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CO_2 EVOLUTION DURING SPRING WHEAT GROWTH UNDER NO-TILL AND CONVENTIONAL TILLAGE SYSTEMS IN THE NORTH AMERICAN GREAT PLAINS REGIONS

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Abstracts

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The soil surface CO_2 flux is the second largest flux in the terrestrial carbon budget after photosynthesis. Plant root and microbial respiration produce CO_2 in soils, which are important components of the global C cycle. This study determined the amount of CO_2 released during spring wheat (*Triticum aestivum* L.) growth under no-till (NT) and conventional tillage (CT) systems. This experiment was conducted at Kansas State University North Agronomy Farm, Manhattan, KS, on a Kennebec silt loam. This study site was previously under dry land continuous corn production with NT and CT for more than 10 years. Spring wheat (*Triticum aestivum* L.) was planted with two tillage systems (NT and CT) as four replicates in March. Surface CO_2 flux was measured weekly during plant growth. Soil water content at the surface (5 cm) tended to be greater in NT and decreased from planting to harvest. Soil microbial activity at the surface was usually higher in NT and decreased from planting to harvest, while activity was constant in the deeper depths. The higher microbial activity at the surface of NT occurred after 60 days of planting where soil water content was the most limiting factor on microbial activity. Soil CO_2 flux varied in response to changes in soil water content and the variation and magnitude of the increase was greater at higher soil water contents. Conventional tillage released 20% more CO_2 to the atmosphere compare to NT after 10 years in the North American Great Plains Regions.

Key words: No-till; conventional tillage; CO_2 flux, wheat

Introduction

Carbon dioxide concentration in the atmosphere is increasing at 0.5% annually, is an important greenhouse gas contributing global warming (Lal and Kimble, 1995). Some researchers have indicated that terrestrial ecosystems play an important role in the global C cycle and contribute to the annual variability of atmospheric CO_2 (Schimel et al., 2001). On a global scale, soil organic matter contains twice as much C as the atmosphere (Schlesinger, 1997; Post et al., 1982; Jenkinson et

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al., 1991), and the source of CO_2 from this globally important pool is mediated by the activities of soil microorganisms. Carbon flow through the terrestrial ecosystem can be defined as fixation of atmospheric CO_2 by photosynthesis, and the transfer of plant, animal, and microbial biomass carbon from one trophic level to another. During this process, some of the carbon in the plant material is mineralized and returned back to the atmosphere with the remaining residing in the soil for longer periods of time in different forms of soil organic matter. If the system is in equilibrium, input of C from primary production is balanced by the output of C as a result of mineralization.

Decomposition of soil organic matter by soil heterotrophs reduces the potential for C storage in the soil. The rate of carbon loss or sequestration from soil is a function of heterotrophic respiration and net primary productivity (NPP) (Buyanovsky et al., 1987). Soil microbial processes are the driving force in nutrient cycling and soil organic matter decomposition (Van Veen et al., 1991). Previous studies indicate that the rate of CO_2 production in the soil is a function of soil temperature and soil water content (Knapp et al., 1998; Sotomayor and Rice, 1999; Meilnick and Dugas, 2000).

Soil surface flux is affected by the factors controlling gaseous diffusion such as pore size distribution, water content, soil and air temperature, and surface wind speed (Raich and Schlesinger, 1992). Land use and management practices are the factors that most effect the decomposition of organic materials in soils (Ajwa and Tabatabai, 1994). To estimate the effects of agricultural practices on greenhouse gas emissions are needed to develop economically efficient and effective policies in mitigating and reducing greenhouse gas emissions in farming systems (California Energy Commission, 2005). Soils under similar plant productivity with different tillage systems sequester different amount of carbon to the soils. The different amount of carbon sequestration under different tillage systems generally attributed to the difference in CO_2 flux to the atmosphere. However, some studies have reported minimal C sequestration with NT adoption in the North American Great Plains Region when adoption is not coupled with cropping intensification (Peterson et al., 1998; Halvorson et al., 2002). The adoption of NT in dry land climates leads to an initial loss of C in the first 5 year (Hendrix, 1997). Long-term tillage causes higher fluxes of CO_2 compared to no-tillage (Dao, 1998; Lupwayi et al., 1999). Leaving residue on the soil surface minimizes the soil–residue contact and lowers surface soil temperature resulting in a lower decomposition rate. In general, the decomposition rates of residue are lower when left on the soil surface than when incorporated into the soil. The reduced residue decomposition and less soil disturbance usually results in greater amounts of soil C and lower CO_2 flux in no-tillage than tilled systems.

