Accurate Soil CO_2 Flux Measurement at High Spatial and Temporal Resolution

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INTRODUCTION

Information about seasonal and spatial variations in soil CO_2 flux is essential to understanding how environmental and biological factors regulate soil CO_2 flux of an ecosystem. We have developed a 16-port automated multiplexing system for measuring soil CO_2 flux at high temporal and spatial scales. It is a closed dynamic system, and has the capability to sequentially measure the soil CO_2 flux at up to 16 locations. Each cycle of measurements can be done in one hour. Soil CO_2 flux is mostly driven by diffusion and mass flow, with the diffusion being controlled by the CO_2 concentration gradient and mass flow pressure fluctuations at the soil surface. In a closed chamber system, the slope of dCO_2/dt is required to compute the flux. To minimize the impact of decreased CO_2 diffusion gradient on the CO_2 flux measurement, the chamber CO_2 concentration versus time is fitted with an exponential function. We have also developed a vent design that helps avoid pressure perturbations inside the chamber. Based on Bernoulli's equation, we allow pressure in the chamber to fluctuate along with pressure at the soil surface outside the chamber under both calm and windy conditions. Pressure data measured in the field shows that the new vent design virtually eliminates the Venturi effect.

In this paper we:

- Present a system overview of the LI-8150 Multiplexer and data showing a leak test using the bellows pump on the LI-8100.
- Present a new way to compute F_{CO2} to minimize the impact of decreased CO_2 diffusion gradient inside the chamber, and demonstrate that there is a consistent underestimation of the F_{CO2} using a linear fit as compared with that of an exponential fit.
- Discuss the theory and data behind the new vent design.
- Present test data from our new multiplexer that demonstrates the temporal and spatial variability of F_{CO2} in a corn field and a grass field, and examine the temperature response of soil CO_2 flux.

Multiplexing System Description

The LI-8150 Multiplexer

The automated multiplexer can sequentially measure soil CO_2 flux at up to 16 different locations and cover an area with a radius of 17 m (Figure 1). The LI-8150 can operate in temperature ranges between -20°C and 45°C. The combined LI-8100 and LI-8150 system allows for wireless communication with a Personal Digital Assistant (PDA). The chambers have a diameter of 20 cm and a volume of 4.03 liters. The chambers move away from the soil when not in measurement mode. This is to minimize the disturbance from the chamber deployment to the soil inside the collar. To ensure quality data, a leak test can be performed with the software. This leak test uses the bellows pump from the LI-8100 analyzer control unit to pressurize each port in sequence. If a particular port does not remain pressurized for a pre-set time interval, a leak is assumed and further investigation is needed (Figure 2).

