Carbon Dioxide Emissions after Application of Different Tillage Systems for Loam in Northern China

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ABSTRACT

Tillage operations influence soil physical properties and crop growth and thus both directly and indirectly the cropland carbon dioxide (CO_2) exchange with the atmosphere. In this study, the results of CO_2 flux measurements on cropland under different tillage practices in northern China are presented. CO_2 flux on croplands with a winter wheat *(Triticum aestivum L.)* and maize (*Zea may L.*) rotation was monitored on plots with conventional tillage (CT), rotary tillage (RT) and no tillage (NT). Soil CO_2 flux was generally greater in CT than in NT and the RT CO_2 flux was only slightly smaller than the CT. Daily soil flux for CT, RT, and NT averaged 11.30g CO_2 m-2 d-1, 9.63 g CO_2 m-2 d-1, and 7.99 g CO_2 m^{-2} d^{-1}, respectively, during the growing period. Analysis of variance shows that these differences are significant for the three tillage treatments. Peak CO_2 emissions were recorded on the CT and RT croplands after tillage operation, demonstrating that the tillage operations result in a rapid physical release of CO_2. At the same time, no obvious increased emission of CO_2 occurred on the NT plot due to no tillage operation.

Keywords: CO_2 flux, winter wheat, conventional tillage, rotary tillage, no tillage

1. INTRODUCTION

Global warming due to increasing greenhouse gas concentrations in the atmosphere has been recognized as the foremost environmental issue in the 21st century (IPCC, 2007). The exchange of greenhouse gases between croplands and atmosphere plays an important role in the global carbon cycle and the carbon concentration in the atmosphere. CO_2 is the most important greenhouse gas and its greenhouse effect accounts for 40 per cent of the current warming.

A large number of studies on soil CO_2 emissions from soils have been conducted to date (e.g., Qi et al, 2007; La Scala et al, 2006; Jacinthe et al, 2002). However, most have focused on the effects of climate change, mainly temperature and rainfall, on soil respiration (e.g. Raich et al, 1995; Mielnick and Dugas, 2000; Richard et al, 2004; Du et al, 1996). Tillage can also have a major influence on soil C emissions, but studies are mostly limited to the period between tillage and crop establishment (La Scala et al, 2001) or short-term CO_2 flux (Reicosky et al, 1999).

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Studies on growing season emissions have largely dealt with grass and forest, but not cropland (e.g. Marja Maljanen et al., 2001; Frank et al, 2002). The effect of tillage practice on CO_2 during crop growing period is not well known, especially for loamy soil in northern China, despite their potential to act as a carbon sink.

As a measure of soil amelioration and water conservation, tillage practices were widely adopted by farmers in the world (e.g., Abbas Hemmat and Iraj Eskndri, 2004; Rachid Mrabet, 2002; Beáta Madari et al, 2005). The impact of conservation tillage practices on carbon sequestration has also received great interest in recent years (Deen et al, 2003). Conservation tillage practices appear to decrease net emission of CO_2 in many areas (Noel et al, 2000; Wan and Lin, 2004; Nobuhisa Koga et al, 2003; Reicosky et al, 1999).

This study aimed to compare the CO_2 emissions on plots after five years of conservation tillage (primarily no-till, NT) to plots under conventional and rotary tillage. At the same time, other soil properties influenced by tillage were measured, and their role for soil-atmosphere CO_2 flux is discussed.

2. MATERIALS AND METHODS

2.1. Study Site

Field experiments were located at the Ecological Station of the Chinese Academy of Sciences in Luancheng, Hebei Province, in the North of China (37°50′N, 114°40′E). The average annual temperature is 12.5℃ with 196 frost-free days. Based on mean monthly temperature, four seasons can be distinguished as spring (February to April), summer (May to July), autumn (August to October) and winter (November to January). Luancheng county is in a semi-humid region, with average annual rainfall gradually decreasing from 556 mm to 400 mm over the past 50 years and for about 27 mm in the past ten years (Guo et al., 2004). On average, 60 per cent of annual rainfall occurs from June to July. At the field site, topsoils (0 to 20 cm depth) are loams.

