Soil Carbon Dioxide Emission as Influenced by Irrigation, Tillage, Cropping System, and Nitrogen Fertilization

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Abstract

Soil and crop management practices can influence CO_2 emission from crop and grasslands and therefore on global warming. We examined the effects of two irrigation systems (irrigated vs. non-irrigated) and six management practices [no-till malt barley (*Hordeum vulgaris* L.) with 67 or 134 kg N ha^{-1} (NTBFN), no-till malt-barley with 0 kg N ha^{-1} (NTBON), conventional-till malt barley with 67 or 134 kg N ha^{-1} (CTBFN), conventional-till malt barley with 0 kg N ha^{-1} (CTBON), no-till pea (*Pisum sativum* L.) with 0 kg N ha^{-1} (NTPON), and undisturbed alfalfa (*Medicago sativa* L.) and grasses with 0 kg N ha^{-1} (UAGON)] on soil surface CO_2 flux and soil temperature and water content at the 0 to 15 cm depth. Weekly CO_2 flux, soil temperature, and soil water content were monitored during the crop growing season from May to November 2005 in Lihen sandy loam (sandy, mixed, frigid, Entic Haplustolls) in western North Dakota. Irrigation increased CO_2 flux by 27% compared with non-irrigation by increasing soil water content during dry periods. Similarly, tillage increased CO_2 flux by 58% compared with non-tillage by increasing soil temperature. The CO_2 flux was 1.5 to 2.5-fold greater in tilled than in non-tilled treatments following heavy rain or irrigation. Nitrogen fertilization increased CO_2 flux compared with no N fertilization in 2 out of 17 measurements while cropping system did not influence CO_2 flux. The CO_2 flux in undisturbed alfalfa and grasses was similar to that in no-tilled crops. The CO_2 flux was linearly related with soil temperature and daily average air temperature at the time of CO_2 measurement. Tillage followed by heavy rain or irrigation during the crop growing season drastically increased CO_2 flux in the coarse-textured soil previously managed under Conservation Reserve Program (CRP) planting for more than 20 yr.

Introduction

Global warming due to increased concentration of greenhouse gases, such as CO_2, in the atmosphere is a major concern. One of the significant sources of CO_2 emission is from agricultural practices, which contribute about 25% of total anthropogenic emissions (Duxbury, 1994; 1995). Soil can act as both source and sink of atmospheric CO_2. The CO_2 fixed in plant biomass through photosynthesis can be stored in the soil as organic C by converting plant residue into soil organic matter after the residue is returned to the soil. While management practices, such as tillage, can increase CO_2 emission from the soil by disrupting soil aggregates, increasing aeration, incorporating plant residue, and oxidizing soil organic C (Reicoscky and Lindstrom, 1993; Beare et al., 1994; Jastrow et al., 1996), no-tillage and increased cropping intensity can increase C storage in the soil (Lal et al., 1995; Paustian et al., 1995). Respiration by plant roots and soil microflora and fauna also contribute a major portion of CO_2 emission from the soil (Rochette and Flanagan, 1997; Curtin et al., 2000). The CO_2 emission from the soil to the atmosphere is the primary mechanism of C loss from the soil (Parkin and Kaspar, 2003) and provides an early indication of C sequestration in the soil when changes in soil organic C due to management practices are not detectable within a short period (Fortin et al., 1996; Grant, 1997).

Reduced tillage is regarded as one of the most effective agricultural practices to reduce CO_2 emission and sequester atmospheric C in the soil (Kern and Johnson, 1993; Lal and Kimble, 1997; Curtin et al., 2000; Al-Kaisi and Yin; 2005). Decreased tillage intensity reduces soil disturbance and microbial activities, which in turn, lowers CO_2 emission (Lal and Kimble, 1997; Curtin et al., 2000). Moreover, no-till with surface residue can further reduce CO_2 emission compared to no-till without residue (Al-Kaisi and Yin, 2005). In contrast, increased tillage intensity increased CO_2 emission by increasing aeration due to increased soil disturbance (Roberts and Chan, 1990) and to physical degassing of dissolved CO_2 from the soil solution (Reicoscky and Lindstrom, 1993; Jackson et al., 2003). The effect of tillage on CO_2 emission, however, was short-lived (<24 h) (Reicoscky and Lindstrom, 1993; Ellert and Janzen, 1999). Rewetting of

dry soil due to irrigation or rainfall increased CO_2 flux by increasing microbial activities, C mineralization, and respiration (Sparling and Ross, 1988; Van Gestel et al., 1993; Calderon and Jackson, 2002).

Cropping system can influence CO_2 emission by affecting on the quality and quantity of residue returned to the soil (Curtin et al., 2000; Al-Kaisi and Yin; 2005; Amos et al., 2005). Increased above- and belowground biomass production can increase the amount of residue returned to the soil (Sainju et al., 2005), thereby increasing CO_2 flux (Franzluebbers et al., 1995; Curtin et al., 2000; Al-Kaisi and Yin; 2005). Increased belowground biomass production can also increase root and rhizosphere respiration, thereby increasing CO_2 flux (Amos et al., 2005). Similarly, residue quality, such as C/N ratio, can alter the decomposition rate of residue (Kuo et al., 1997; Sainju et al., 2002), thereby influencing CO_2 emission (Al-Kaisi and Yin, 2005). Nitrogen fertilization had little effect on CO_2 emission from the soil surface (Rochette and Gregorich, 1998; Wagai et al., 1998; Amos et al., 2005).