Many studies have been contacted to measure CO_2 flux under different plant productivity in the world. However, few studies have been done after switching from ten years of continuous corn production with NT and CT to spring wheat production in the North American Great Plain. The objective of this study was to determine soil surface CO_2 flux during spring wheat growth in no-till and conventional tillage systems. In addition, to determine the relationship between CO_2 flux and soil water content and temperature during spring wheat growth.

Materials and Methods

Site Description

This experiment was conducted at Kansas State University North Agronomy Farm, Manhattan, KS, on a Kennebec silt loam (Fine-silty, mixed, superactive, mesic Cumulic Hapludoll). The annual average temperature and precipitation were 13°C and 890 mm. The experimental site had been in continuous corn production with no-till (NT) and conventional tillage (CT) systems for more than 10 years. During the 10 years of continuous corn production, there was not significant difference in corn yield between NT and CT plots. The two tillage systems, NT and CT were randomly distributed to the plots (3x8 m) before 10 years ago for continuous corn production. Conventional tillage system included fall chiseling (on October 18) and spring disking (on March 14). Spring wheat (*Triticum aestivum* L.) was planted as 130 kg seed ha^{-1} with two tillage systems (NT and CT) as four replicates on March 21. After planting, 55 kg N ha^{-1} was applied as NH_4NO_3 to the surface.

Field Measurements

Soil surface CO_2 flux was measured using a portable gas exchange (infrared) gas analyzer (LI-COR 6200, LI-COR Inc, Lincoln, NE, USA) adapted by Norman et al. (1992). This system utilizes a dynamic chamber with a volume of 884 cm^3 and surface area of 43 cm^2, which was placed on the bare surface of soil using a foam gasket with similar diameter. This foam gasket was used to prevent disturbance during the soil CO_2 flux reading (Bremer et al., 1998).

Soil surface CO_2 flux was measured weekly at the middle of the day during wheat growth. For each measurement three sampling locations were randomly selected from each plot and two consecutive measurements were made at the each sampling location. Estimated CO_2 flux during wheat growth was determined by integrating the area under the each curve. Soil temperature was determined at 5 cm depth. Soil temperature at 5 cm depth was measured during CO_2 readings using a digital temperature probe (Fisher Scientific Inc., Pittsburgh, PA).

Bulk density was determined using a thin, stainless steel core (5 cm diameter) forced into the soil to a depth of 30 cm (5 cm increments) in April. Cores were removed and placed in individual aluminum sampling containers and brought to laboratory for drying at 105°C for 24 h.

Soil Sampling and Analysis

Soil samples were taken weekly during wheat growth from 0-5, 5–15, and 15-30 cm depths. Soil samples were collected in polyurethane whirl-pak bags then placed inside a portable cooler, transported to the laboratory and stored at 4°C until analysis. Soil samples were passed through a 4-mm mesh to homogenize and remove large fragments and plant materials. Soil water content was determined by drying 10 g field moist soil at 105°C for 24 h.

Soil C and N contents were determined using air-dried sub-samples. The sub-samples were meticulously cleaned of plant material and ground to a fine powder with a mortar and pestle. The inorganic carbons were removed using a diluted HCl solution. Samples were then analyzed through direct combustion using a Carlo Erba Elemental Analyzer, Model 1500 CNS Analyzer (Carlo Erba Strumentazione, Milan, Italy).

Soil microbial activity was measured by placing 20 g of fresh soil in a 160 mL serum bottle and incubated for 48 h at 25°C. The evolved CO_2-C was measured 4 to 5 times during the incubation by taking gas samples from the headspace of each serum bottle. The concentration of CO_2–C was measured on a Shimadzu Gas Chromatograph - 8A (Shimadzu Inc., Kyoto, Japan). Microbial respiration rate was determined by the slope of CO_2-C concentration vs. time. Microbial respiration served as an indicator of soil microbial activity.

