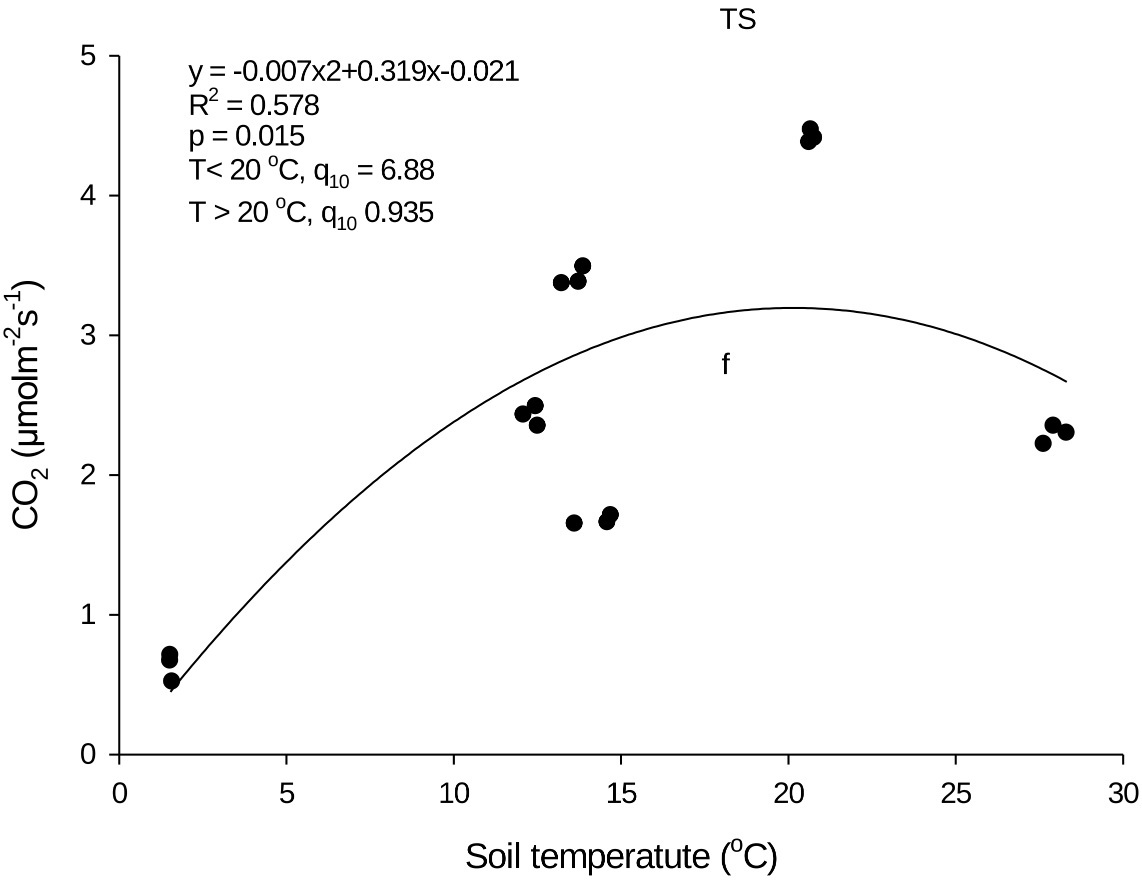
Differences in CSWC were related to soil water infiltration and reduced water evaporation. The TW and TS system had crop residues on the soil surface or incorporated into the soil, which obviously prevented soil water from evaporation during a dry period, while enhancing rainfall infiltration into the soil. This finding is consistent with Li et al. (2011) and Nielsen et al. (2005). However, our finding did not corroborated with Rashidi and Keshavarzpour (2007), who determined that conventional tillage had higher moisture than conservation tillage. They noted that conventional tillage improved

