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Crop rotation and nitrogen fertilization effect on soil CO_2 emissions in central Iowa

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ABSTRACT

Depending upon how soil is managed, it can serve as a source or sink for atmospheric carbon dioxide (CO_2). As the atmospheric CO_2 concentration continues to increase, more attention is being focused on the soil as a possible sink for atmospheric CO_2. This study was conducted to examine the short-term effects of crop rotation and N fertilization on soil CO_2 emissions in Central Iowa. Soil CO_2 emissions were measured during the growing seasons of 2003 and 2004 from plots fertilized with three N rates (0, 135, and 270 kg N ha^{-1}) in continuous corn and a corn–soybean rotation in a split-plot design. Soil samples were collected in the spring of 2004 from the 0–15 cm soil depth to determine soil organic C content. Crop residue input was estimated using a harvest index based on the measured crop yield. The results show that increasing N fertilization generally decreased soil CO_2 emissions and the continuous corn cropping system had higher soil CO_2 emissions than the corn–soybean rotation. Soil CO_2 emission rate at the peak time during the growing season and cumulative CO_2 under continuous corn increased by 24 and 18%, respectively compared to that from corn–soybean rotation. During this period, the soil fertilized with 270 kg N ha^{-1} emitted, on average, 23% less CO_2 than the soil fertilized with the other two N rates. The greatest difference in CO_2 emission rate was observed in 2004; where plots that received 0 N rate had 31% greater CO_2 emission rate than plots fertilized with 270 kg N ha^{-1}. The findings of this research indicate that changes in cropping systems can have immediate impact on both rate and cumulative soil CO_2 emissions, where continuous corn caused greater soil CO_2 emissions than corn soybean rotation.

1. Introduction

Soil is the largest reservoir of terrestrial carbon (C) storing approximately 53% of the terrestrial C (Lal, 2004). The atmospheric carbon dioxide (CO_2) concentration has increased about 85 ppm in the last 100 years (Lal, 2004) and approximately 10% of the CO_2 in the atmosphere passes through the soil each year (Raich and Potter, 1995). The increase in atmospheric CO_2 concentration has increased the effort that is being devoted to explore the potential of agricultural land to sequester C. Several soil management practices influence the potential of agricultural soil to be utilized as a sink of CO_2. Nitrogen fertilization and crop rotation may play a significant role in impacting soil C (Lal, 2004). Nitrogen fertilization impacts the soil C pool in two ways. One, increasing N fertilization will increase crop biomass in several crops and two, N availability is critical for the microbial decomposition of crop residue (Green et al., 1995).

Limited information is available regarding the effects of N fertilization on in situ soil CO_2 emissions from agricultural

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ecosystems. Kowalenko et al. (1978) and Fogg (1988) found increased N fertilization depressed soil CO_2 emissions. The effects of N deposition on soil CO_2 emissions have also been studied in forest and grassland ecosystems (Micks et al., 2004; Bowden et al., 2004; Burton et al., 2004). These studies reported results similar to Kowalenko et al., 1978 and Fogg (1988). The reason for the depression of soil CO_2 emissions due to N fertilization is relatively unclear. Previous studies have suggested that the depression occurred because increased N reduced enzymatic activity (Fogg, 1988; Bowden et al., 2004; Burton et al., 2004), decreased pH (Aerts and de Caluwe, 1999), or decreased microbial biomass (Soderstrom et al., 1983).

Generally, plant biomass (above and below ground) is the primary source of C input into the soil C pool, which contributes to soil CO_2 emissions. Both crop rotation and N fertilization can affect the amount of plant biomass returned to the soil in a given year. In crops that cannot fix atmospheric N, N fertilization has been shown to increase crop biomass (Halvorson et al., 2002, 1999). Even though N fertilization consistently increases crop biomass, it has variable effects on soil C. In a 12-year study, Halvorson et al. (2002) found that N fertilization had no effect on SOC content of different N treatments, despite the increase of wheat biomass returned to the soil. Other researchers have found that increased N fertilizer rates can increase SOC content in long-term corn and wheat cropping systems (Liang and Mackenzie, 1992; Halvorson et al., 2002). Further illustrating the effect N has on SOC in different cropping systems, Russell et al. (2005) found that 90 kg N ha^{-1} increased SOC in continuous corn and N fertilization had no effect on SOC in a corn–soybean rotation.