The experimental design was completely randomized design with four replications. Four single CO_2 measurements from each plot were taken and averaged during sampling. Analysis of variance and separation of means by least significant differences test ($p<0.05$) were performed on soil surface CO_2 flux using SAS procedures (SAS Institute Inc., 1996). Linear regression analysis was conducted to the soil surface CO_2 flux versus soil water content and soil temperature using SAS (SAS Institute Inc., 1996).

Results

Soil Properties

Soil pH was the similar in both tillage systems

Table 1
Soil chemical and physical properties of Kennebec silt loam under no-till (NT) and conventional tillage (CT) systems

Soil properties	Depth, cm	NT	CT
pH	0 - 5	6.6 - 0.1*	6.4 – 0.2
	5 – 15	6.8 – 0.0	6.5 – 0.1
	15 – 30	6.6 – 0.0	6.4 – 0.0
Carbon, g C m^{-2}	0 – 5	1210 - 76	1010 - 81
	5 – 15	1100 - 36	1100 - 48
	15 – 30	870 - 23	910 - 65
Nitrogen, g N m^{-2}	0 – 5	124 - 21	96 - 19
	5 – 15	98 - 17	108 - 13
	15 – 30	79 - 14	106 - 11
C:N	0 – 5	9.8 – 3.6	10.5 – 4.2
	5 – 15	11.2 – 2.1	10.2 – 3.7
	15 – 30	11.0 – 1.6	8.6 – 5.9
Bulk density, g cm^{-3}	0 – 5	1.36	1.42
	5 – 15	1.45	1.47
	15 - 30	1.44	1.55

* Mean standard error

and ranged from 6.4 to 6.8 (Table 1). Soil organic C and N were slightly higher in NT at 0-5 cm compared to CT and other soil depths. Soil bulk density was similar in both tillage systems.

The daily precipitation and average air temperature during the experiment was presented in Figure 1. Average air temperature increased from

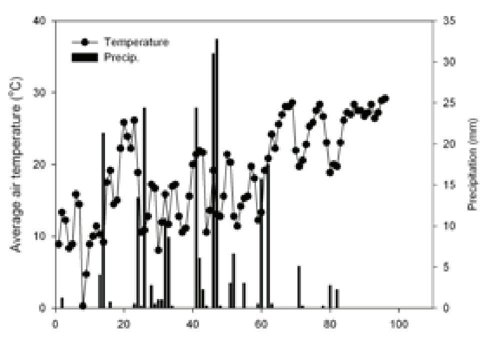

Fig. 1. Average air temperature and daily precipitation in Kennebec silt loam through spring wheat growth

planting through harvest. The greatest precipitations occurred between 40 and 50 days after planting. Soil water content decreased from planting through harvest at 0-5 cm depth in both tillage systems (Figure 2). The CT plots had the lowest soil water content throughout wheat growth compared to the NT plots. A similar trend was measured at the deeper depths with a greater variation. Soil temperature was initially greater in the CT plots; however, during the wheat growth, soil temperature was similar for all treatments (Figure 3). The emergence of wheat was greater in the CT plots compared to the NT plots due to greater soil surface temperature in the CT plots. However, at the end of maturity wheat growth was similar in both NT and CT systems.

Microbial Activity

Soil respiration, as an index of microbial activity, was generally higher at the surface and decreased with soil depth in the both tillage systems