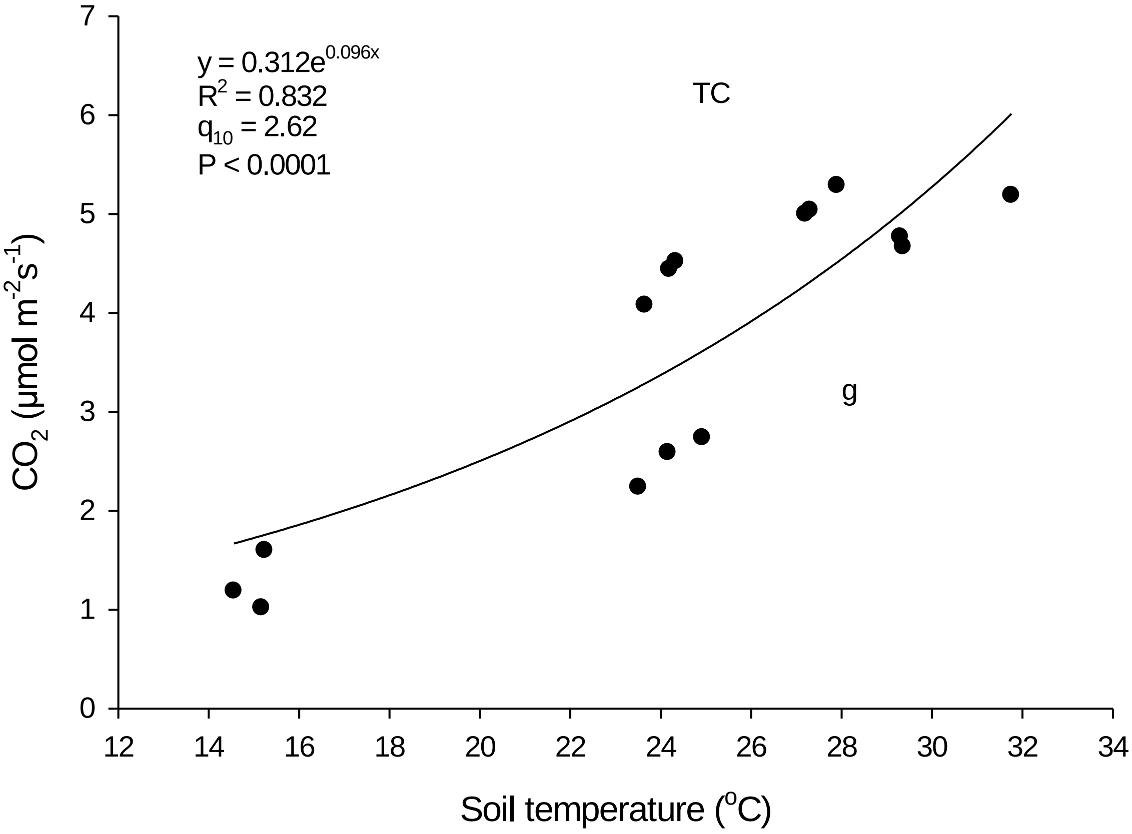

y = -0.0092x^2 + 0.327x + 0.61
R^2 = 0.483
p = 0.047
T < 20 ^{o}C, q$_{10}$ = 2.367
T > 20 ^{o}C, q$_{10}$ = 0.776
TC
a
CO$_2$ (μ molm^{-2}s^{-1})
0
1
2
3
4
5
0
5
10
15
20
25
30
Soil temperature (^{o}C)
y = -0.016x^2 +0.591x- 0.131
R^2 = 0.849
P = 0.015
T< 20 ^{o}C, q$_{10}$ = 3.61
T > 20 ^{o}C, q$_{10}$ = 0.863
TW
b
CO$_2$ (μmolm^{-2}s^{-1})
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
Soil temperature (^{o}C)