Management practices can affect soil temperature and water content (Curtin et al., 2000; Al-Kaisi and Yin, 2005) which directly influence CO_2 emission rates (Bajracharya et al., 2000b; Parkin and Kaspar, 2003; Amos et al., 2005). For example, tillage can dry the soil but no-till can increase soil water content and reduce soil temperature because of residue accumulation at the soil surface (Curtin et al., 2000; Calderon and Jackson, 2002; Al-Kaisi and Yin, 2005). Similarly, cropping system can reduce soil temperature by providing shade with increased biomass growth but can reduce soil water content due to increased evapotranspiration (Amos et al., 2005).

Little is known about the combined effects of irrigation, tillage, cropping system, and N fertilization on CO_2 flux in transitional land that has been converted from Conservation Reserve Program (CRP) planting to agricultural use. The CO_2 flux from the conversion of no-till to conventional till, from dryland to irrigated, or from less intensive to more intensive cropping system could be different from the flux obtained during the reverse trend of land conversion. We hypothesized that the individual and combined uses of irrigation, tillage, cropping system, and N fertilization have differential effects on soil surface CO_2 flux in the transitional land. Our objectives were to: (1) determine the effects of irrigation, tillage, cropping system, and N fertilization on soil surface CO_2 flux during the crop growing season in land converted from CRP to agricultural use, and (2) compare CO_2 fluxes in the agricultural system and undisturbed alfalfa and grasses.

Materials and Methods

The experiment was conducted in 2005 on a transitional land that was converted from CRP planting to agricultural use in the Nesson Valley in western North Dakota. The resident vegetation was dominated by alfalfa (*Medicago sativa* L.), crested wheatgrass [*Agropyron cristatum* (L.) Gaertn], and western wheatgrass [*Pascopyron* smithii (Rydb.) A. Love]. The soil was a Lihen sandy loam (sandy, mixed, frigid, Entic Haplustolls). The soil sampled in April 2005 before the initiation of the experiment had 720 g kg^{-1} sand, 200 g kg^{-1} silt, 80 g kg^{-1} clay, 12.5 g kg^{-1} organic C, and 7.7 pH at the 0 to 20 cm depth.

The treatments consisted of two irrigation systems (irrigated vs. nonirrigated) and management practices consisting of six combined treatments of tillage, cropping system, and N fertilization rates [no-till malt barley with N fertilization (NTBFN), no-till malt barley with no N fertilization (NTBON), conventional-till malt barley with N fertilization (CTBFN), conventional-till malt barley with no N fertilization (CTBON), no-till pea with no N fertilization (NTPON), and undisturbed alfalfa and grasses with no N fertilization (UAGON)]. The N fertilization rate for irrigated no-till and conventional-till malt barley was 134 kg N ha^{-1} and for non-irrigated no-till and conventional-till malt barley was 67 kg N ha^{-1}. For conventional-till malt barley, plots were tilled with a rototiller to a depth of 10 cm in April 2005 to prepare seed bed and to kill the resident vegetation. The UAGON treatment consisted of alfalfa and grasses that were continued from previous vegetation. Resident vegetation in no-till plots, except the undisturbed alfalfa and grasses treatment, was killed by applying glyphosate [N-(phosphonomethyl) glycine] at 3.5 kg a.i. (active ingredient) ha^{-1} prior to crop planting. The experiment was arranged in randomized complete block with irrigation as the main plot and management practices as the split-plot treatment. Each treatment had three replications. The size of the experimental unit was 10.6 x 3.0 m.

Figure 1. Soil surface CO_2 flux measurement with Environmental Gas Monitor chamber and data logger

In May 2005, malt barley (cv. Certified Tradition, Busch Agricultural Resources, Fargo, ND) was planted at 3.8 cm depth at the rate of 90 kg ha^{-1} in the irrigated treatment and 67 kg ha^{-1} in the non-irrigated treatment with a no-till drill. Similarly, pea (cv. Majorete, Macintosh Seed, Havre, MT) was planted at 200 kg ha^{-1} in irrigated and non-irrigated treatments. In irrigated malt barley, half of N fertilizer as urea (or 67 kg N ha^{-1}) was banded at planting and other half was broadcast at 4 wk after planting. In non-irrigated malt barley, all N fertilizer was banded at planting. The P fertilizer as triple super phosphate and K fertilizer as muriate of potash were banded at 25 kg P ha^{-1} and 21 kg K ha^{-1}, respectively, each to malt barley and pea at planting. The amount of N, P, and K fertilizers to malt barley and pea were based on soil test and crop requirement. No fertilizers were applied to alfalfa and grasses in UAGON treatment which resembled undisturbed CRP planting. However, as with other management practices, half of UAGON treatment in split-plot arrangement received irrigation and other half did not. Appropriate types and amounts of herbicides and pesticides were used to control weeds and pests during growth and after harvest of malt barley and pea. In irrigated plots, water was applied at amounts ranged from 10 to 25 mm of rain from 17 June to 14 July 2005 (a total of 87 mm) based on soil moisture content. In July and August, malt barley and pea were hand harvested from an area of 0.5 x 4 m^2 and straw (leaves and stems) was returned to the soil.

