Soil Carbon Dioxide Flux in Conventional and Organic Cropping Systems: Comparison of Measurement Methods and Relationship with Soil Moisture

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INTRODUCTION

Soil CO_2 flux in organic cropping systems, which often rely on significant tillage for weed control and on carbon (C) additions such as animal and plant manures as sources of plant nutrients, have not been well studied. Some evidence suggests that organic systems may have lower global warming potential (GWP) and higher soil C sequestration than conventional till systems but that no till systems have the lowest GWP (Robertson et al., 2000; Drinkwater et al., 1998). Further study of organic systems, whose popularity is increasing is warranted.

Accurate measurement of soil carbon dioxide (CO_2) flux is necessary to evaluate the effects of cropping systems on global warming potential and to provide accurate estimates of carbon (C) budgets. No single measurement technique has currently been accepted as a standard. Static and dynamic chamber-based methods using infrared gas analysis (IRGA) are commonly used but chamber-based systems can bias measurements by altering soil gas concentration gradients and creating pressure differentials between the chamber and outside air (Davidson et al. 2002).

OBJECTIVES

The objectives of this study were to compare the effect of conventional versus organic agricultural cropping systems on soil CO_2 flux, to compare static versus dynamic soil CO_2 flux measurements under field conditions, and to explore the relationship between soil CO_2 flux and soil moisture.

MATERIALS AND METHODS

Site. USDA-ARS Beltsville Farming Systems Project, a long-term study established in 1996. Soils are Ultisols.

Cropping Systems.

1. No till corn-soybean-wheat/soybean (C-S-W/S) rotation using synthetic fertilizers and herbicides.
2. Chisel till C-S-W/S rotation using synthetic fertilizers and herbicides.
3. Organic C-S-W rotation using moldboard plowing, legume cover crop, broiler litter and cultural weed management.

→ All rotations in corn in 2004, the year measurements were made.

Table 1. CO_2 flux and other measurements

	Method	
	Dynamic	Static
Cropping systems sampled	No till, Organic	No till, Organic, Chisel till
Sampling frequency	~weekly	~weekly
PVC collar no., size	12, 10 cm (d), 4.5 cm (h)	4, 30 cm (d), 5 cm (h)
Instruments	PP Systems EGM (IRGA)	Samples taken manually at 0, 4, 8, 12 mins; samples analyzed by IRGA or TCD
Flux measurement	By EGM unit	Linear regression of CO_2 concentration vs. time
Soil moisture (adjacent to each ring)	TDR, 6 cm waveguide	TDR, 5 and 12 cm waveguides
Soil temperature	15 cm	2, 5, 9 cm

Soil bulk density, used to calculate soil porosity and to calibrate TDR probes was determined by the core method. Soil dissolved organic carbon (DOC) was extracted with deionized water after sampling on 8/6/2004. Concentrations were determined by IRGA following oxidation by persulfate and ultraviolet light.

Statistics.

Repeated measures ANCOVA was used to determine the effect of agricultural management on CO_2 flux using dynamic method flux data and SAS Proc Mixed. Linear and quadratic effects of VWC were included as covariates to account for and examine the influence of soil moisture. Flux data were standardized to 25ºC by dividing the flux by $Q_{10}=3^{[(temperature-25)/10]}$ to account for the effects of temperature (Sikora and Rawls, 2000). Differences in soil porosity and DOC due to treatment were analyzed using SAS Proc Mixed.

RESULTS

Figure 1. Soil CO_2 flux by a static measurement method for three agricultural management systems over time

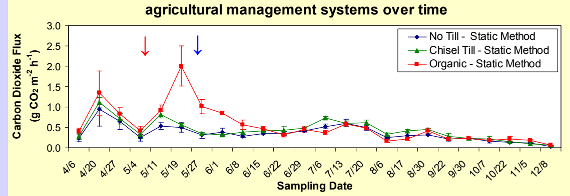


Figure 2. Comparison of soil CO_2 flux by dynamic and static measurement methods over time