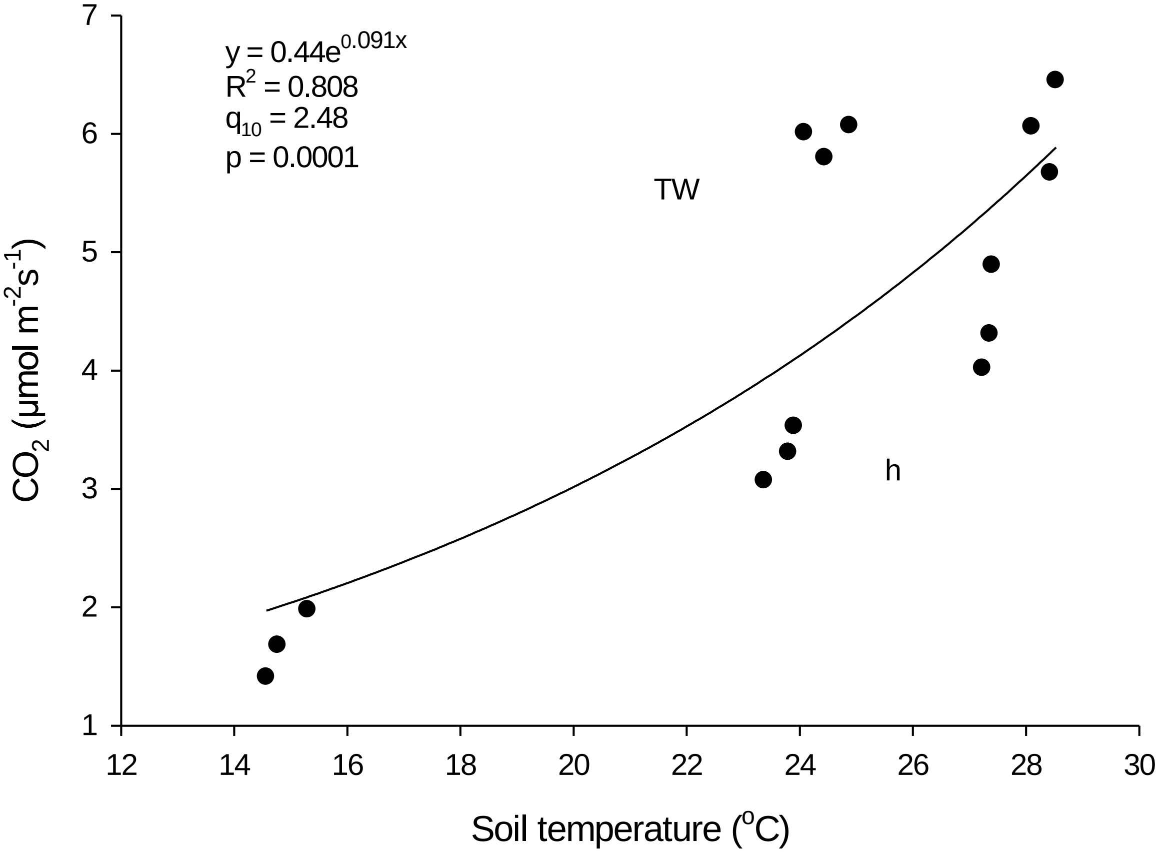

y = -0.008x2 + 0.327x+0.156
R2 = 0.545
P = 0.0305
T < 20 oC, q10 = 5.29
T > 20 oC, q10 = 1.71
TS
c
CO2 (µmol m-2-s-1)
0
1
2
3
4
5
0
5
10
15
20
25
30
Soil temperature (OC)


y = 0.0092x2 + 0.342x+0.194
R2 = 0.548
P = 0.015
T < 20 oC, q10 = 3.012
T > 20 oC, q10 = 0.837
TC
d
CO2 (µmolm-2s-1)
0
1
2
3
4
5
0
5
10
15
20
25
30
Soil temperature (oC)


y = -0.015x^2 + 0.548x-0.056
R^2 = 0.861
p = 0.007
T< 20 ^{o}C, q$_{10}$ = 4.36
T > 20 ^{o}C, q$_{10}$ = 0.904
TW
e
CO$_2$ (µmol m^{-2}s^{-1})
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
Soil temperature (^{o}C)


