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Comparison of soil carbon dioxide flux measurements by static and portable chambers in various management practices

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ABSTRACT

Portable chamber provides simple, rapid, and inexpensive measurement of soil CO_2 flux but its effectiveness and precision compared with the static chamber in various soil and management practices is little known. Soil CO_2 flux measured by a portable chamber using infrared analyzer was compared with a static chamber using gas chromatograph in various management practices from May to October 2008 in loam soil (Luvisols) in eastern Montana and in sandy loam soil (Kastanozems) in western North Dakota, USA. Management practices include combinations of tillage, cropping sequence, and N fertilization in loam and irrigation, tillage, crop rotation, and N fertilization in sandy loam. It was hypothesized that the portable chamber would measure CO_2 flux similar to that measured by the static chamber, regardless of soil types and management practices. In both soils, CO_2 flux peaked during the summer following substantial precipitation and/or irrigation (>15 mm), regardless of treatments and measurement methods. The flux varied with measurement dates more in the portable than in the static chamber. In loam, CO_2 flux was 14–87% greater in the portable than in the static chamber from July to mid-August but 15–68% greater in the static than in the portable chamber from late August to October in all management practices. In sandy loam, CO_2 flux was 10–229% greater in the portable than in the static chamber at all measurement dates in all treatments. Average CO_2 flux across treatments and measurement dates was 9% lower in loam but 84% greater in sandy loam in the portable than in the static chamber. The CO_2 fluxes in the portable and static chambers were linearly to exponentially related (R^2 = 0.68–0.70, $P \leq 0.01$, n = 40–56). Although the trends of CO_2 fluxes with treatments and measurement dates were similar in both methods, the flux varied with the methods in various soil types. Measurement of soil CO_2 flux by the portable chamber agreed more closely with the static chamber within 0–10 kg C ha^{-1} d^{-1} in loam soil under dryland than in sandy loam soil under irrigated and non-irrigated cropping systems.

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1. Introduction

Agricultural practices contribute about 25% of the total anthropogenic source of CO_2, a greenhouse gas responsible for global warming (Post et al., 1990; Duxbury, 1994). Management practices, such as crop residue input to the soil, tillage, and cropping sequence, can emit CO_2 as a result of soil organic matter and crop residue mineralization and root and microbial respiration (Curtin et al., 2000; Sainju et al., 2008, 2010). In contrast, atmospheric CO_2 absorbed by plants during photosynthesis is stored in the soil as organic matter after crop residues are returned to the soil, a process known as C sequestration (Lal et al., 1995; Paustian et al., 1995). In the terrestrial ecosystem, soils are important reservoir of C containing about 1500 Pg C, which is three times greater than that stored in the vegetation (Schlesinger, 1997). Agricultural soils contain around 170 Pg C to a depth of 1 m (Cole et al., 1996), out of which 54 Pg C has been estimated to be lost through CO_2 emissions in the last two centuries (Paustian et al., 1995). Carbon storage in the soil is determined by the balance between the amount of plant residue C added to the soil and rate of C mineralized as CO_2 emission in unmanured soil (Rasmussen et al., 1980; Peterson et al., 1998).

Soil and crop management practices, such as irrigation, tillage, cropping sequence, and N fertilization can influence soil surface CO_2 emissions (Curtin et al., 2000; Sainju et al., 2008). Irrigation can increase CO_2 emissions compared with no irrigation by increasing soil water availability (Sainju et al., 2008), microbial activity, C mineralization, and respiration (Calderon and Jackson, 2002). Decreased tillage intensity reduces soil disturbance and microbial activity, which in turn, lowers CO_2 emissions (Curtin et al., 2000). In contrast, increased tillage intensity increases CO_2 emissions by increasing aeration due to greater soil disturbance (Roberts and Chan, 1990), and by physical degassing of dissolved