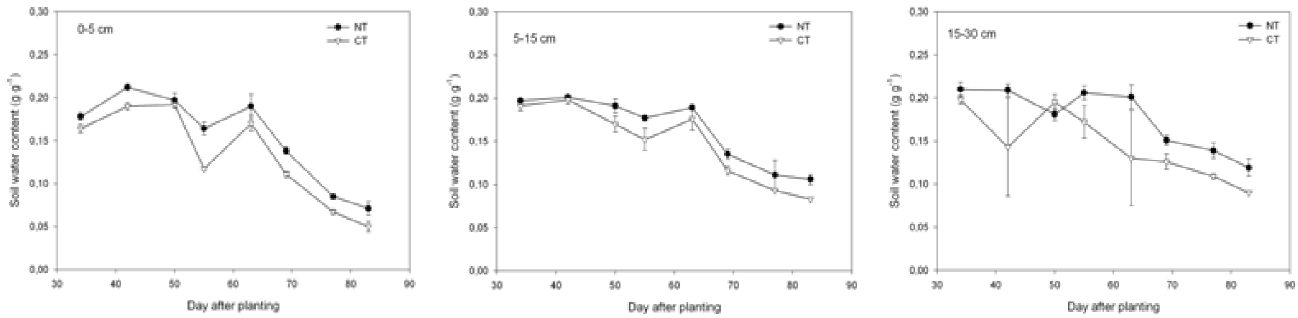

Fig. 2. Soil water content in no-till (NT) and conventional tillage (CT) systems at 0-5, 5-15, and 15-30 cm depths during spring wheat growth. The bars represent the standard error

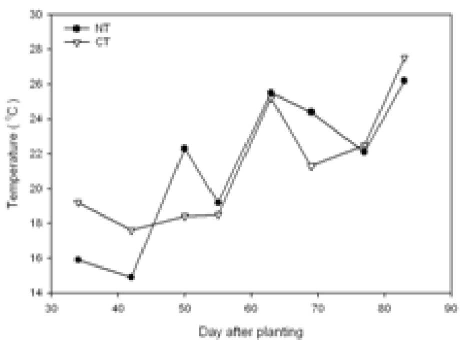

Fig. 3. Soil surface temperature at 0-5 cm depth in no-till (NT) and conventional tillage (CT) measured with temperature probe during spring wheat growth

cially at the surface. The variation in the microbial activity was usually greater in the surface while the variation decreased with the depth.

Soil Surface CO_2 Flux

The carbon dioxide in the soil was produced by microbial and root respiration. The soil surface CO_2 flux was significantly higher ($p < 0.05$) in CT than NT system (Figure 5). The initial CO_2 flux was greater in CT plots (6.27 µmol CO_2 m^{-2} s^{-1}) compared to NT plots (2.50 µmol CO_2 m^{-2} s^{-1}) during the 60 days. Carbon dioxide flux increased during the growing season and the lowest CO_2 flux during wheat growth was measured at the flowering stage as 2.93 µmol CO_2 m^{-2} s^{-1}.

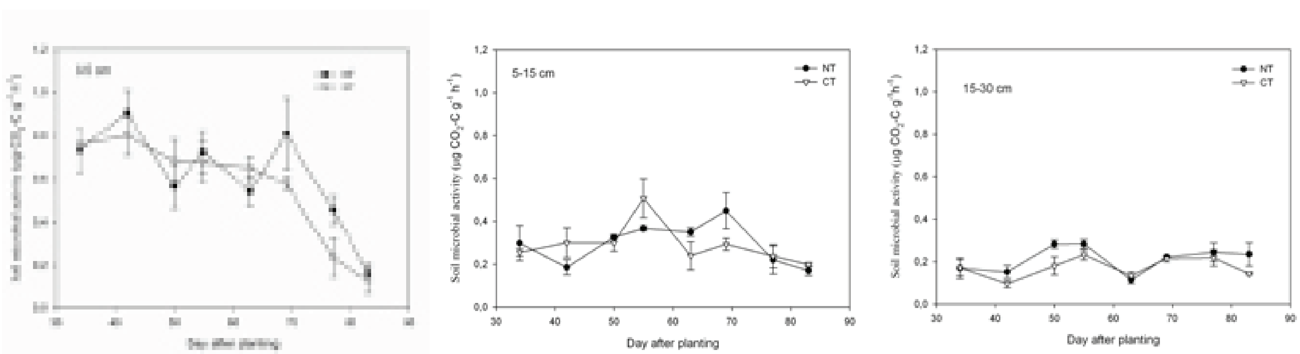

Fig. 4. Soil microbial activity in no-till (NT) and conventional tillage (CT) systems at 0-5, 5-15, and 15-30 cm depths. The bars represent the standard error

(Figure 4). Microbial activity generally decreased from planting to harvest at 0-5 cm depth, while microbial activity was constant at 5–15 and 15–30 cm depths. In addition, microbial activity during dry season was slightly greater in NT than CT especially at the surface.