Crop rotation and N fertilization have the potential to affect soil CO_2 emissions and the soil C pool. Because Iowa is the largest corn producing state in the U.S. and N is applied to 94% of these hectares (NASS, 2002), it is important to understand the effects of different crop rotations and N fertilization on the soil C dynamics. The objective of this study was to evaluate the short-term effects of crop rotation and N fertilization on soil CO_2 emissions in Central Iowa.

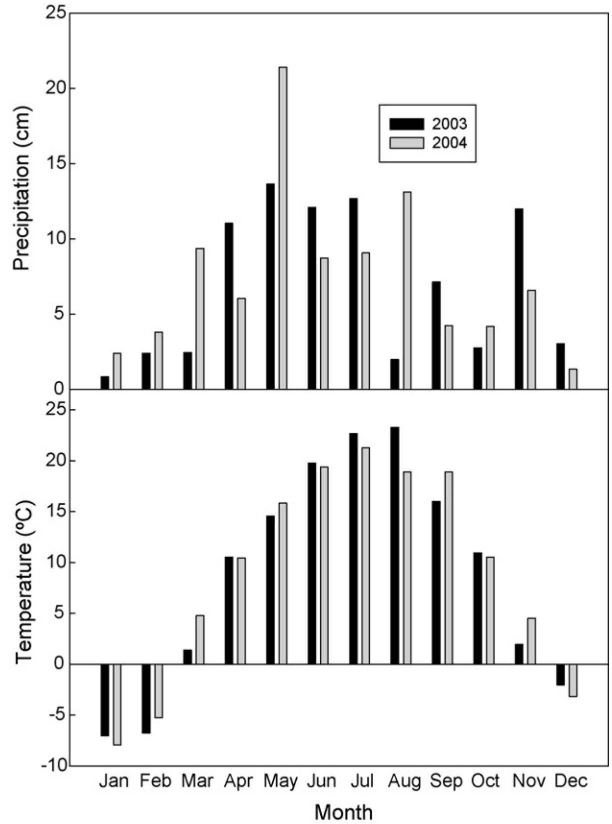

Fig. 1 – Mean monthly precipitation and air temperature at the study site in 2003 and 2004.

2. Materials and methods

2.1. Site and treatment description

This study was conducted on a Clarion loam (Fine-loamy, mixed, calcareous, mesic Typic Haplaquoll) at the Burkey research farm 16 km west of Ames, Iowa. Mean monthly temperature and rainfall at the research site in 2003 and 2004 are presented in Fig. 1. The initial values of soil organic matter, pH, and bulk density are 63 g kg^{-1}, 6.5, and 1.3 g cm^{-3}, respectively. Soil CO_2 emissions were measured during the 2003 and 2004 growing seasons and soil samples were taken during the spring of 2004. The experimental design was a split plot with crop rotation (continuous corn and corn–soybean) being the main treatment and N rate (0, 135, and 270 kg N ha^{-1}) as the sub-plot. The treatments were randomly arranged in three replications with sub-plots measuring 4.5-m wide by 22.8-m long.

The site was in a corn–soybean rotation and in a chisel plow tillage system prior to the initiation of this study and the treatments of this study were established in the spring of 1999. The corn was planted in April and harvested in September every year for both crop rotations. The soybeans in the corn–soybean rotation were planted in odd years in May and harvested in the same month as corn. No crop was grown in the plots from September through April. The study site had two sets of corn–soybean rotation plots so each year there were corn–soybean rotation plots growing corn each year.

Nitrogen fertilizer was applied to corn by hand broadcasting NH_4NO_3 prior to planting. Ammonium nitrate was incorporated when the pre-plant herbicide was incorporated. Glyphosate-resistant corn was planted on 29 April 2003 at 74,600 plants ha^{-1} and on 27 April 2004 at 79,500 plants ha^{-1}. Prior to planting, metolachlor was sprayed on all plots at a rate of 1.85 L ha^{-1} and immediately incorporated with a field cultivator. One post-emergence application of glyphosate at a rate of 2.32 L ha^{-1} was applied to the corn plots on 4 June 2003 and 28 May 2004. Plots were harvested in October using a two-row plot combine. After harvest, the plots were chisel plowed using a commercially available chisel plow with straight shanks and twisted sweeps. Shanks were spaced 30 cm apart and the depth of tillage was approximately 25 cm.

