Agricultural Production Practices Effect on Soil Carbon Dynamics and Carbon Dioxide Emission.

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INTRODUCTION

Conservation tillage systems such as no-tillage, strip-tillage, and chisel plow are increasingly used for crop production in the Midwest during the past decade due to their profitability and environmental advantages over moldboard plow. For example, no-tillage systems were used in over 22% of all cropland area in the Midwest in 2002 (Conservation Technology Information Center, 2003), which almost doubled the amount in 1992. In contrast, conventional tillage accounted to 35% of all croplands in the Midwest. Deep rip has been used as an effective tool to overcome soil compaction. Although deep rip is not a conservation tillage system, it still results in less soil disturbance and mixing and thus greater crop residue coverage left on the soil surface than moldboard plow. There are few studies that quantify the effects of these main tillage alternatives with different intensities on soil CO_2 emission and C storage compared with more intensive tillage systems (i.e., moldboard plow) in the Midwest where a corn soybean rotation has been the primary cropping system for decades. Even though moldboard plow use has been limited recently in the Midwest region, the inclusion of it in this study is to show the most extreme intensive tillage effect on soil C dynamics as we evaluate a suite of tillage systems differing in their intensities of soil disturbance at different depths.

OBJECTIVE

The objectives of this study are to evaluate: 1) the short-term response of soil organic C pools to different tillage systems, 2) immediate and short-term effects of a suite of tillage systems with different intensities of soil disturbance on soil CO_2 emission, and 3) the influences of tillage systems on soil mineralizable C pools.

MATERIALS AND METHODS

Site Description

- This study was conducted in 1998 through 2001 on a Clarion-Nicolet-Webster soil association at the Iowa State University Agronomy Research Farm, Ames, IA. The surface horizon (0-15 cm) of this site had 29.0 kg m^{-3} of soil organic C. The crop rotation was a corn-soybean rotation with chisel plow for the past decade.

Experimental Design and Implementation

- The study was designed as a randomized complete block design with three replicates. It included no-tillage, strip-tillage, deep rip, chisel plow, and moldboard plow treatments (Table 1), and was established in a corn-soybean rotation in the fall of 1997.

Soil and Crop Residue Sampling and Analysis

- Soil sampling for total soil organic C (TC), mineral fraction C (MFC), and particulate organic matter C (POMC) was conducted at depths of 0 to 5, 5 to 10, and 10 to 15 cm for each plot in fall 2000 after corn harvest. A crop residue sample was collected from each plot after corn harvest in fall 2001 before any tillage operations were performed.
- Soil organic C, MFC, and POMC concentrations and C concentrations in crop residue were determined by dry combustion with a LECO CHN 2000 analyzer (LECO, St. Joseph, MI).
- Total C input from crop residue was estimated for 1998 to 2000 as the quotient of grain yields by harvest index, then multiplied by C concentrations in crop residue. The harvest index used in this computation was 0.59 for corn and 0.57 for soybean (Licht, 2003).

Soil CO_2 Emission Measurements

- The soil CO_2 emission was measured for the following times after tillage operations: 0, 2, 4, 8, 12, 24, 48, 96, 192, 288, and 480 hr in the fall of 2001 with a LI-6400 CO_2 analyzer (LI-COR, Lincoln, NE). Simultaneously, soil moisture and temperature were measured in the top 5 cm.

Soil Mineralizable C Determination

- To calculate the amount of soil mineralizable C (i.e. the maximum cumulative soil CO_2 emission) for different tillage systems, the Lineweaver-Burk transformation (Tabatabai, 1994) of the Michaelis-Menton equation was used: $1/c = 1/C_{max} + K_m/C_{max} \times 1/T$, where C (kg CO_2 ha^{-1}) is cumulative soil CO_2 emission at a specific time after tillage operations, T is the time (hr) after tillage operations, C_{max} (kg CO_2 ha^{-1}) is the potential maximum amount of cumulative soil CO_2 emission under a specific tillage system, and K_m is the Michaelis constant, which equals to the time (hr) at half-maximum cumulative soil CO_2 emission.

Statistical Analysis

- Analysis of variance for TC, MFC, or POMC was conducted using the mixed procedure with repeated measures by treating soil depth as a nonrandomized factor. Annual C input from crop residue was analyzed with the mixed procedure. Soil CO_2 emission at each measuring time was analyzed with the ANOVA procedure.
- Mean separations were achieved by using the adjusted Tukey's least significant difference (LSD) for TC, MFC, POMC, and annual C input from crop residue. A protected LSD was used to separate treatment means for soil CO_2 emission.
- Regression analyses were performed between cumulative soil CO_2 emission and TC, MFC, POMC, or the time following tillage practices over the entire 20-day measurement period.
- Regression analysis was conducted between the inverse of cumulative soil CO_2 emission and the inverse of time after tillage operations for each treatment for the entire 20-day period according to the Lineweaver-Burk transformation of the Michaelis-Menton equation.

Table 1. Tillage system, tillage depth, and width of disturbed soil zone due to tillage operations.