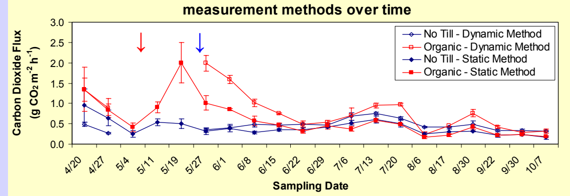
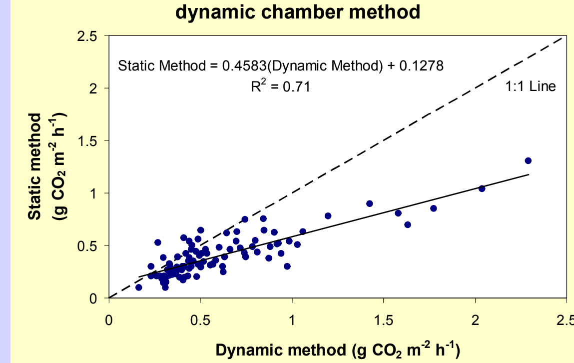


Table 2. Cumulative CO_2 flux by static and dynamic methods (g CO_2 m^{-1} h^{-1})

	Static Method		Dynamic Method
Cropping System	April to December	April to October	April to October
Organic	12.88 [a]	8.71	13.31
No Till	8.62 [b]	6.82	7.68
Chisel Till	10.38 [ab]		

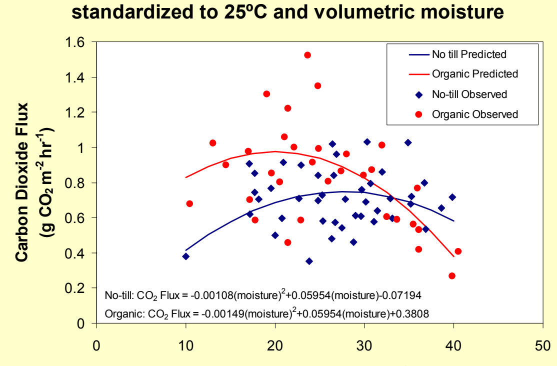
- CO_2 flux was greater in the Organic system than in the Chisel and No Till systems in spring, especially following moldboard plow incorporation of hairy vetch (5 May (↓)) and disk incorporation of poultry litter (May 25 (↓)). Rotary hoeing (2 and 9 June) and cultivation (21 and 28 June) in the Organic system did not appear to have an effect on CO_2 flux.
- Excluding results from those dates that were strongly affected by incorporation of vetch and/or manure, CO_2 flux measured by static and dynamic methods responded exponentially to increases in soil temperature in all three systems (data not shown).
- Patterns of CO_2 flux over time were similar whether measured using static or dynamic methods.
- CO_2 flux measurements were generally higher when using dynamic rather than static method.
- Cumulative mean flux using the dynamic method was 35% and 11% greater than using the static method for the Organic and No Till systems, respectively (for the period April to October 2004) (Table 2).

Figure 3. Relationship between soil CO_2 flux measured using a static chamber method and a dynamic chamber method



- There was a linear relationship between the values by the static and dynamic methods. Flux values determined by the static method were, on average, approximately one half the values of dynamic method flux.
- Some of the variability around the regression line may be due to spatial variability, since flux measurements using the two methods were not made at exactly the same locations.

Figure 4. Relationship between soil CO_2 flux standardized to 25ºC and volumetric moisture



- Quadratic relationships between soil CO_2 flux and soil moisture were different in Organic and No till systems, with CO_2 flux maximums at different VWC for each system.
- Maximum CO_2 flux occurred at:
  - 20.0% VWC in the Organic system soils (~38.4% Water Filled Pore Space (WFPS)),
  - 27.6% VWC in the No Till system soils (~52.5% WFPS).
- Flux was:
  - Greater in Organic system than in No Till system below 29.1% VWC (P<0.05),
  - Greater in No Till system than in Organic system above 39.8% VWC (P<0.05),
  - Not different between systems between 29.2% and 39.7% VWC (P<0.05).

- Organic system soils had greater dissolved organic carbon (DOC) than did the No Till soils.
- No Till system soils had greater porosity than did Organic system soils, allowing for greater gas movement within No Till soils and between the soil and atmosphere.