Basic physical and chemical properties of soils are listed in Table 1. The climate and soils provide the possibility of a double harvest, usually in an annual winter wheat-maize rotation.

Table 1. Selected physical and chemical properties of the soils (0-20cm)

Texture	Bulk density (g cm^{-3})	Total N (g kg^{-1})	Hydrolysable N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Organic matter (g kg^{-1})
Sand loam	1.39	0.69	34.27	51.3	102.5	12.6

At the experimental field sites, the growing season for winter wheat (*Zea mays L.*) lasts from October to early June and for maize from June to the end of September. On 1 October 2001, three plots of 1/3 ha were established at the experimental site, each on the same soil type, altitude, slope, and aspect. Three different tillage treatments were applied every October: (1) conventional tillage by plough (CT), (2) rotary tillage (RT), and (3) no tillage (NT). CT operations disturbed the soil to approximately 20 cm depth, RT to 5 cm. No tillage was applied before maize sowing in June. Straw left after harvest remained on the plots so that differences in soil structure are a result of differences in tillage only. The maize seed was placed manually in the soil before harvesting the winter wheat. Wheat and maize were fertilized with 448.5 and 172.5N kg/ha in each plot, respectively.

2.2 Measurement of CO_2 Emissions and Soil Biomass

The CO_2 gas collected using closed chamber (30 cm by 30cm by 60cm) is illustrated as Figure 1. A pedestal was inserted in the soil for five centimeters during the entire test period. The CO_2 chamber was placed on the pedestal and the joint between the pedestal and the chamber was filled with water to avoid an exchange of air between outside atmosphere and the chamber. In the fields, three locations were selected on each treatment for placing closed chambers. The CO_2 measurements were made every other week over the whole period of the experiment which lasted from 5 April to 8 November 2005. Daily differences were covered by taking measurements late in the morning and late in the afternoon. The CO_2 samples were collected using an injector that draws out the air from the closed chamber, three times in 30 minutes. The gases that were drawn out of the closed chamber were puffed into a sealed plastic bag through a turn valve, and returned to the laboratory. CO_2 concentration of the samples was determined using a gas chromatograph (model HP6890N, FID detector; Poropak Q column). The detector and column were set at 200 and 70℃, respectively. The CO_2 flux was calculated from the rate of CO_2 concentration (ml m^{-3}) in the close chamber during the 30-min period. The method used to calculate CO_2 flux has been described by Dong et al. (2003).