2.2. Field CO_2 measurements

Four PVC rings 10 cm in diameter were placed in each plot after corn emergence, two in the row and two between the rows. Carbon dioxide emissions were measured at each PVC ring with a Li-Cor 6400 (Li-Cor Corp., Lincoln, NE) equipped with a 6400-09 soil chamber. Measurements of soil CO_2 emission rate were taken every 7–10 days between 900 and 1600 h from June through August, then bi-weekly from September until harvest. Soil temperature and soil moisture were measured in the top 5 cm outside the ring at the time of measuring CO_2 emission. Soil temperature was measured with a thermometer provided with the Li-Corr 6400 and soil moisture was measured with a TRIME-FM TDR (Mesa Corp., Phoenix, AZ). Cumulative CO_2 emission at a given time was calculated using the following relationship

$$CO_2\text{-C}\,(\text{kg ha}^{-1}) = \sum_{i=\text{first}}^{n=\text{last}} X_i + X_{i+1} * N + X_{i+2} * N + \ldots + X_{i+n} * N$$

where (*i*) is first week of the growing season when first CO_2 rate was taken, (*n*) is the last week of the growing season when last CO_2 rate was taken, *X* is CO_2 rate (kg ha^{-1} day^{-1}), and *N* is number of days between two consecutive CO_2 rate measurements.

2.3. *Soil sampling and analysis*

In the spring of 2004, soil samples were collected from all treatments at the 0–15 cm soil depth. A composite soil sample consisting of 8–12 cores was collected using a soil probe with an inside diameter of 1.9 cm. The composite soil samples were stored at 4 °C until further processing could be conducted. Prior to conducting soil C analysis, the soil samples were defrosted, 2 mm sieved, and allowed to air dry. A subsample was analyzed for SOC and total nitrogen (TN) contents by dry combustion using a LECO CHN 2000 analyzer (LECO Corporation, St. Joseph, MI).

Bulk density was determined at the time of soil sampling for soil TC and TN (Culley, 1993). Three soil cores were collected for each depth per plot using a 1.9-cm inside diameter soil probe. Careful attention was paid to make sure there was no compaction during sampling. Soil cores were measured and cut into increments consistent at the same soil depth of soil sampling. The soil increments were put into metal cans and oven dried at 105 °C for 24 h.

2.4. *Statistical analysis*

Statistical analysis was preformed by using the SAS system (SAS, 2005). The Mixed procedure was used to analyze the daily soil CO_2 emission rate for each N rate and crop rotation–year combination. The GLM procedure was used to conduct an analysis of variance on the cumulative CO_2 emissions, SOC, and residue input. Duncan's multiple range test was used for means separation. Significance was assessed at $P < 0.10$, which is consistent with other studies dealing with soil CO_2 emissions (Curtin et al., 2000).

3. Results

The statistical analysis of the cumulative soil CO_2 emissions and soil CO_2 emission rates data show that there was no significant interaction between crop rotation and N rate; therefore, the soil CO_2 emission results will be presented by focusing on the main effects of crop rotation and N rate.

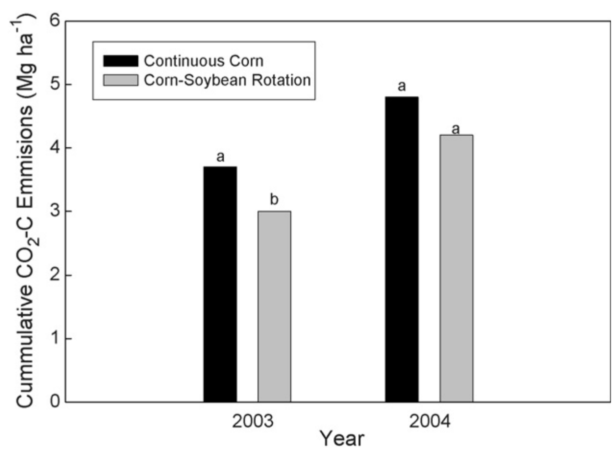

Fig. 2 – Cumulative soil CO_2 emissions from continuous corn and a corn soybean rotation in 2003 and 2004. Different letters above bars, within each year, indicate differences at $P < 0.10$.