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CO_2 from the soil solution (Jackson et al., 2003). Cropping can increase CO_2 emissions compared with fallow by increasing root respiration and the amount of crop residue returned to the soil (Curtin et al., 2000; Amos et al., 2005; Sainju et al., 2007, 2008). Similarly, residue quality, such as C/N ratio, can alter the decomposition rate of residue (Kuo et al., 1997), thereby influencing CO_2 emissions (Al-Kaisi and Yin, 2005). Nitrogen fertilization, however, has variable effect on CO_2 emissions (Mosier et al., 2006; Al-Kaisi et al., 2008). Management practices can also indirectly influence CO_2 emissions by altering soil temperature and water content (Parkin and Kaspar, 2003; Amos et al., 2005; Sainju et al., 2008). Coarse-textured soil can emit greater CO_2 flux than fine-textured soil (Sainju et al., 2008).

Measurement of CO_2 flux with the static chamber using gas chromatograph is a standard method where gas samples are collected over a certain intervals of time and flux is calculated as a result of concentration gradient over time (Hutchinson and Mosier, 1981; Liebig et al., 2010). The benefits of this method are (1) continuous measurement of CO_2 flux at the same place without soil disturbance for a long time, resulting in more accurate determination of the flux and (2) measurement of all greenhouse gas (CO_2, N_2O, and CH_4) fluxes in one gas sample at the same time (Hutchinson and Mosier, 1981; Liebig et al., 2010). Such measurements are, however, tedious, complex, and expensive. Other disadvantages of this method are the underestimation of CO_2 flux due to suppression of the gas concentration gradient at the soil surface following chamber deployment and the microclimate effect inside the chamber that alter the flux (Healy et al., 1996; Rochette and Bertrand, 2007; Venterea, 2010). The infrared CO_2 analyzer attached to the data logger in the portable chamber can immediately analyze CO_2 flux and therefore provides a simple, rapid, and inexpensive method of measuring the flux (Sainju et al., 2008, 2010). The disadvantages of this method are (1) measurement within a short equilibration period (2 min), resulting in potential error due to flushing in of atmospheric CO_2 inside the chamber, (2) determination of CO_2 flux only as opposed to determination of three greenhouse gases at the same time in the static chamber method, and (3) high spatial and temporal variability (Sainju et al., 2008, 2010).

Although CO_2 flux measurements have been compared using static and dynamic chamber methods (Rochette et al., 1992; Nay et al., 1994; Jensen et al., 1996), little is known about their comparison of measurements in various soil types and management practices in dryland and irrigated cropping systems. We hypothesized that CO_2 flux measured by the portable chamber method would be similar to that measured by the static chamber method, regardless of management practices and soil and climatic conditions. Our objective was to compare and relate CO_2 flux measured by the static chamber using gas chromatograph and the portable chamber using infrared analyzer in various irrigation, tillage, cropping sequence, and N fertilization practices in sandy loam and loam soils under dryland and irrigated cropping systems in U.S. northern Great Plains.

2. Materials and methods

2.1. Experimental sites and treatments

Soil CO_2 fluxes were measured in plots established in 2006 in a dryland farm site 11 km west of Sidney, eastern Montana, and in 2005 in an irrigated site in Nesson Valley, western North Dakota, USA. In Sidney, the soil was Williams loam (fine-loamy, mixed, frigid, Typic Argiborolls [International classification: Luvisols]) with 350 g kg^{-1} sand, 325 g kg^{-1} silt, 325 g kg^{-1} clay, 1.42 Mg m^{-3} bulk density, and 7.2 pH at the 0–15 cm depth. Previous cropping system for the last 6 yrs was spring wheat (*Triticum aestivum* L.)-fallow. In Nesson Valley, the soil was Lihen sandy loam (sandy, mixed, frigid, Entic Haplustolls [International classification: Kastanozems]) with 720 g kg^{-1} sand, 120 g kg^{-1} silt, 160 g kg^{-1} clay, 1.51 Mg m^{-3} bulk density, and 7.7 pH at the 0–15 cm depth. Previous cropping history for the last 20 yrs was dominated by alfalfa (*Medicago sativa* L.), crested wheatgrass (*Agropyron cristatum* [L.] Gaertn), and western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Love). Soil organic C concentrations at 0–5 and 5–15 cm depths before the initiation of the experiment were 13.3 and 10.6 g kg^{-1}, respectively, in Sidney and 13.7 and 9.9 g kg^{-1}, respectively, in Nesson Valley.