Immediately after planting, soil surface CO_2 flux was measured weekly in all treatments during and after the crop growing season from May to November 2005 until the ground froze. All measurements were made between 9 A.M. and 12 A.M. of the day to reduce variability in CO_2 flux due to diurnal changes in temperature (Parkin and Kaspar, 2003). The CO_2 flux was measured with an Environmental Gas Monitor chamber attached to a data logger (model no. EGM-4, PP System, Haverhill, MA) (Figure 1). The chamber is 15 cm tall, 10 cm in diameter, and has capacity to measure CO_2 flux from 0 to 9.99 g CO_2-C m^{-2} h^{-1}. The chamber was placed at the soil surface for 2 min in each plot until CO_2 flux measurement was recorded in the data logger. A flag was placed as a marker in the plot where CO_2 flux was measured throughout the study period. At the time of CO_2 measurement, soil temperature near the chamber was measured from a depth of 0 to 15 cm from a probe attached to the data logger. Similarly, gravimetric soil water content was measured near the chamber by collecting soil sample from the 0 to 15 cm depth with a probe (2.5 cm diameter) every time CO_2 flux was measured. The moist soil was oven-dried at 110°C and water content

was determined. Daily average air temperature and total rainfall during the study period were collected from a meteorological station located at 0.8 km from the study site.

Data for CO_2 flux, soil temperature, and soil water content were analyzed by using the Analysis of Repeated Measures procedure in the MIXED model of SAS (Littell et al., 1996). Irrigation was considered as the main plot, management practices as the split plot, and date of measurement as the repeated measure treatment in the analysis. Means were separated by using the least square means test when treatments and interactions were significant. Statistical significance was evaluated at $P \leq 0.05$ unless otherwise mentioned. Regression analysis was done between CO_2 flux and average daily air temperature, soil temperature, and soil water content to determine their relationships.

Results and Discussion

Climate

Rainfall and air temperature influence soil water content and soil temperature, which in turn, directly influence CO_2 flux from the soil surface (Bajracharya et al., 2000; Curtin et al., 2000; Parkin and Kaspar, 2003). Daily total rainfall was higher in May and June 2005 during the critical growing period of crops, and then declined from July to November as the crop matured (Figure 2A). Since air temperature is more correlated with CO_2 flux than soil temperature (Parkin and Kaspar, 2003), daily average air temperature was also measured to determine its influence on soil CO_2 flux, besides measuring soil temperature and water content. As expected, daily average air temperature increased from May to August and then declined (Figure 2B).

Effect of Irrigation

Soil temperature at the 0 to 15 cm depth followed a trend similar to that of air temperature (Figure 3B) but was less variable (Figure 2B). Irrigation resulted in a significant ($P \leq 0.001$) interaction with date of measurement on soil temperature, water content, and CO_2 flux (Table 1). Soil temperature was lower in irrigated than in non-irrigated treatment in Days 176, 195, 202, 208, and 217 of the year (Figure 2B). In contrast, soil water content at the 0 to 15 cm depth was higher in irrigated than in non-irrigated treatment in Days 176, 202, 208, and 217 of the year. It is not surprising to observe lower soil temperature and higher water content with irrigated treatment in these days when irrigation was done to meet the crop water requirement during periods of higher air temperature and lower rainfall (Figures 2A, 2B, 3C). Increased water content and evaporation from the soil surface probably reduces soil temperature, as wet soil is slower to change in temperature than dry soil (Bajracharya et al., 2000b; Parkin and Kaspar, 2003). Increased rainfall increased soil water content of both irrigated and non-irrigated treatments in May and June when no irrigation was done.