3.1. *Effects of crop rotation on soil CO_2 emission*

In 2003, cumulative CO_2 emissions were 18% greater from the soil of the continuous corn compared to the soil in a corn–soybean rotation (Fig. 2). The only day of year that a difference was observed in soil CO_2 emission rate was on DOY 237, where soil of the continuous corn plots had a 24% greater CO_2 emission rate compared to the corn–soybean rotation (Fig. 3c). Changes in soil CO_2 emission rate during that time appear to follow changes in soil moisture content in both cropping systems (Fig. 1 and Fig. 3a). However, a decline in CO_2 emission appears to be affected by the decline in soil moisture content in both crop systems. In 2004, the comparison of cumulative CO_2 emissions from soil of the two crop systems was not statically significant. However, there were 3 days in which significant differences in soil CO_2 emission rate were observed. The continuous corn plots had 14% greater soil CO_2 emissions than the corn–soybean rotation plots on DOY 163 and 240 (Fig. 4a). The greatest difference in soil CO_2 emission rate occurred on DOY 210 when soil CO_2 emissions from the continuous corn plots were 26% greater than the corn–soybean rotation plots. The changes in soil CO_2 emission rates during the growing season follow the changes of both soil moisture content and soil temperature, where increases in both moisture content and soil temperature led to increase in soil CO_2 emission and vise versa (Figs. 1, 3 and 4).

3.2. *Effect of N rate on soil CO_2 emissions*

In 2003, the cumulative soil CO_2 emissions from the 270 kg N ha^{-1} N rate plots was 18% less than that of the 0 N and 135 kg N ha^{-1} N rate plots across both crop rotations (Fig. 5). Similarly, the soil CO_2 emission rates were also decreased with the 270 kg N ha^{-1} N rate treatment on several days in 2003 (Fig. 6c). The greatest differences were observed

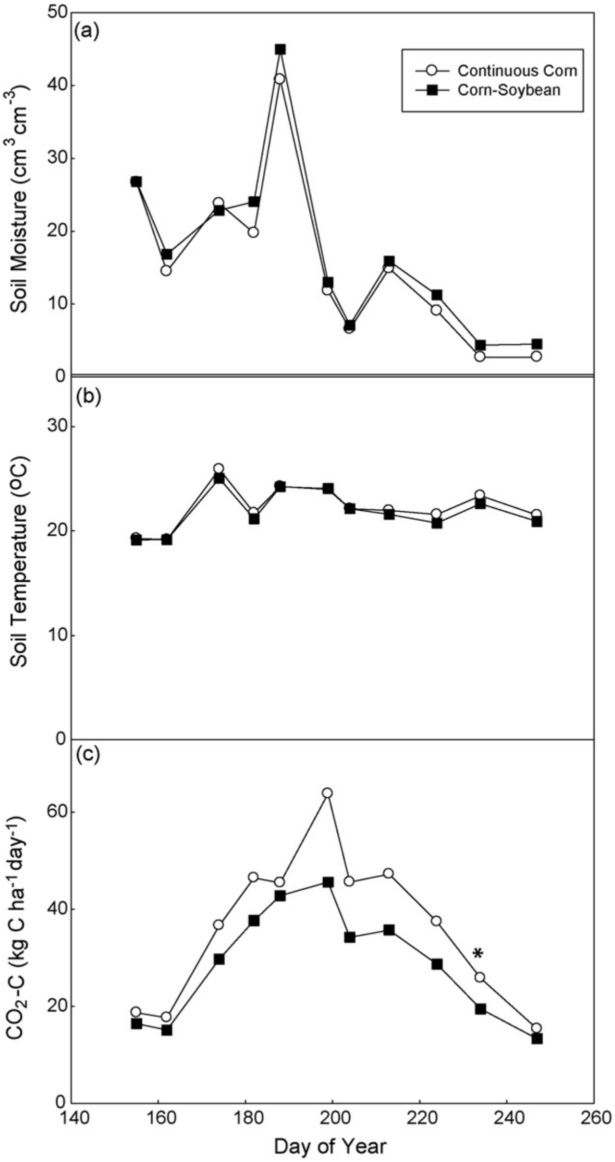

Fig. 3 – (a) Soil water content, (b) soil temperature, and (c) soil CO_2 emissions rate measured in 2003 in continuous corn and a corn–soybean rotation plots. (*) Indicates significant differences at $P < 0.10$.