TS
y = -0.007x2+0.319x-0.021
R^2 = 0.578
p = 0.015
T< 20 ^{o}C, q$_{10}$ = 6.88
T > 20 ^{o}C, q$_{10}$ 0.935
f
CO$_2$ (µmolm^{-2}s^{-1})
0
1
2
3
4
5
0
5
10
15
20
25
30
Soil temperatute (^{o}C)


y = 0.312e^0.096x
R^2 = 0.832
q10 = 2.62
P < 0.0001
TC
g
CO2 (µmol m-2s-1)
0
1
2
3
4
5
6
7
12
14
16
18
20
22
24
26
28
30
32
34
Soil temperature (oC)


y = 0.44e^0.091x
R^2 = 0.808
q10 = 2.48
p = 0.0001
TW
h
CO2 (µmol m-2s-1)
1
2
3
4
5
6
7
12
14
16
18
20
22
24
26
28
30
Soil temperature (oC)

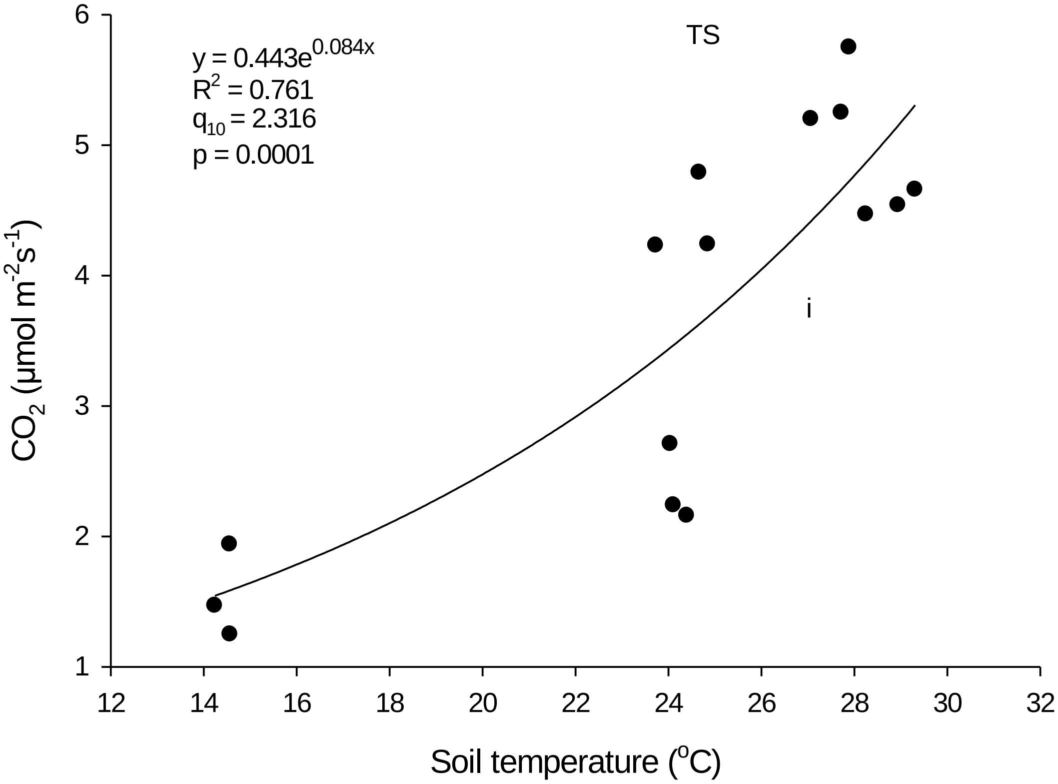
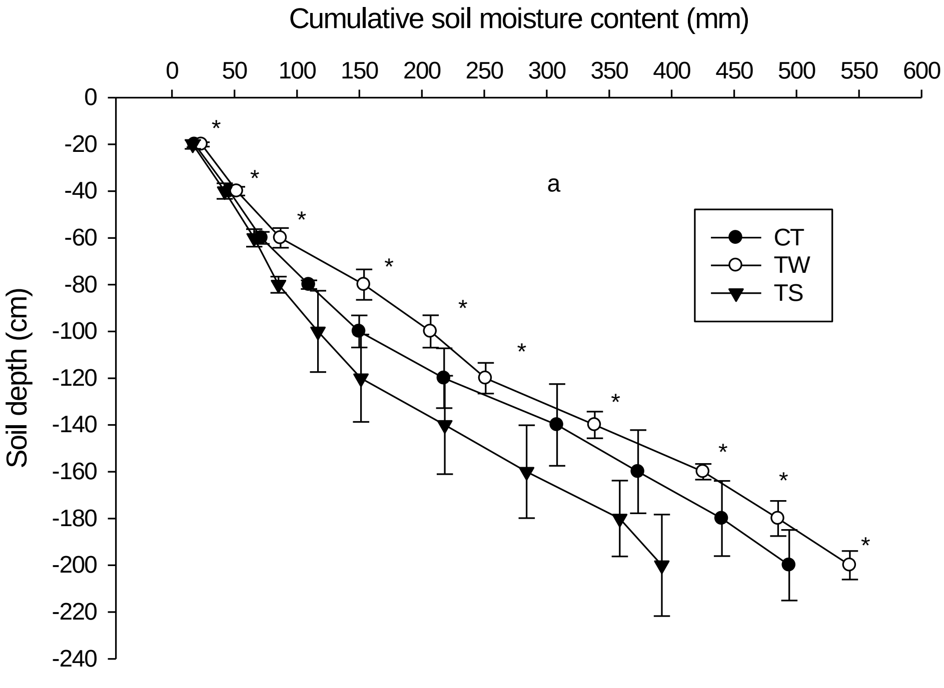