Estimated soil surface flux was 20% higher in CT compared to NT. The CO_2 flux released from NT and CT systems during the wheat growth was estimated by integrating the area under the each

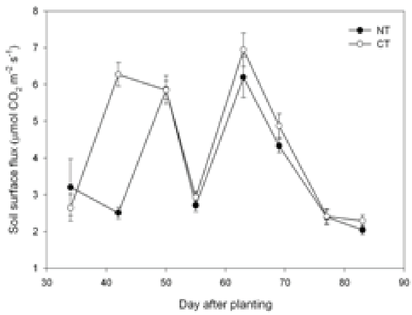

Fig. 5. Soil surface CO_2 flux in no-till (NT) and conventional tillage (CT) during spring wheat growth. The bars represent the standard error

Discussion

The higher microbial activity at 0-5 cm depth of both tillage systems was likely the result of the greater soil organic carbon on the surface. However, the constantly decreases of microbial activity from planting through harvest at the surface soil could be attributed to the decreases of soil water content. The higher standard errors on the soil surface microbial activity were the result of the greater variations of environmental factors (soil water, temperature, and organic carbon). The effects of limited resources in the deeper depths decrease microbial activity from the surface through the deeper depths. By the end of growing season, microbial activity was similar in the both tillage systems likely due to lower root exudation and soil water content (Kocyigit and Rice, 2006).

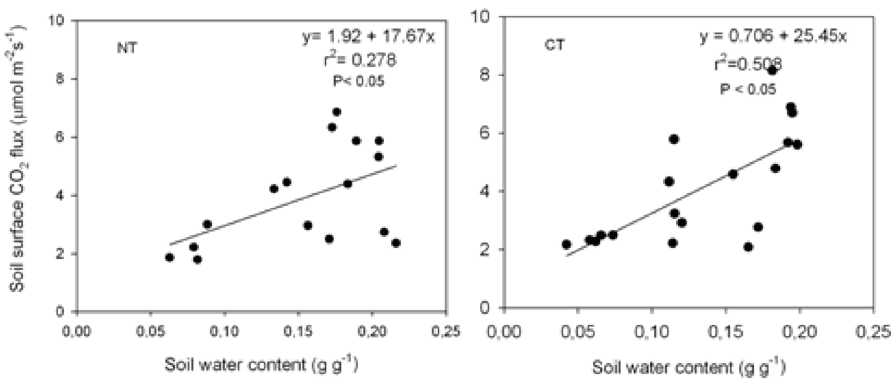

Fig. 6. Soil surface CO_2 flux vs. soil water content in no-till (NT) and conventional tillage (CT) systems

curve in Figure 5. The greatest CO_2 flux was 233 g CO_2-C m^{-2} in CT plot while NT was 192 g CO_2-C m^{-2}. In order to determine which environmental factors (soil temperature and water content) is more important on soil surface CO_2 flux; regression were done in the both tillage systems. There was a significant relationship (r^2=0.18-0.50; $p < 0.05$) between soil water content and soil CO_2 flux in the both tillage systems (Figure 6). Generally, the relationship between soil water content and CO_2 flux was significant compared to soil temperature. The increase in soil water content increased the soil CO_2 flux. However, the relationship between the soil surface temperature and soil CO_2 flux was generally weak and not significant (r^2<0.27; $p >$ 0.05) in this study (data not presented).

The soil surface flux indicated a greater efflux of CO_2 in CT (233 g CO_2-C m^{-2}) than NT (192 g CO_2-C m^{-2}). Six et al. (2004) reported C emission at 5 and 10 years of NT adoption in dry climates, but during the second decade the trend changed to net C sequestration. In this study, the experiment field previously under continuous corn production with NT and CT for 10 years before conversion to the spring wheat. Thus, these measurements were done after 10 years of NT and CT systems. Doyle (2002) reported 1100 (± 133) g CO_2-C m^2 during a whole year from winter wheat grown in Oklahoma under intensive tillage which was higher than our findings. Conventionally tilled spring wheat grown in Canada had an average annual efflux of ~360 g C m^{-2} (Curtin et al., 2000), which is higher compared to this study.