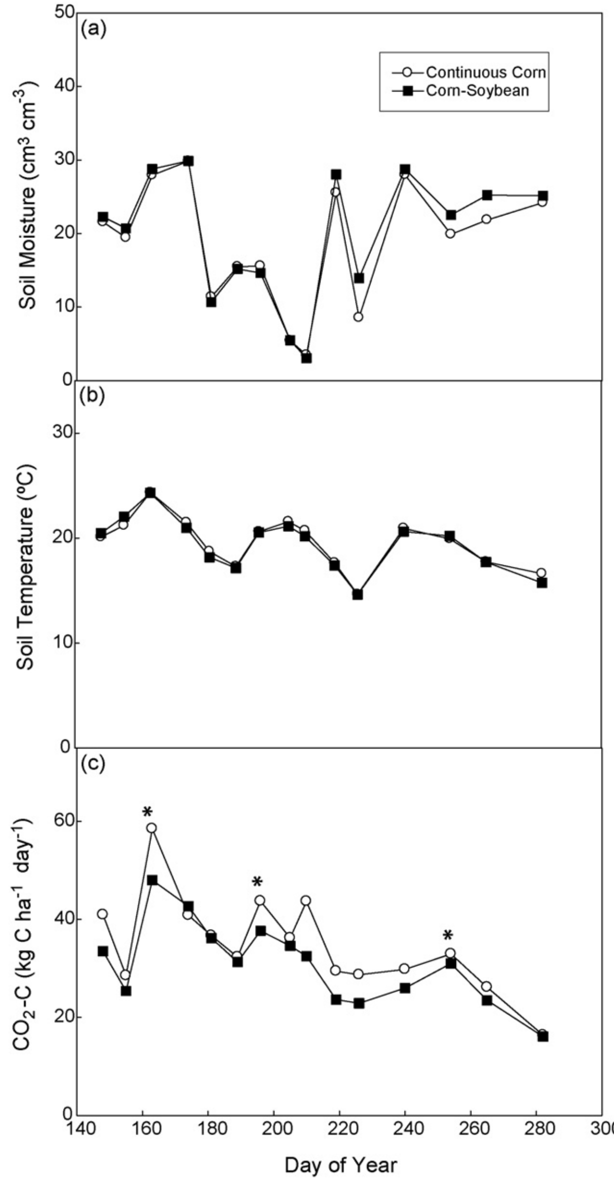

Fig. 4 – (a) Soil water content, (b) soil temperature, and (c) soil CO_2 emissions measured in 2004 in continuous corn and a corn–soybean rotation plots. (*) Indicates significant differences at $P < 0.10$.

during the middle of the growing season between DOY 180 and 220. During this period, the soil fertilized with 270 kg N ha^{-1} emitted, on average, 23% less CO_2 than the soil fertilized with the other two N rates. However, in 2004, cumulative soil CO_2 emissions were not affected by N rate, but there were a few days during the growing season on which the soil CO_2 emission rates were significantly different and the 270 kg N ha^{-1} rate caused the lowest soil CO_2 emission rate (Fig. 7c). These differences follow the same trend that was observed in 2003. Most of the differences occur between DOY 180 and 220, and again, the 270 kg N ha^{-1} N rate caused a reduction in soil CO_2 emissions. The greatest difference in 2004 occurred on DOY 205 when the plots that received 0 N fertilizer emitted 31% more soil CO_2 than plots fertilized with 270 kg N ha^{-1}. Soil CO_2 emission rate during the 2004 growing season, within all N rate treatments, was affected by both soil moisture content and soil temperature, where a decline in soil moisture content below 30 cm^3 cm^{-3} and 20 °C soil temperature led to decline in soil CO_2 emission rate (Fig. 7a–c).