Figure 2. Relationship between soil respiration rate and soil temperature (n= 18 for wheat, n= 15 for maize). CT: rotary tillage without crop residues in winter and summer; TW: rotary tillage with crop residue incorporation into soil in winter and no tillage with crop residues use as mulch in summer, TS rotary tillage with crop residue incorporation into soil in summer and no tillage with crop residues use as mulch in winter. (a, b, c) and (d, e, f) under wheat 2013-2014 and 2014-2015, respectively. (g, h, i) under maize in 2014.



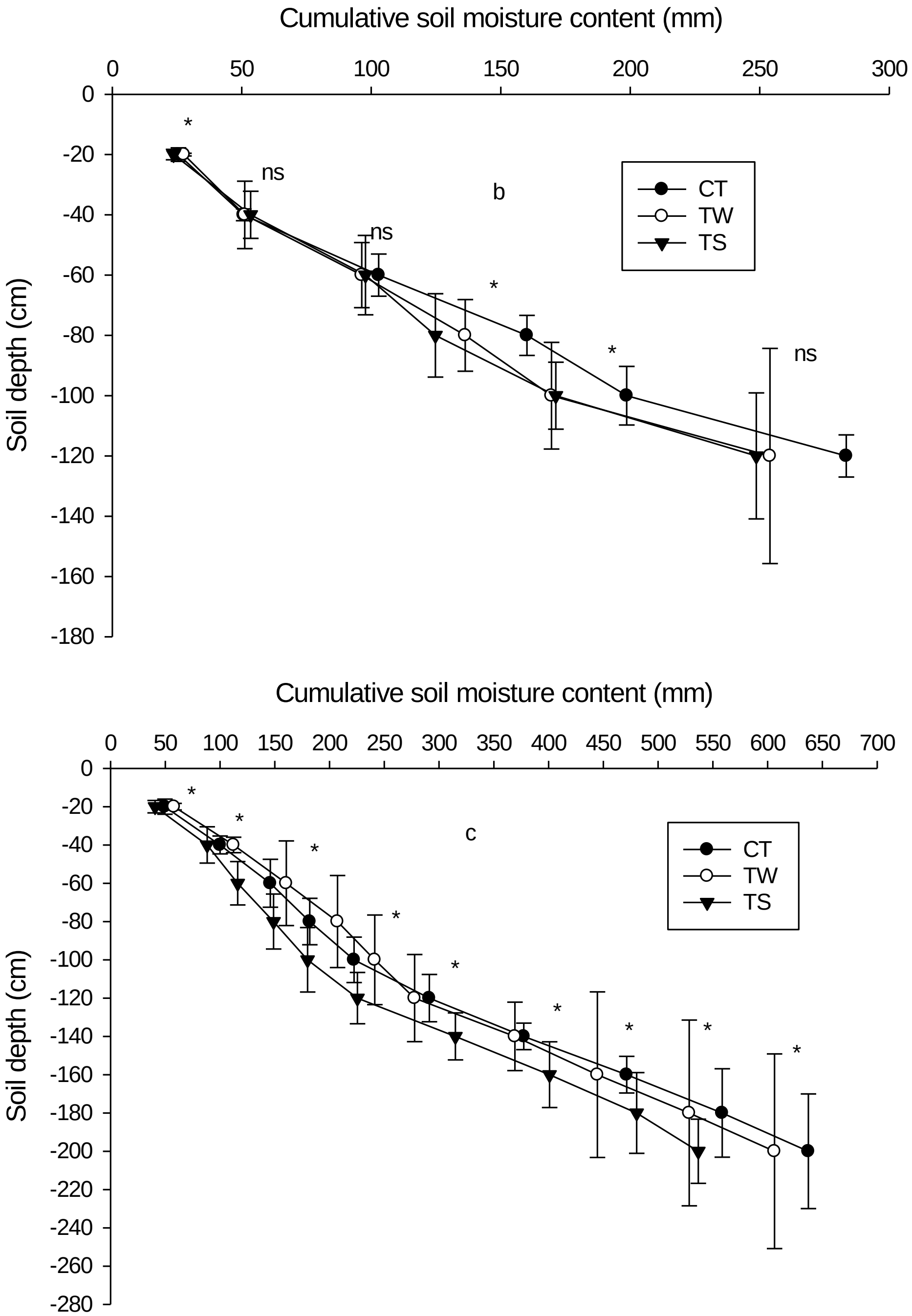


Figure 3 (a, b and c) cumulative soil water content during wheat and maize growing period. *Indicates significant differences among treatments P< 0.05; ns: indicates no significant differences among treatments (n= 6 for wheat, n= 5 for maize) CT: rotary tillage without crop residues in winter and summer; TW: rotary tillage with crop residue incorporation into soil in winter and no tillage with crop residues use as mulch in summer. TS rotary tillage with crop residue incorporation into soil in summer and no tillage with crop residues use as mulch in winter.

porosity, tortuosity and water holding capacity of soil. The highest CSWC recorded under CT during the summer can be explained by higher precipitation.

Conclusion

In this study, the CT, TW, and TS practices were found to have different effects on CO_2 rate as well as soil CSWC. TW and TS, improved CSWC, however TW had the highest CO_2, thus adoption of TS could be promoted in North China. The potential effects of TW and TS on soil quality were more apparent at 0 to 20 than 20 to 40 cm depth. This study shows that using conservation tillage is beneficial in North China and enhances soil quality compared with conventional tillage. However, longer-term study of the relationship among conservation tillage, soil properties, and environmental conditions is needed in North China. Further, it is better to collect more data on soil respiration that will help to identify the maximum cumulative CO_2 emitted by each treatment.

Conflict of Interests

The authors have not declared any conflict of interests

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