The CO_2 flux increased from 31 kg CO_2-C ha^{-1} d^{-1} in Day 122 to 427 kg CO_2-C ha^{-1} d^{-1} in Day 188 of the year, after which it declined (Figure 3A). The flux was higher in irrigated than in non-irrigated treatment in Days 158, 176, 179, and 188. Increased soil moisture content rather than a difference in soil temperature (Figures 3B and 3C) probably increased CO_2 flux with irrigation during these periods. Increased CO_2 flux after irrigation or after a heavy rain in dry soil resulting from increased C mineralization have been known (Howard and Howard, 1993; van Gestel et al., 1993; Curtin et al., 2000; Calderon and Jackson, 2002). Since a major portion of soil CO_2 flux is contributed by respiration from plant roots, rhizosphere, and microbial flora and fauna (Rochette and Flanagan, 1997; Curtin et al., 2000), it is likely that irrigation of dry soil increased microbial activities and CO_2 emission. Averaged across measurement dates, irrigation decreased soil temperature by 0.8°C and increased soil water content by 6% and CO_2 flux by 15% (Table 2).
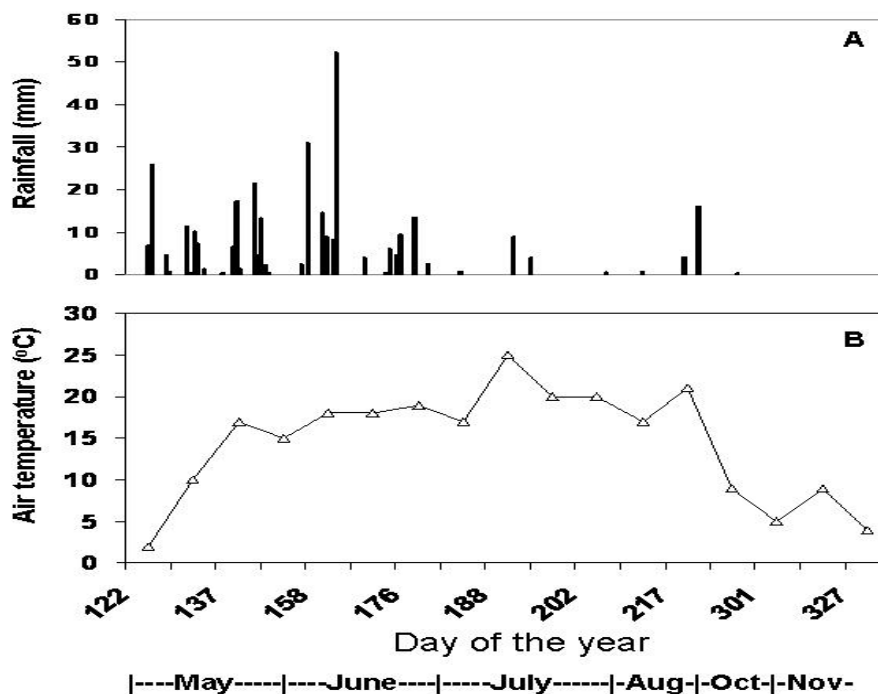
Figure 2. Daily (A) total rainfall and (B) average air temperature at the time of CO_2 flux measurement from May to November 2005 in western North Dakota.

Table 1. Analysis of variance for soil surface CO_2 flux and soil temperature and water content at the 0 to 15 cm depth.

Source	Soil CO_2 flux	Soil temperature	Soil water content
Irrigation (I)	**	*	*
Management practices (M)	***	***	***
I × M	NS†	**	NS
Date of measurement (D)	***	***	***
I × D	***	**	***
M × D	***	***	**
I × M × D	NS	*	*

* Significant at $P \leq 0.05$.
** Significant at $P \leq 0.01$.
*** Significant at $P \leq 0.001$.
† Not significant.

Table 2. Effects of irrigation and management practices on soil surface CO_2 flux and soil temperature and water content at the 0 to 15 cm depth averaged across dates of measurement.

Irrigation	Management practices†	Soil surface CO_2 flux (kg CO_2-C ha^{-1} d^{-1})	Soil temperature (°C)	Soil water content (g kg^{-1})
Irrigated		194a‡	14.8a	97.3a
Non-irrigated		169b	15.6b	91.9b
	NTBFN	164b	15.0c	97.1a
	NTPON	155b	15.2b	96.5a
	CTBFN	250a	15.0c	95.3a
	UAGON	150b	15.3b	86.9b
	NTBON	145b	15.2b	97.9a
	CTBON	242a	15.5a	94.7a

† Management practices are CTBFN, conventional-till malt barley with 67 or 134 kg N ha^{-1}; CTBON, conventional-till malt barley with 0 kg N ha^{-1}; NTBFN, no-till malt barley with 67 or 134 kg N ha^{-1}; NTBON, no-till malt barley with 0 kg N ha^{-1}; NTPON, no-till pea with 0 kg N ha^{-1}; and UAGON, undisturbed alfalfa and grasses with 0 kg N ha^{-1}.
‡ Numbers followed by different letters within a set of a column are significantly different at $P \leq 0.05$ by the least square means test.

Effect of Management Practices

Differences in soil temperature, water content, and CO_2 flux between management practices at some measurement dates resulted in a significant ($P \leq 0.01$) management practice × measurement date interaction (Table 1). Soil temperature was higher in UAGON than in all other practices, except in NTBON, in Day 176 (Figure 4B). Soil temperature was also higher in CTBON than in most of the other management practices from Day 195 to 217. While soil water content was consistently lower in UAGON from Day 137 to 158 and from Day 202 to 217, it was higher in NTPON from Day 144 to 166, higher in NTBON in Days 176, 179, 202, and higher in NTBFN in Days 208 and 217 than in most of the other management practices (Figure 4C). Increased soil temperature and decreased water content in UAGON was probably due to greater water requirement of alfalfa and grasses. Similarly, increased soil temperature and reduced water content in CTBON was likely a result of drying up of soil due to tillage and reduced plant growth. The plant biomass and yield were lower in CTBON (data not shown), probably due to low N availability, since N fertilizer was not applied in this treatment. Tillage can result in drying up of soil due to increase in water vapor flux (Kessavalou et al., 1998), and decreased shading with reduced plant growth can increase soil temperature (Amos et al., 2005). In contrast, increased soil water content and decreased soil temperature in NTBON, NTPON, and NTBFN was probably due to less soil disturbance, followed by residue accumulation at the soil surface. Increased soil water content and decreased soil temperature in no-till than in conventional till have been reported by several researchers (Curtin et al., 2000; Calderon and Jackson, 2002; Al-Kaisi and Yin, 2005).