$$F = \frac{\Delta m}{\Delta t}.D\frac{V}{A} = hD\frac{\Delta m}{\Delta t}$$

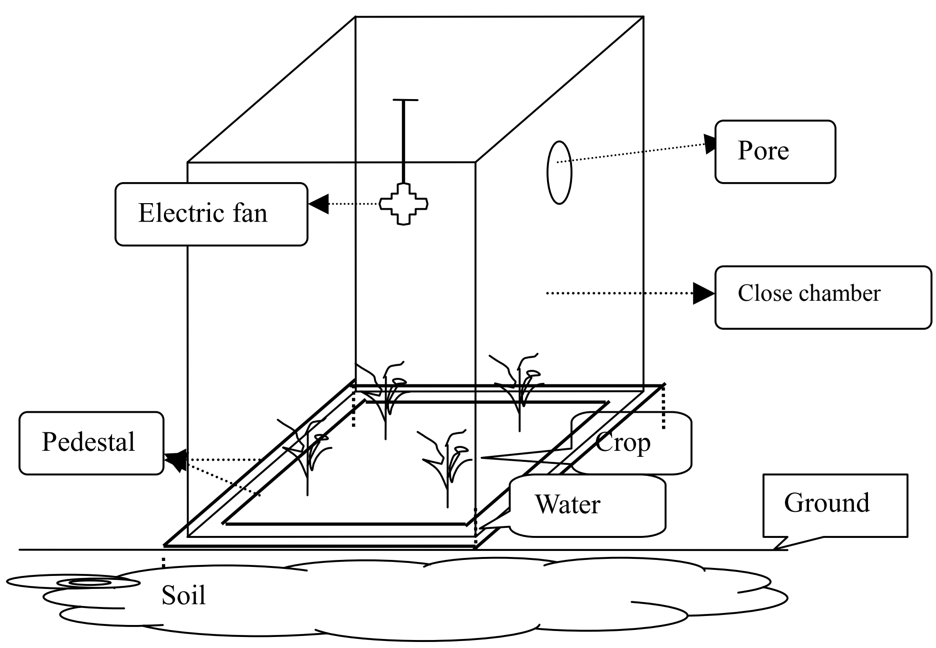

Fig. 1
Schematic diagram of close chamber in the field during the period of collected CO_2 gas (Hu

2006).

Note: F refers to flux of CO_2, V is the volume of the chamber, A the earth area sealed the chamber at four sides, D is the gas density of the chamber (D=n/v=P/RT, mol/m^3, P the air pressure, T the temperature inside the chamber and R the air constant, $\frac{\Delta m}{\Delta t}$ denotes linear slope of concentration change with time over measurement period and h represents the height of the chamber.

Above and underground biomass was measured by weighing oven dried (70℃) plants collected from three representative 1 m^2 areas. Gravimetric soil water content was measured at time of CO_2 flux measurements by drying soil samples at 105℃ for at least 24 h. Soil temperature was measured using geothermometer installed at 15cm soil depth inside the closed CO_2 sampling chamber 30 minutes after the chamber had been placed on the pedestal.

2.4 Statistical Analysis

The SPSS analytical software package was used for all statistical analyses. Mean values were calculated for each of the measurements, and ANOVA was used to assess the effects of conservation tillage on CO_2 fluxes and biomass. When this indicated a significant F-value ($P<0.05$), multiple comparisons of annual mean values were made on the basis of the least significant difference (LSD).

3. RESULTS AND DISCUSSION

3.1. Biomass Production

Biomass production was lowest on NT, while there were no significant differences in biomass production between CT and RT (Fig.2). When the grain and straw were considered, CT gives higher winter wheat yields with 19.15 t ha^{-1}compared to RT (17.5 t ha^{-1}) and NT (14.4 t ha^{-1}). The maize yields showed the similar differences between treatments. These results are in contrast of other studies which resulted in increased yields for reduced and no tillage systems compared to conservation tillage. For example, He et al., (2007) reported mean yields of 3.14t ha^{-1} for no tillage crop yields and only 2.47t ha^{-1} for conventional tillage from 1993 to 2000 years. The differences in yields were particularly pronounced in dry years (Wang et al, 2007).