In this study, spring wheat growth and grain yield was similar in the both tillage systems (average grain yield 2350 kg ha^{-1}). This indicated that the similar amount of carbon was assimilated from atmosphere through stover and grain yields. Therefore, carbon addition to the soil was equal in NT and CT and the only difference was observed in CO_2 efflux during wheat growth. Conventional tillage resulted in 20% higher CO_2 compared to NT. Curtin et al. (2000) measured a similar percent (20-23%) reduction in total CO_2 flux in NT compared to CT under wheat production in Canada. No-till reduced CO_2 emissions, but usually had little or no effects on soil C inputs. Since, tillage had negligible effects on C inputs; lower CO_2 emissions under NT compared to CT can be attributed to slower decomposition of crop residues resulting in net C gain. However, some studies around the world indicated that NT increases plant growth and C input to the soil while others NT reduces plant growth and C input to the soil. The C flux measurements and soil surface C data suggest C sequestration in NT. The adoption of NT would increase C in stable or passive soil organic matter fractions. However, a portion of the C gained under NT would also be in the light fraction (Curtin et al., 2000), which is labile and vulnerable to rapid decomposition (Gregorich and Janzen, 1996). Beare et al. (1994) proposed that some of the organic C gained under NT may be sequestered within soil aggregates, where it would be protected from rapid decomposition.

The greater soil CO_2 flux in CT is the result of disturbance effect on decomposition of soil organic matter and increased porosity allowing for faster diffusion of gases. Precipitation can directly control gas diffusion from soil to atmosphere. During the greatest precipitation, between 40 and 50 days after planting, CT released significantly greater CO_2 compared to NT. The greater CO_2 flux in CT plots may be the result of the greater variation of soil water content at 15 – 30 cm depth and soil surface temperature on 42 day after planting. The higher surface temperature and lower soil water content in CT plots could have increased microbial activity and root respiration. Also, tillage breaks down soil aggregates and releases physically protected organic matter in the soil which increases microbial activity and eventually soil CO_2 flux. Reicosky et al. (1999) reported that cumulative CO_2 flux from CT at the end of 80 h was nearly three times higher than NT. Conventional tillage also had greater soil surface temperature, which could increase microbial activity. The NT plots had lower initial soil surface temperature and greater water content that could minimize microbial activity and decomposition of soil organic matter.

Soil CO_2 flux varied in response to changes in soil water content. At higher soil water content levels, soil CO_2 flux increased in either tillage system, but the variation and magnitude of the increase was greater. The positive correlation between soil water content and CO_2 flux may be the result of lack of water on plant growth, root respiration and microbial activity. Therefore, the increases of soil water content increased soil CO_2 flux in the both tillage systems. The lack of response to soil temperature could be the result of plant phenomenon. While soil temperature generally increased from planting through harvest, plant root respiration decreases through plant maturity (Kocyigit and Rice, 2006). Hence, the relationship between soil temperature and CO_2 flux was weak compared to the relationship between soil water and CO_2 flux. Doyle (2002) also reported a low importance of temperature on CO_2 flux. Rochette et al. (1999) reported a high positive correlation between soil temperature and soil CO_2 flux for a warm season crop (corn) and unplanted plots in Canada (r^2=0.96 and 0.83).

Conclusions

In this study, carbon assimilation from atmosphere was the similar in NT and CT systems. The midday measurement of soil CO_2 flux is 20% more in CT compared to NT system during spring wheat growth.

Thus, soil under NT over 10 years in the North American Great Plains Region has a potential sequester 20% more C compared to CT during spring wheat growth.

Microbial activity is the one of the sources of CO_2 flux, and decreases from planting to harvest at the surface while it is constant at the deeper depths. In addition, the variation in microbial activity is greater at the surface while it is lower at the deeper depths. In this study, the relationship between soil water content and CO_2 flux was significant while the relationship between soil temperature and CO_2 flux was not significant.

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