Management practices, especially tillage, increased CO_2 flux more than the irrigation treatment by ≥ 159 kg CO_2-C ha^{-1} d^{-1} at certain measurement dates (Figure 4A). Drastic increases occurred in tilled treatments immediately following heavy rain or irrigation in Days 130, 158, 188, 195, 202, and 208 when CO_2 fluxes in CTBFN and CTBON were 1.5 to 2.5-fold higher than in other treatments. The flux was also higher in NTBFN and NTPON than in UAGON in Day 179 but was higher in UAGON than in NTPON in DAY 195. Similarly, the flux was higher in NTBFN than in NTBON and UAGON in Day 188 and was higher in CTBFN than in CTBON in Day 202.

The CO_2 flux of as much as 300 kg CO_2-C ha^{-1} d^{-1} following tillage and heavy rain in dry soil in northern Great Plains had been known (Curtin et al., 2000). Our results of CO_2 flux of as much as 600 kg CO_2-C ha^{-1} d^{-1} in CTBFN and CTBON following heavy rain or irrigation seems to be extreme but could be due to tillage in the soil that had been under CRP management for more than 20 years before the study was initiated. Tillage can result in an immediate short-term outburst of CO_2 due to decrease in partial pressure of CO_2 in soil air, followed by disturbance in soil aggregation and pores, and sudden release of CO_2 from the soil solution (Reicoscky et al., 1995; Ellert and Janzen, 1999; Rochette and Angers, 1999). The effect of tillage on the CO_2 flux was short-lived, as suggested by others (Reicosky and Lindstrom, 1993; Al-Kaisi

and Yin, 2005), because fluxes were lower after tillage in the initial periods of study in Days 122, 137, and 144, regardless of management practices (Figure 4A). However, fluxes triggered in tilled treatments in Days 130, 158, 188, 195, 202, and 208 immediately after heavy rains and irrigation in dry soil. Under raindrop and irrigation impact, the soil surface may have sealed in the tilled treatment, temporarily trapping CO_2. As the water drained and soil surface dried, trapped CO_2 may have released in a brief, intense burst, as suggested by Curtin et al. (2000). Another possibility would be that tillage accompanied by rainfall and irrigation could have increased microbial activities, thereby increasing C mineralization and CO_2 flux. Better soil structure along with increased surface residue cover could have reduced surface sealing in the no-till treatment. Changes in soil organic C content due to short-term burst of CO_2 from tillage would be minor because only a small portion of soil organic matter mineralizes during the initial phase of tillage (Curtin et al., 2000; Al-Kaisi and Yin, 2005).Tillage also may have indirectly influenced CO_2 flux during these periods by increasing soil temperature (Figure 4B). Although CO_2 flux can be influenced by a range of factors including soil temperature, water content, wind speed, and CO_2 concentration gradient, greater fluxes in this study than those obtained by Curtin et al. (2000) could also be due to a difference in soil texture. Soil texture in our study was sandy loam and in their study was silt loam. The CO_2 flux increases with decrease in clay content (Parkin and Kaspar, 2003). Nevertheless, our study shows that tillage accompanied by heavy rain or irrigation can cause a sudden outburst of CO_2 during the crop growing season in the summer from areas previously under CRP management.

The CO_2 flux was similar under malt barley and pea in NTBON and NTPON, suggesting that cropping system did not influence CO_2 emission. Al-Kaisi and Yin (2005) reported no significant difference in CO_2 flux between corn (*Zea mays* L) and soybean (*Glycine max* L.). However, lower CO_2 flux in UAGON than in other treatments on some measurement dates was probably a result of decreased soil water content (Figures 4A, 4B, 4C). The greater CO_2 flux in NTBFN than in NTBON and in CTBFN than in CTBON in Days 188 and 202 suggests that N fertilization increased CO_2 flux when soil water content is adequate. Limited or no increase in CO_2 flux with increased N fertilization rate had been reported by several researchers (Rochette and Gregorich, 1998; Wagai et al., 1998; Amos et al., 2005).