Tillage system	Shank or disk spacing	Tillage depth	Disturbed zone
	cm		
Strip-tillage	76	20	20
Deep rip	76	40-46	30-40
Chisel plow	30	22-25	20
Moldboard plow	76	25	46

Table 3. Tillage effects on C input from aboveground corn and soybean residue during the first 3 yr in a corn–soybean rotation.

Tillage system	C input†		
	Corn	Soybean	Total
	Mg ha^{-1}		
No-tillage	5.47a‡	2.76a	8.23ab
Strip-tillage	5.02a	2.44a	7.46b
Deep rip	5.86a	2.84a	8.70a
Chisel plow	5.65a	2.64a	8.29a
Moldboard plow	5.86a	2.90a	8.76a

† Carbon input under columns of corn, soybean, and total refers to C input from one-yr corn, two-yr soybean, and all three years, respectively.
‡ Values in column followed by the same letter are not significantly different at P < 0.05.

Table 5. Maximum mineralizable soil C under different tillage systems estimated with the Lineweaver-Burk transformation of the Michaelis-Menten equation.

Tillage system	C_{max} (kg ha^{-1})
No-tillage with residue	435
No-tillage without residue	775
Strip-tillage	629
Deep rip	935
Chisel plow	1010
Moldboard plow	1294

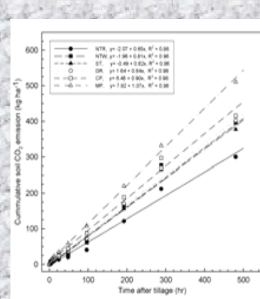

Fig. 2. Tillage and crop residue effects on cumulative soil CO_2 emission after 3 yr in a corn-soybean rotation. NTR, no-tillage with residue; NTW, no-tillage without residue; ST, strip-tillage; DR, deep rip; CP, chisel plow; MP, moldboard plow.

Table 2. Tillage effects on soil organic C in the soil profile after 3-yr management in a corn-soybean rotation.

Tillage system	TC†				MFC				POMC			
	Soil depth (cm)				Soil depth (cm)				Soil depth (cm)			
	0-5	5-10	10-15	0-15	0-5	5-10	10-15	0-15	0-5	5-10	10-15	0-15
	Mg ha^{-1}											
No-tillage	17.05a‡	16.93a	18.60a	52.57a	12.04a	13.29a	14.72a	40.04a	5.01a	3.64a	3.88a	12.53a
Strip-tillage	16.89a	17.56a	18.54a	52.98a	12.24a	13.70a	14.89a	40.83a	4.66a	3.86a	3.65a	12.16a
Deep rip	12.26b	13.00b	19.40a	44.67ab	8.68b	10.21b	13.72ab	32.60b	3.58a	2.79a	5.69a	12.06a
Chisel plow	12.88b	12.47b	18.29a	43.64ab	8.94b	10.66b	14.72a	34.33ab	3.94a	1.81a	3.56a	9.31a
Moldboard plow	11.37b	14.23ab	14.31b	39.90b	8.64b	11.90ab	11.96b	32.50b	2.72a	2.33a	2.35a	7.40a

† TC, total soil organic C; MFC, mineral fraction C; POMC, particulate organic matter C.
‡ Values in column followed by the same letter are not significantly different at P < 0.05.

Table 4. Tillage and crop residue effects on soil CO_2 emission after 3 yr in a corn-soybean rotation.

Tillage system	Time period after tillage operations										
	0-2 hr	2-4 hr	4-8 hr	8-12 hr	12-24 hr	1-2 d	2-4 d	4-8 d	8-12 d	12-20 d	Total
	kg ha^{-1}										
No-tillage with residue	2.31e†	1.61c	3.40c	2.89d	3.00d	6.89d	20.62c	80.60a	90.86a	88.19c	300.36c
No-tillage without residue	2.09e	1.74bc	4.56b	3.49bc	3.73d	11.79bcd	36.63ab	101.12a	112.27a	118.94bc	396.36b
Strip-tillage	3.46d	1.97bc	4.16bc	3.28bcd	4.32cd	11.35cd	31.96bc	96.45a	108.89a	111.73bc	377.57bc
Deep rip	4.37c	2.46ab	4.08bc	2.99cd	6.68bc	15.73bc	36.50ab	98.28a	98.47a	132.66b	402.20b
Chisel plow	6.68b	2.82a	4.87b	3.70b	7.44b	18.63ab	43.06ab	101.51a	108.54a	118.61bc	415.83b
Moldboard plow	7.87a	3.20a	5.96a	5.66a	12.41a	23.43a	50.09a	111.94a	111.36a	179.43a	511.34a

† Values in column followed by the same letter are not significantly different at P < 0.05.

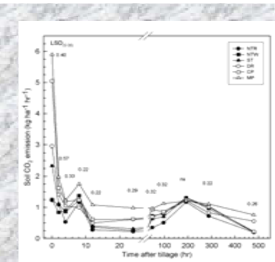

Fig.1. Tillage and crop residue effects on soil CO_2 emission after 3 yr in a corn-soybean rotation. Least significant difference (LSD) at P < 0.05 for each measuring time is provided in the graph; NS, not significant at P <0.05. NTR, no-tillage with residue; NTW, no-tillage without residue; ST, strip-tillage; DR, deep rip; CP, chisel plow; MP, moldboard plow.