4. Discussion

Crop rotation effect on soil CO_2 emission was more pronounced in the 2003 growing season where soil in continuous corn emitted significantly greater CO_2 than the soil in a corn–soybean rotation. However, there were no statistical differences in cumulative CO_2 emissions in 2004 due to crop rotation or N rate. The general effect of crop rotation

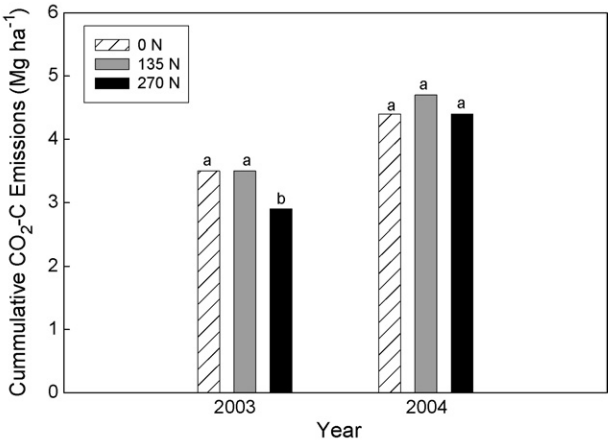

Fig. 5 – Cumulative soil CO_2 emissions across continuous corn and corn–soybean rotation with three different N rates in 2003 and 2004. Different letters above bars, within each year, indicate significant differences at $P < 0.10$.

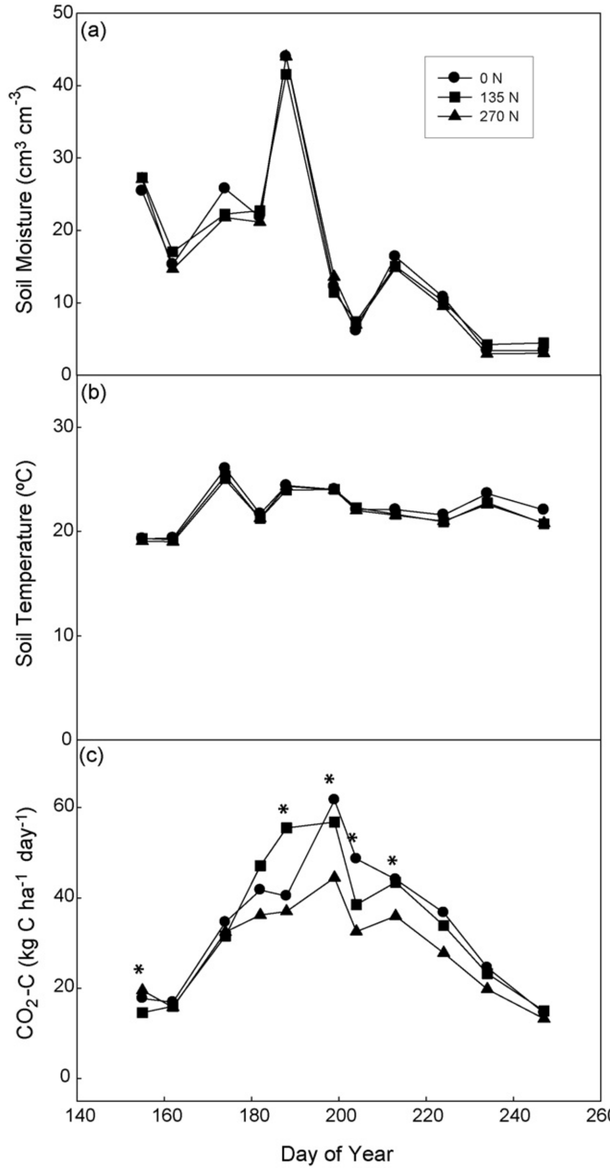

Fig. 6 – (a) Soil water content, (b) soil temperature, and (c) soil CO_2 emissions rate measured in 2003 across continuous corn and corn–soybean rotation with three different N rates. (*) Indicates significant differences at $P < 0.10$.