Averaged across measurement dates, CTBFN and CTBON increased soil surface CO_2 flux by an average of 58% compared with other treatments (Table 2). These treatments also increased soil temperature and reduced soil water content, except in UAGON. Eliminating the short-term burst of CO_2 immediately after tillage (Al-Kaisi and Yin, 2005) which was not measured in this study, tillage can increase CO_2 flux by an average of 90 kg CO_2-C ha^{-1} d^{-1} (246 kg CO_2-C ha^{-1} d^{-1} in tilled vs. 156 kg CO_2-C ha^{-1} d^{-1} in non-tilled treatments) or 19.3 Mg CO_2-C ha^{-1} compared with no-tillage from May to November (214 d). If the loss was estimated for the entire year using the same rate of CO_2 emission, it would be 32.8 Mg CO_2-C ha^{-1} yr^{-1}. When CO_2 flux from tilled treatments during the peak emission periods in Days 130, 158, 179, 188, 195, and 202 were eliminated, the loss of CO_2 flux in tilled vs. non-tilled treatment averaged 4.7 Mg CO_2-C ha^{-1} yr^{-1}. The value could, however, be overestimated, because CO_2 flux rates are lower in winter than in summer (Follett, 1997; Bajracharya et al., 2000a). Furthermore, half of this CO_2 loss would be contributed by respiration from plant roots and soil microflora and fauna (Curtin et al., 2000). Soil C sequestration rate in northern Great Plains using no-till management compared with