Table 3. Dissolved organic carbon and porosity for the No till and Organic Systems

System	Dissolved Organic Carbon (mg kg^{-1})	Porosity (cm^3 cm^{-3})
No Till	41.0 ± 3.43 [b]	0.48 ± 0.0039 [c]
Organic	62.2 ± 6.23 [a]	0.42 ± 0.0085 [d]

Means in the same column with the same letter (a,b) are not significantly different (0.05).
Means in the same column with the same letter (c,d) are not significantly different (0.001).

DISCUSSION

Cropping System Comparisons

- Cumulative CO_2 flux was greater in the Organic system than in the No Till system, largely due to a large and prolonged CO_2 spike following incorporation of vetch cover crop on 5 May (~1200 kg ha^{-1}) and poultry litter on 25 May (~1200 kg ha^{-1}) in the Organic system (Figure 1 and Table 2).
- The effect on C balance and GWP of higher CO_2 flux in the Organic system than in the No Till system has to be evaluated by taking into consideration differences in C, fertilizer and lime inputs between systems.

Methods Comparison

- Increasing CO_2 concentrations within the static chamber, even during the relatively short 12-minute lid deployment time, might have decreased the CO_2 concentration gradient between the soil and the chamber headspace, resulting in an underestimation of CO_2 flux (Nay et al. 1994, Davidson et al. 2002, Pumpanen et al. 2004).
- In contrast, PP Systems-based dynamic chamber methods may overestimate flux due to the effect of the chamber fan. Le Dantec et al. (1999) proposed that the high fan speed (0.9 m s^{-1}) creates turbulence that disrupts the laminar boundary layer over the soil, increasing the concentration gradient and the measured flux rate.
- Actual CO_2 fluxes in these cropping systems are likely somewhere between the values measured by the two systems we used

Relationship with Soil Moisture

- Differences in the relationship between soil moisture and CO_2 flux for the Organic and No Till system soils (Figure 4) are likely due to at least two factors: soil DOC and porosity (Table 3). At low soil moisture levels water availability limits soil microbial respiration. At high soil moisture levels water fills the majority of soil pores reducing soil aeration. As soil moisture concentrations rise, soil microbial respiration increases to a point at which oxygen availability begins to limit aerobic microbial activity (Linn and Doran 1984). Maximum soil microbial respiration occurs at the point where the interaction of soil moisture content and oxygen availability are least limiting.
  - The Organic system soils have greater DOC than the No Till system soils likely due to the additional C inputs in the Organic system (cover crop and poultry litter) and due to tillage, which can expose physically protected DOC to the activities of soil microorganisms. This higher DOC likely contributed to greater CO_2 flux at soil moisture below 29.1% VWC in the Organic system (Figure 4).
  - Lower porosity in the Organic system soils was probably a result of tillage and likely contributed to the maximum soil CO_2 flux occurring at a lower soil moisture content than in the No Till system soils. Oxygen diffusion into soil and CO_2 efflux decrease with decreasing porosity, especially as the relative proportion of soil macropores decreases. Although we did not measure macroporosity directly, it is likely that macroporosity is reduced in the Organic system soils compared to the No Till system soils in response to tillage.
  - It is possible that the combination of higher DOC and lower porosity in the Organic system soils contributed to the relatively sharp decrease in soil CO_2 flux at high soil moisture levels.

CONCLUSIONS

Cumulative CO_2 flux from the Organic system soil was greater than from the No Till system soil due to the effect of greater inputs of C and tillage. Carbon dioxide flux measured by the dynamic method generally exceeded corresponding measurements by the static method. This resulted in a greater estimated cumulative flux from these cropping systems when measured using the dynamic than the static method. A linear relationship was found between static method and dynamic method flux measurements. Different quadratic relationships between VWC and CO_2 flux were found for the Organic and No Till systems. Organic system soils demonstrated a greater rate of change in response to changes in VWC. Vetch and manure incorporation into Organic system soils likely increased DOC which could have resulted in higher rates of CO_2 flux relative to the un-amended No Till system soils. Greater porosity in the No Till system soil allowed for gas exchange at higher VWC (and greater WFPS) possibly resulting in a maximum flux at greater soil moisture than in the tilled Organic management system.