was that the plots in continuous corn had greater soil CO_2 emissions than the corn–soybean rotation. The difference in soil CO_2 emission that was observed in the continuous corn cropping system can be attributed to greater crop residue incorporation over a 2-year period compared to the corn–soybean rotation (Table 1). There was no difference in SOC at top 15 cm between the continuous corn cropping system and the corn soybean rotation (Table 2). Therefore, the greater soil CO_2 emissions with continuous corn can be attributed to greater residue as a source of CO_2 during the growing season. Other parameters that could influence soil respiration were measured including microbial biomass, pH, soil NO_3 (data not presented), but there were no significant effect on these parameters by the two crop rotations. The greater residue biomass produced by the continuous corn plots than that with the corn–soybean rotation plots over the 2 years of our study supports our hypothesis that the increased soil CO_2 emissions from continuous corn is due to increased residue.

Soil CO_2 emissions are often positively correlated with plant biomass production. Raich and Tufeckcioglu (2000) conducted an extensive literature review and found soil CO_2 emissions were positively correlated to litterfall in forests ($r^2 = 0.90$) and annual net primary production in grasslands ($r^2 = 0.80$). An experimental study conducted in Central Iowa also found that soil CO_2 emissions were greater from Switchgrass (*Panicum virgatum)* than a corn–soybean rotation, where Switchgrass had almost double the crop residue input to the soil (Al-Kaisi and Grote, 2007).

The high N rate of 270 kg N ha^{-1} depressed cumulative CO_2 emissions in 2003 compared to the other two N rates. This effect was observed on several days over the course of our 2-year study, where soil CO_2 emission rate was decreased with the increase of N application rate. It has been observed that increased N can cause a depression in soil CO_2 emissions not only in agricultural soils (Kowalenko et al., 1978; Fogg, 1988), but also in forest soils (Micks et al., 2004; Bowden et al., 2004; Burton et al., 2004). According to these studies, soil CO_2 emissions are reduced by between 15 and 41% due to N additions. These studies do not cite one specific mechanism for this depression in CO_2 emissions due to N fertilization, so it is relatively unclear as to why this happens. Fogg (1988) suggested that the ligninase enzyme, which is used to initiate lignin decomposition, is inhibited by increasing soil N concentrations. Fungal populations, which decompose lignin, and the activity of many other soil enzymes have been found to be decreased by N additions (DeForest et al., 2004). This hypothesis is supported by work conducted by Burton et al. (2004) when they found that N fertilized plots averaged 15% less soil CO_2 emissions than unfertilized plots. Similar to Fogg (1988) and DeForest et al. (2004), Burton et al. (2004) suggest that there is some decrease in extracellular enzyme activity