tilled treatment has been estimated at 5 to 6 Mg ha^{-1} yr^{-1} after 13 to 14 yr or about 400 kg C ha^{-1} yr^{-1} (Curtin et al., 2000). These data show that tillage can cause a drastic loss of soil C as CO_2 emission within a short period of time, but it takes a long time to sequester C using no-till practices.
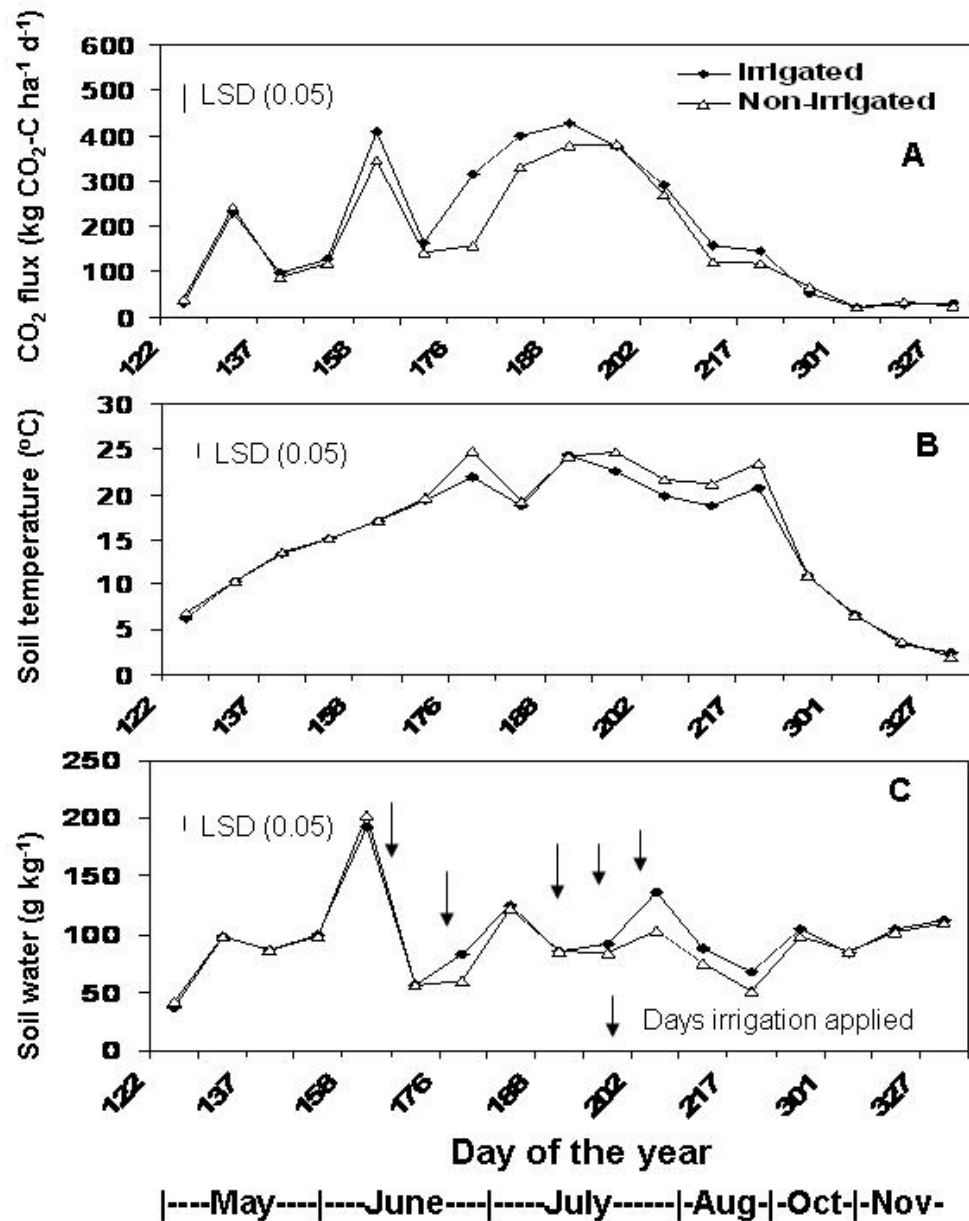
Figure 3. Effect of irrigation on (A) soil surface CO_2 flux and soil (B) temperature and (C) water content at the 0 to 15 cm depth averaged across management practices from May to November 2005 in western North Dakota. LSD (0.05) is the least significant difference between treatments at $P < 0.05$.
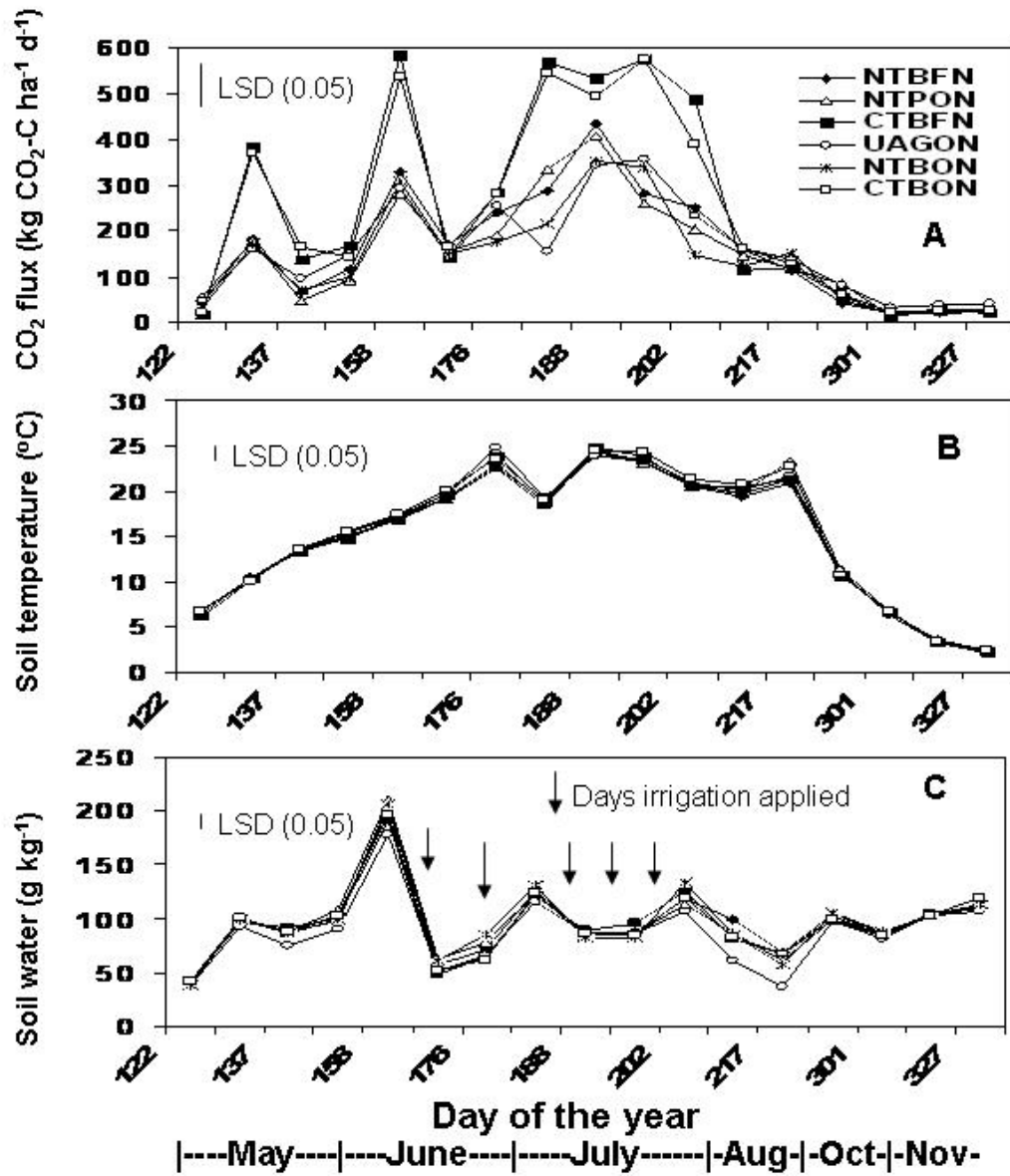
Figure 4. Effects of management practices on (A) soil surface CO_2 flux and soil (B) temperature and (C) water content at the 0 to 15 cm depth averaged across irrigation systems from May to November 2005 in western North Dakota. Management practices are CTBFN, conventional-till malt barley with 67 or 134 kg N ha^{-1}; CTBON, conventional-till malt barley with 0 kg N ha^{-1}; NTBFN, no-till malt barley with 67 or 134 kg N ha^{-1}; NTBON, no-till malt barley with 0 kg N ha^{-1}; NTPON, no-till pea with 0 kg N ha^{-1}; and UAGON, undisturbed alfalfa and grass with 0 kg N ha^{-1}. LSD (0.05) is the least significant difference between treatments at $P < 0.05$.