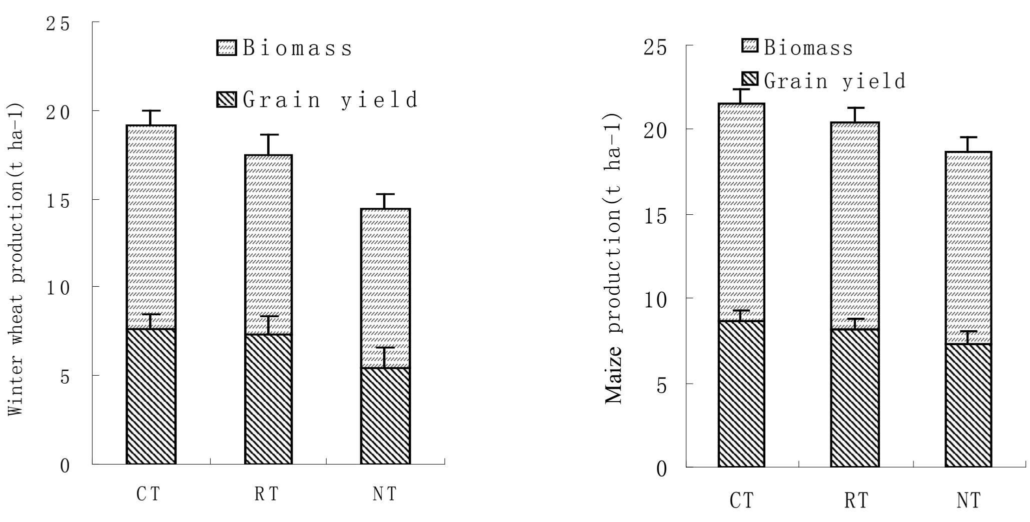

Fig.2 Yields of winter wheat and maize in the three tillage systems. Means and standard errors are shown.

3.2. Soil Temperature, Air Temperature, Soil Water

Air and soil and soil moisture from April to November are shown in Figures 3 and 4. Atmospheric and soil temperature followed a similar trend (Fig.3), but soil temperature was 4 to 5℃ higher than air temperature. This difference reflects the heating by absorption of solar radiation during the time preceding the measurements.

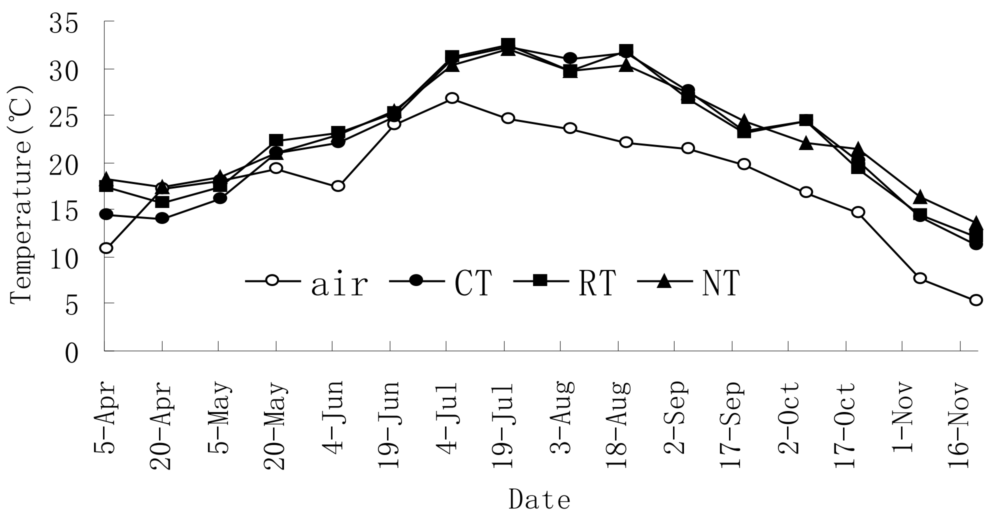

Fig.3 Air (at 2 m height) and soil temperature as influenced by different tillage systems.

Tillage practices affected soil temperature. In the early measurement stage, soil temperature was significantly higher under RT and NT than under CT. Based on the total biomass (Fig. 2), NT and RT had a lower crop density, leaving more soil uncovered and exposed to direct sunshine. During the winter-wheat harvest season and maize growing season, soil temperatures were not significantly different, indicating that the ripening wheat and the straw cover after wheat harvest reduced the warming. Summer rainfall probably also introduced a cooling effect. After tillage at the beginning of October, CT and RT experienced higher soil temperatures than NT. The higher temperatures are attributed to higher rates of evaporation from the open structure generated by tillage, which accelerates drying and heating (Licht and La-Kaisi, 2005). The increase in temperature coincides with higher CO_2 emissions in CT and RT (Fig. 5), which will be discussed in section 3.3.