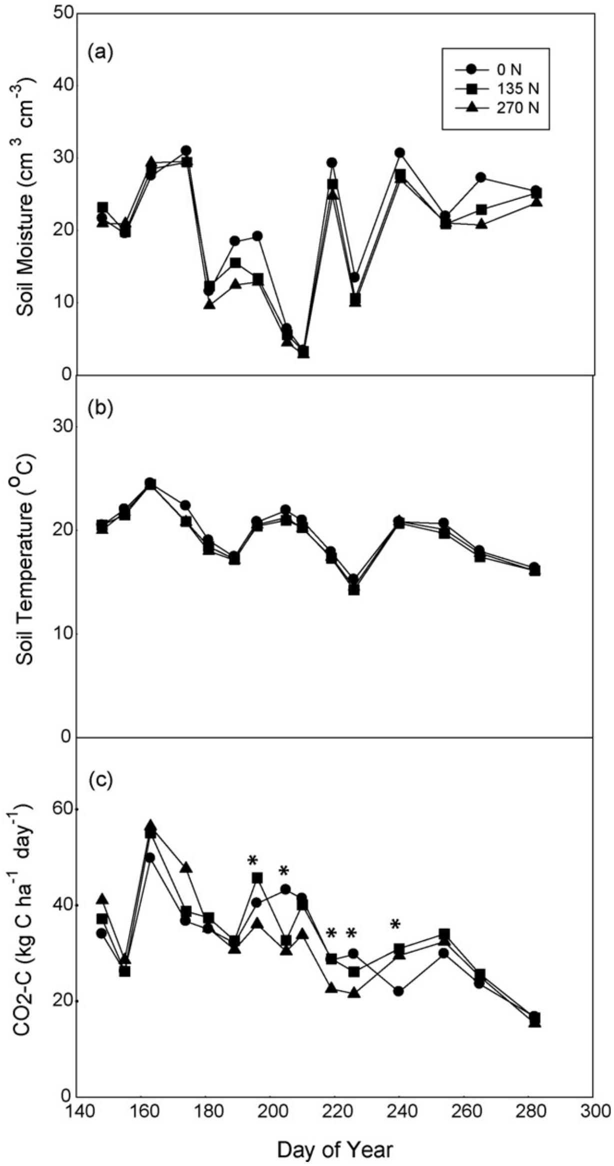

Fig. 7 – (a) Soil water content, (b) soil temperature, and (c) soil CO_2 emissions rate measured in 2004 across continuous corn and corn–soybean rotation with three different N rates. (*) Indicates significant differences at $P < 0.10$.

due to increased N application. Reduced root activity, decreased rhizodeposition, and forest mortality were factors that were used to describe the 41% decrease in soil CO_2 emissions observed by Bowden et al. (2004).

It was reported that soil microbial activity may increase due to N fertilization as a result of increased plant biomass production, which upon incorporation stimulates soil biological activity (Dick, 1992). However, the lack of a significant effect of N application on increasing CO_2 emission during the growing season with both rotations coincided with the limited effect N fertilization had on soil C change over 3 years in this study. The 270 kg N ha^{-1} plots consistently receive more residue biomass than the 0 N plots because corn responds quite well to N fertilization (Table 1). It is reasonable to expect that high input of residue amount associated with high N fertilization (270 kg N ha^{-1}) would lead to greater potential C input in soil. However, an increase in SOC was not observed in this study with the 270 kg N ha^{-1} plots and each N application treatment resulted in similar SOC contents (Table 2). This suggests that at some time prior to field measurement of soil CO_2 emission, a significant amount of C was lost as CO_2 during the residue decomposition process that was stimulated by the addition of the N fertilizer.

Table 1 – Crop residue produced by treatments in years preceding CO_2 emission measurements

	Year (Mg ha^{-1})		Total
	2002	2003	
Crop rotation			
CC	6.7 a[a]	6.2 a	12.9 a
CS	1.8 b	6.2 a	8.0 b
N Rate (kg N ha^{-1})			
0	3.4 a	5.0 a	8.4 a
135	4.3 b	6.8 b	11.1 b
270	4.7 b	7.0 b	11.7 b

[a] All residue inputs were estimated using a harvest index similar to that used in Al-Kaisi and Yin (2005).

Table 2 – Soil organic carbon measured at the 0–15 cm soil depth in April 2004

	SOC (Mg ha^{-1})
Crop rotation	
CC	37.6 a
CS	39.4 a
N Rate (kg N ha^{-1})	
0	37.2 a
135	39.2 a
270	38.8 a

5. Conclusions

The findings from this study are consistent with those from previous studies conducted in other types of ecosystems. It was found that soil CO_2 emissions were greater in continuous corn than from plots in a corn–soybean rotation. Soil CO_2 emission rate at peak time during the growing season and cumulative CO_2 under continuous corn increased by 24 and 18%, respectively compared to that from corn–soybean rotation. This difference was attributed to the fact that the continuous corn plots received a greater amount of crop residue than the plots in a corn–soybean rotation. The highest rate of N application decreased soil CO_2 emissions in 2003 compared to the two lower N rates. During this period, the soil fertilized with 270 kg N ha^{-1} emitted, on average, 23% less CO_2 than the soil fertilized with the other two N rates. The greatest difference in soil CO_2 emission rate was observed in 2004; where plots that received 0 N fertilizer had 31% greater CO_2 emission rate than plots fertilized with 270 kg N ha^{-1}. The findings of this research indicate that changes in cropping systems can have immediate impacts on both the rate of and cumulative soil CO_2 emissions, where continuous corn caused greater soil CO_2 emissions than corn soybean rotation.

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