Relationship between Carbon Dioxide Emission and
Temperature and Soil Water Content

A regression analysis between CO_2 flux and soil temperature at the 0 to 15 cm depth averaged across irrigation and management practices treatments and daily average air temperature at the time of CO_2 measurement revealed that CO_2 flux was linearly related ($R^2 = 0.55$ to 0.56, $P \leq 0.001$, n = 17) with both soil temperature and air temperature (Figures 5A and 5B). Both soil temperature and air temperature accounted for 55 to 56% of the variability in CO_2 flux with similar slopes. Soil water content at the 0 to 15 cm depth was weakly related ($R^2 = 0.18$, $P \leq 0.10$, n = 17) with CO_2 flux.

The significant relationship between CO_2 flux and soil temperature is well known (Follett, 1997; Bajracharya et al., 2000b; Parkin and Kaspar, 2003). High CO_2 flux usually occurs in the summer when soil temperature is higher and soil water content and substrate C availability is adequate, while low emission occurs in the winter when soil biological activity is minimal due to near-freezing soil temperature (Kirschbaum, 1995; Follett, 1997; Bajracharya et al., 2000a; 2000b). Parkin and Kaspar (2003) reported that soil surface CO_2 flux was better related with air temperature than with soil temperature because of plant residue at the soil surface. Our results showed that CO_2 flux was equally related with both soil temperature and daily average air temperature at the time of CO_2 flux measurement. Significant effects of irrigation and management practices on CO_2 flux and soil temperature and water content (Table 1) suggests that these treatments modified soil temperature and water content which influenced microbial activities and C mineralization, thereby resulting in different CO_2 fluxes between treatments at various measurement dates.

Conclusions

Results of this study showed that both irrigation and tillage influenced soil temperature and water content and increased soil surface CO_2 flux from areas previously managed under CRP planting for more than 20 years. Tillage followed by heavy rain or irrigation drastically increased the flux during the crop growing season from May to August 2005. The CO_2 flux was influenced by soil temperature and water content which were modified by treatments. Cropping system and N fertilization had limited or no effect on CO_2 flux in the first year after the establishment of treatments. The CO_2 flux in undisturbed alfalfa and grasses was similar to that in no-till malt barley and pea treatments. Long-range studies are needed to determine the effects of treatments on CO_2 flux under various climatic and environmental conditions to estimate C loss from the soil ecosystem.
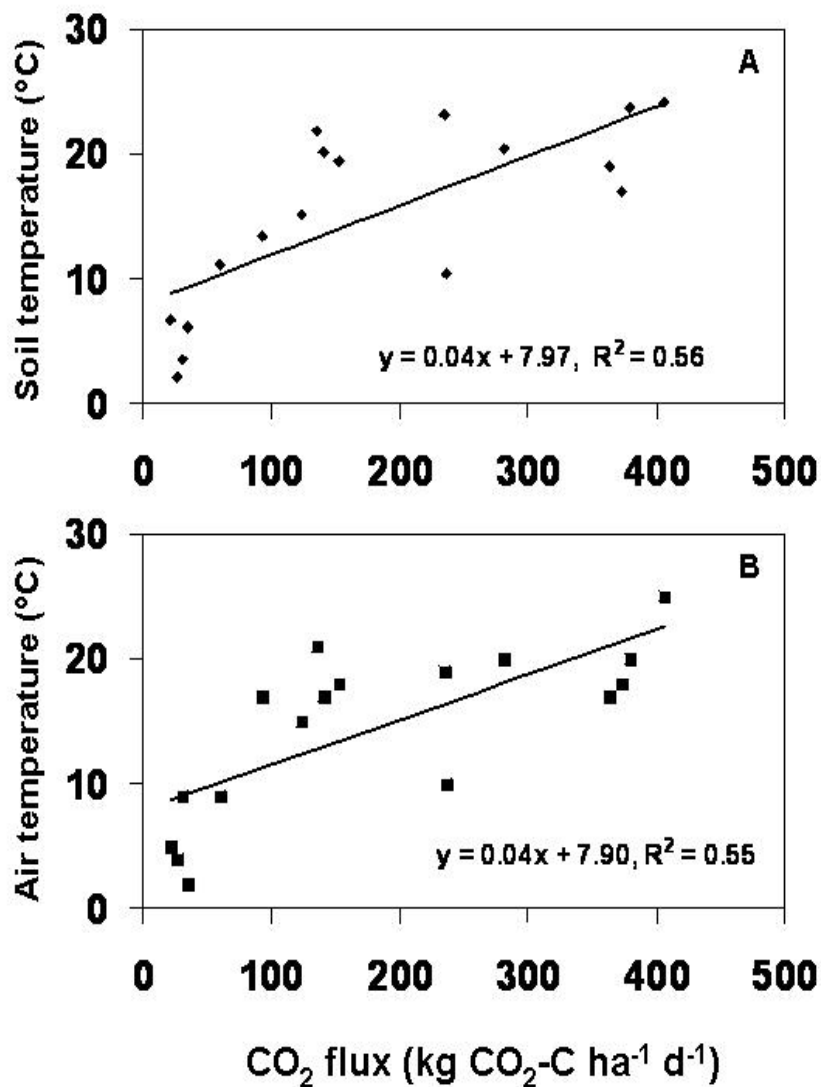
Figure 5. Relationship between soil surface CO_2 flux and (A) soil temperature at the 0 to 15 cm depth averaged across irrigation and management practices and (B) daily average air temperature at the time of CO_2 measurement.

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