Soil water content generally matched the rainfall pattern between April and November (Fig.4). However, several differences between treatments are noteworthy. From April to June, the NT plot had greater soil water content than CT and RT. This is attributed to initially higher surface retention and infiltration on the NT surface (Shaver et al., 2002). In addition, the wheat on the NT was noticeably smaller than on CT and RT during the winter, which may have also reduced transpiration. In the course of the growing season, soil moisture on NT remained higher than on CT and RT. The higher soil moisture on NT is attributed to the mulching with the straw cover left on the soil after harvest. Such mulching improves infiltration and reduces evaporation (Bussiere and Cellier, 1994; Dahiya et al., 2003).

On CT and RT, there is no or only a limited mulching effect because most crop residues were imbedded into the soil by tillage after maize harvest.

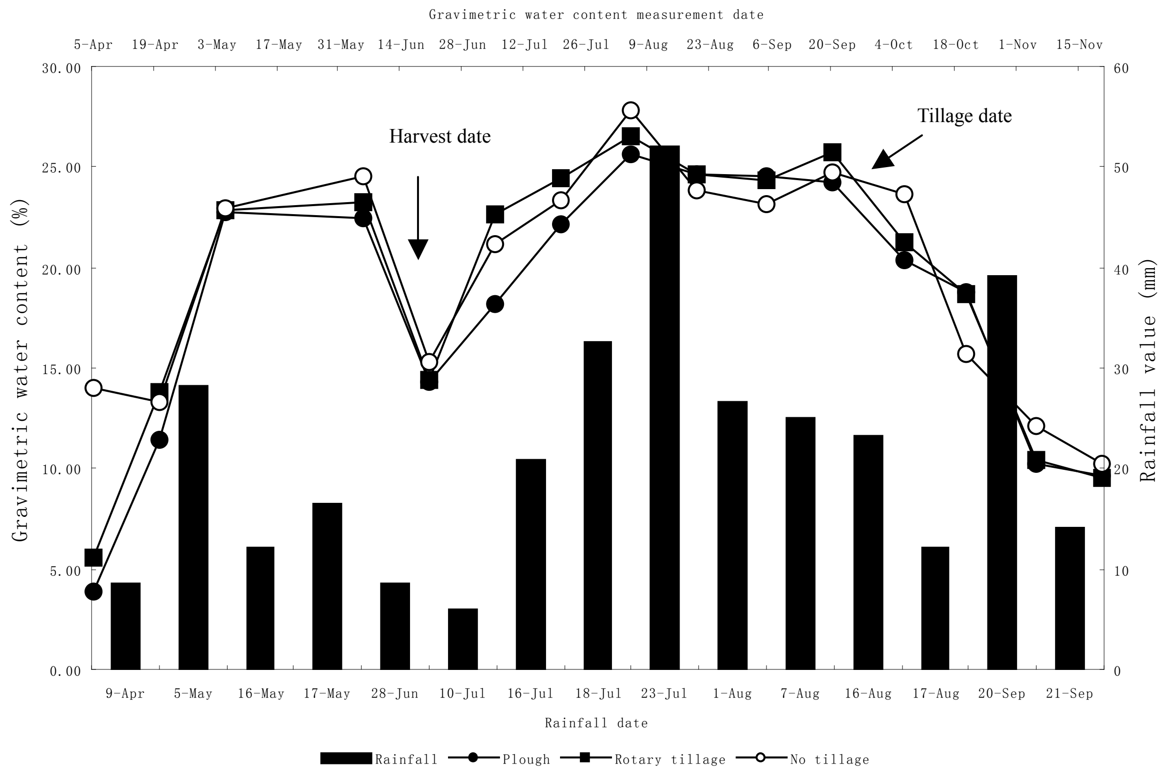

Fig.4. Gravimetric water content in the range 0-20cm layer and rainfall.