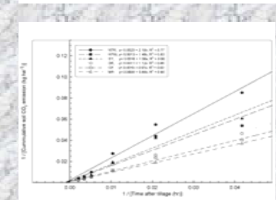

Fig. 3. Linear plot of the Michaelis-Menten equation for cumulative soil CO_2 emission. NTR, no-tillage with residue; NTW, no-tillage without residue; ST, strip-tillage; DR, deep rip; CP, chisel plow; MP, moldboard plow.

RESULTS AND DISCUSSION

Tillage Effects on Soil Organic C

- Total soil organic C in no-tillage and strip-tillage treatments was 32%, and 36% to 41% greater at the 0- to 5- and 5- to 10-cm soil depths, respectively, compared with chisel plow (Table 2). Mineral fraction C with no-tillage and strip-tillage was increased by 35 to 42% and 25 to 29% in 0 to 5 and 5 to 10 cm, respectively, relative to chisel plow.
- Total C input from crop residue was 10% lower with strip-tillage than chisel plow over the 3-yr period (Table 3). All other tillage systems had similar C input as chisel plow. Therefore, C input from crop residue did not contribute to the increase in TC or MFC with no-tillage and strip-tillage in such a short period.

Tillage and Crop Residue Effects on Soil CO_2 Emission

- No-tillage with and without residue, strip-tillage, deep rip, and chisel plow treatments reduced CO_2 emission rate by 79, 79, 60, 50, and 14% respectively, compared with moldboard plow immediately after tillage operation (0th hr) (Fig. 1).
- Two hours after tillage operation, CO_2 emission rate under no-tillage with and without residue and strip-tillage was 43 to 58% less than moldboard plow (Fig. 1), while chisel plow and deep rip had statistically similar CO_2 emission as moldboard plow.
- Beyond 2 hr following tillage operations, tillage alternatives frequently had lower CO_2 emission than moldboard plow (Fig. 1).
- The maximum CO_2 emission rate from all tilled treatments was observed immediately after tillage operations (i.e. at the 0th-hr time) (Fig. 1), then it declined sharply by 52 to 68% within the first 2 hr following tillage operations. While CO_2 emission from no-tillage with and with out residue covers declined by only 12 to 33% during the same period. After the first 2 hr, changes in CO_2 emission rate were much smaller regardless of tillage treatment.
- Cumulative CO_2 emission for the entire 20-day period was 41, 26, 21, and 19% lower under no-tillage with residue, strip-tillage, deep rip, and chisel plow than moldboard plow, respectively (Table 4).
- Cumulative CO_2 emission under no-tillage without residue was 24% greater than that from no-tillage with residue.

Regression of Cumulative Soil CO_2 Emission with Soil Organic C Pools and Time

- No significant linear or quadratic relationship between cumulative soil CO_2 emission and TC, MFC, or POMC was observed over the 20-day measurement period regardless of treatment (data not presented). This finding indicates that soil organic C substrate is not the limiting factor to soil CO_2 emission in this study.
- Cumulative soil CO_2 emission and time after tillage operations was linearly related regardless of treatment (Fig. 2). Slope of the equation decreased as tillage intensity is reduced.

Soil Mineralizable C under Different Tillage Systems

- There was a linear relationship between the inverse of cumulative soil CO_2 emission and the inverse of time after tillage operations regardless of tillage system (Fig. 3). Inverse of the intercept of each linear relationship represents the size of potentially mineralizable C pool (C_{max}) due to the effect of each tillage system.
- The C_{max} value was lower with less intensive tillage systems compared with moldboard plow (Table 5). No-tillage with and without residue, strip-tillage, deep rip, and chisel plow reduced the size of mineralizable portion of the maximum C pool (C_{max}) by 66, 40, 51, 28, and 22% relative to moldboard plow, respectively.

CONCLUSIONS

- Reducing tillage intensity increases soil C storage in a corn-soybean rotation during 3 yr. This short-term tillage effect is not attributed to the C input from crop residue, but likely is related to decreased mineralization of soil organic matter, especially under no-tillage.
- Soil CO_2 emission is lower with conservation tillage or other alternatives relative to moldboard plow. The greatest differences in CO_2 emissions occurred immediately following tillage operations.
- Conservation and other tillage alternatives lowered cumulative soil CO_2 emission by 19 to 41% compared with moldboard plow. Carbon dioxide emission is 24% less in no-tillage with residue than without residue.
- Relationship between soil CO_2 emission and soil C (i.e., TC, MFC, or POMC) content is not observed over the short period of measurement. However, positive linear relationship between cumulative CO_2 emission and time is observed.
- Soil mineralizable C pool is reduced by 22 to 66% with no-tillage and less intensive tillage alternatives relative to moldboard plow.
- From a short-term perspective, adopting less intensive tillage alternatives, such as no-tillage and strip-tillage, and leaving more crop residue cover on the soil surface are effective in reducing soil CO_2 emission, thus improving soil C sequestration in a corn-soybean rotation in Corn-Belt soils.

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