In Sidney, main-plot treatments were three cropping sequences {(no-tilled continuous malt barley (*Hordeum vulgaris* L.) [NTCB], no-tilled malt barley-pea (*Pisum sativum* L.) [NTB-P], and conventional-tilled malt barley-fallow [CTB-F])}, each with two split-plot N fertilization rates of 0 and 80 kg N ha^{-1}. While NTCB had only one cropping phase (malt barley), other cropping sequences had two phases in the rotation. For example, NTB-P had malt barley and pea phases and CTB-F had malt barley and fallow phases. Malt barley was planted annually in NTCB, in rotation with pea in NTB-P, and in rotation with fallow in CTB-F. Each phase of the cropping sequence occurred in every year. The 80 kg N ha^{-1} was the recommended rate of N fertilization to malt barley in dryland cropping systems at the experimental site. In NTCB and NTB-P, plots were left undisturbed, except for fertilizer application and planting crops in rows. The CTB-F was the conventional farming system where plots were tilled with field cultivator equipped with C-shanks and 45-cm wide sweeps and coiled-toothed spring harrows with 60 cm rods. Plots were tilled to a depth of 10 cm during planting and fallow periods two to three times a year for seedbed preparation and weed control. Nitrogen fertilizer was applied at 0 or 80 kg N ha^{-1} to malt barley. Before applying N fertilizer, soil samples to a depth of 60 cm were tested for NO_3–N content and N fertilization rates were adjusted. For pea, N fertilizer was not applied. Weeds in no-tilled treatments were controlled by applying preplant and postharvest herbicides and in conventional-tilled treatments by a combination of herbicides and conventional tillage to a depth of 10 cm as needed. Treatments were laid out in split-plot arrangement in a randomized complete block with three replications. The split plot size was 12.0 m × 6.0 m.

In Nesson Valley, main-plot treatment consisted of two irrigation systems (irrigated vs. non-irrigated) and split-plot treatment of five management practices (conventional-tilled malt barley with 67–134 kg N ha^{-1} [CTBFN], conventional-tilled malt barley with 0 kg N ha^{-1} [CTBON], no-tilled malt barley-pea with 67–134 kg N ha^{-1} [NTB-PN], no-tilled malt barley with 67–134 kg N ha^{-1} [NTBFN], and no-tilled malt barley with 0 kg N ha^{-1} [NTBON]). In NTB-PN, both malt barley and pea phases were present in every year. The recommended N fertilization rates for irrigated and non-irrigated malt barley at the site were 134 and 67 kg N ha^{-1}, respectively. The variation in N rates between irrigated and non-irrigated malt barley was due to the differences in grain yields and N uptake between irrigated and non-irrigated conditions. Soil NO_3–N test to a depth of 60 cm was used to adjust N rate before applying N fertilizer. No N fertilizer was applied to pea. While plots in no-tilled treatments were left undisturbed, except for planting and applying fertilizers, plots in tilled-treatments were plowed with a rototiller and a single-pass field cultivator to a depth of 10 cm at planting. Weeds were controlled with herbicides in no-tilled plots and a combination of herbicides and tillage in tilled plots, similar to Sidney. Treatments were laid out in split-plot arrangement in a randomized complete block with three replications. The size of each experimental unit was 10.6 m × 3.0 m.

2.2. Crop management

In Sidney, six-row malt barley (cultivar Certified Tradition, Busch Agricultural Resources, Fargo, North Dakota) was planted to