3.3. Changes of CO_2 Flux Under Different Tillage Practices

CO_2 fluxes calculated from the concentrations measured in the sampling chamber are presented in Figure 5. Emissions followed similar patterns initially, increasing towards the wheat filling stage in early summer. Such an increase has been observed in other studies (e.g. Huang 2004; Du et al, 1996). Despite the similarity in pattern, the absolute values of emissions differed between tillage treatments and were always higher on CT and RT than NT.

Major differences of CO_2 emissions developed over the summer after wheat harvest. On CT, emissions remained on a similar level throughout the early part of the maize growing season before gradually increasing with plant development. On RT and NT on the other hand, wheat harvest is associated with a clear decline in emissions. Subsequently, values increased with maize growth, but remained below the values of CT. Emissions declined again after harvest, followed by short peaks associated with tillage in October on CT and RT. Peak emissions during this later stage were approximately twice as high on CT and RT than NT.

The emission patterns can be attributed to the combined effects of soil temperature, water availability and tillage. In the early summer, the increasing temperatures enhance microbial activity, which offsets photosynthesis from the growing plants and leads to higher CO_2 net emissions (Huang, 2004; Du et al., 1996). Tillage operations in October also resulted in a rapid physical release of CO_2 (Prior et al, 2000; Reicosky et al, 1999), which explains the high CO_2 emissions on CT and RT in October. Increased soil temperatures and good aeration after tillage may be responsible for the sustained emissions on CT even after wheat harvest. Finally, rainfall, high temperatures, and the straw available for decomposition embedded in the soil resulted in a soil environment which enhanced high microbial activity during the summer and autumn on CT and RT.

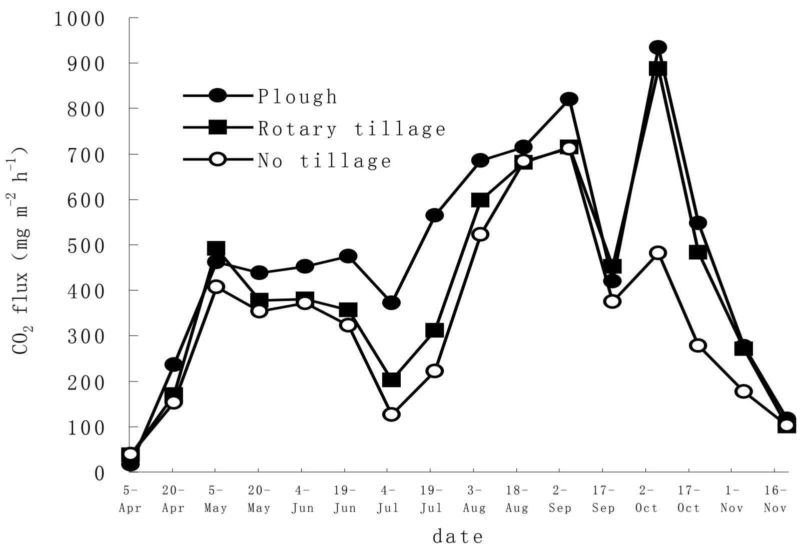

Fig.5. Mean CO_2 flux over the period studied.

4. CONCLUSIONS

CO_2 were measured on winter wheat-maize cropland after four years of different tillage treatments, continued conventional tillage, rotary tillage, and no tillage. The emissions reflect the combined effect of climate, crop growth, plant photosynthesis and microbial respiration. In general, emissions were highest during the wet and hot summer when straw from the winter wheat harvest was decomposed. However, on conventional tillage plots, emissions were significantly higher throughout most of the growing season, which is attributed to the breaking and loosening and mixing of the soil, leading to faster drying, higher soil temperatures and good aeration. A peak of emissions on conventional and rotary tillage plots after October tillage is also attributed to the exposure of a larger soil surface the atmosphere than on the no tillage plot.

However, while the results of this study give a good indication of the significance of tillage practices for CO_2 emissions during the growing season, further research on the soil processes and structural properties which are responsible for the emissions patterns has to be conducted. It would be of particular importance to understand how differences in emissions are linked to the development of soil organic matter content.

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