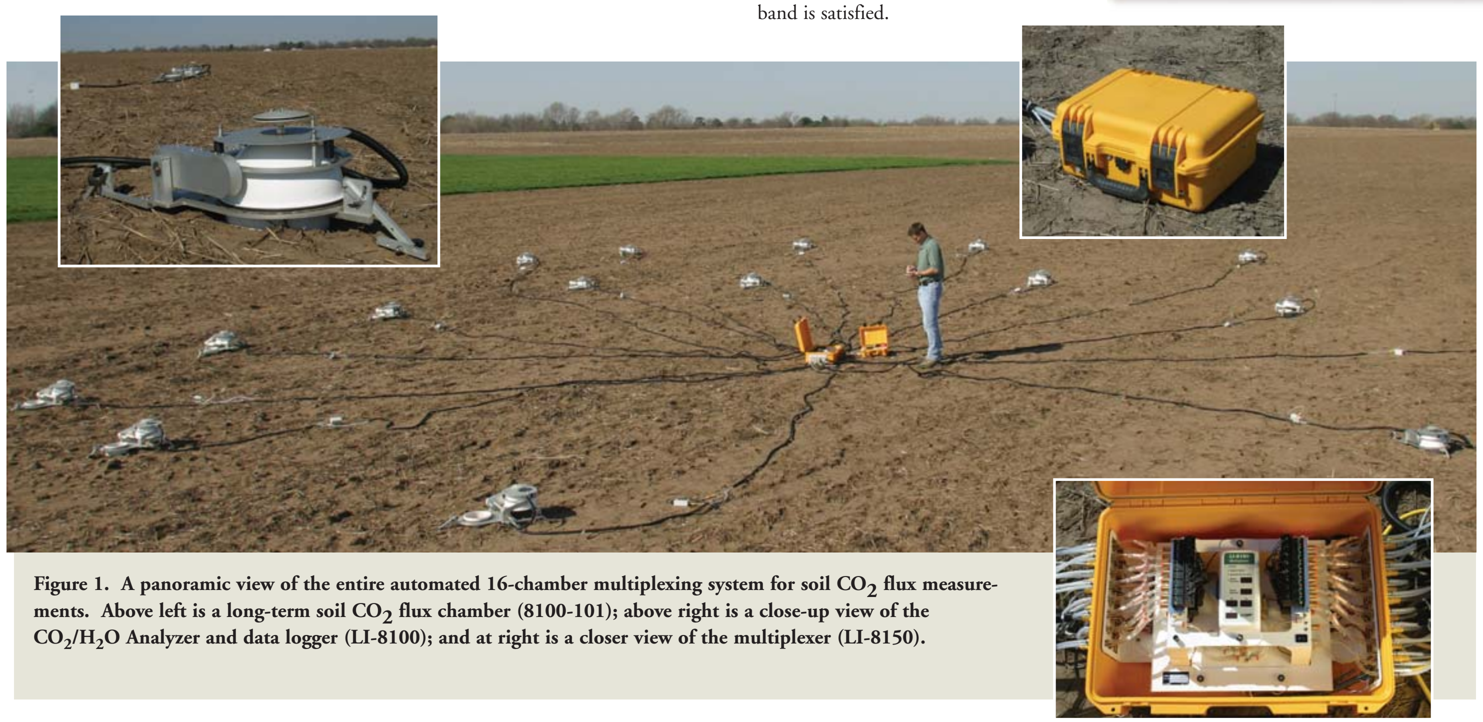


Figure 1. A panoramic view of the entire automated 16-chamber multiplexing system for soil CO_2 flux measurements. Above left is a long-term soil CO_2 flux chamber (8100-101); above right is a close-up view of the CO_2/H_2O Analyzer and data logger (LI-8100); and at right is a closer view of the multiplexer (LI-8150).

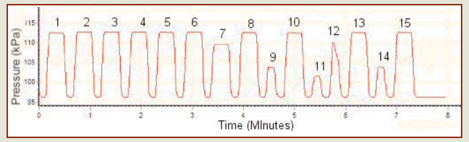


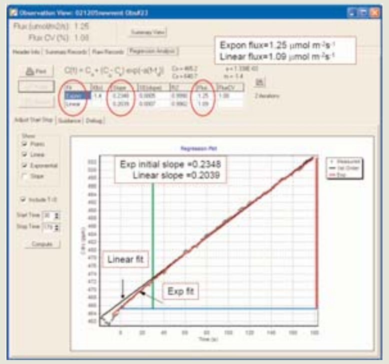
Figure 2. Results from a leak test that show no leaks on chambers 1-6, 8, 10, 13, and 15. Port 7 had twice the cable length attached, explaining the drop in pressure but still showed no leak. Ports 9, 11, 12, and 14 did have a leak. Port 16 was used as the purge port and was tested after all the others. The total time it takes to run a 16-chamber leak test is less than 15 minutes.

Soil CO_2 Flux Estimation

The LI-8100 and LI-8150 Multiplexer is a non-steady state, closed chamber system. When the chamber is in measurement mode, sample air is drawn from the chamber to the CO_2 gas analyzer, then sent back to the chamber. F_{CO2} is estimated based on the increase rate of CO_2 concentration (dCO_2/dt). Obtaining the slope of dCO_2/dt allows the chamber CO_2 concentration to rise; thus the soil CO_2 flux inside the chamber is suppressed due to the decreased CO_2 diffusion gradient. To overcome this, we first fit the time series of chamber CO_2 concentration (C_t) with the following exponential function after a dead band is satisfied.

$$C_t = C_x + (C_o - C_x)\, e^{-a(t-t_o)}$$

Where C_x is CO_2 concentration in the soil surface layer, C_o is initial chamber CO_2 concentration when the chamber closes. F_{CO2} is then estimated by calculating the initial slope from this exponential function at t_o, which is when the chamber CO_2 concentration equals the ambient (Figure 3). The underestimation of F_{CO2} when using linear fit gets more severe when you have lighter soil or forest soil with a lot of organic matter because of high conductance at the soil surface.



Expon flux=1.25 µmol m-2s-1
Linear flux=1.09 µmol m-2s-1

Exp initial slope =0.2348
Linear slope =0.2039

Figure 3. LI-8100 approach to measure the soil CO_2 flux (F_{CO2}) at ambient CO_2 concentration. In this example, the measurement lasts for 2 min with a dead band of 30 s.

Chamber Pressure Equilibrium

Many studies have demonstrated that a small pressure change inside the chamber can cause a large bias for the measured F_{CO2} (Denmead *et al.*, 1979; Davidson *et al.*, 2002), so it is necessary to prevent any pressure difference between the chamber and ambient air if measured values of F_{CO2} are to accurately represent rates outside the chamber.

Each chamber is equipped with our newly designed vent that maintains pressure equilibrium inside the chamber and the ambient air under calm and windy conditions (Xu *et al.*, 2005) (Figure 4). The new vent was based on Bernoulli's equation. This novel vent design reduces the speed of wind as it passes over the vent opening, increases the static pressure of the air at the vent opening and eliminates the pressure differences between the chamber and the surrounding air. This solves the problem of unequal pressure equilibrium under windy conditions (Bain *et al.*, 2005).

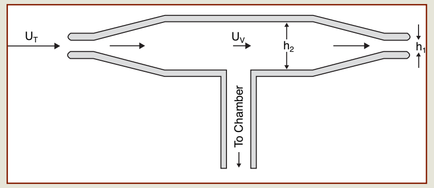


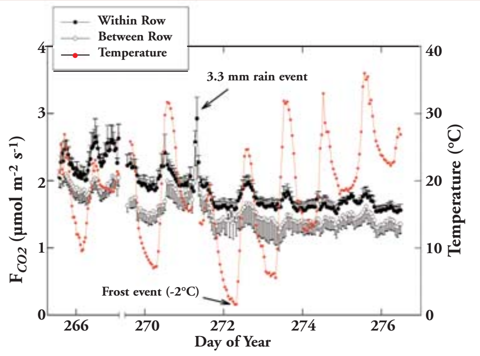
Figure 4. Cross-section view of the new vent design (patent pending). T is the wind speed at the height of the vent, Uv is the wind speed inside the vent near the vent tube, and h1 and h2 are the edge and the central distances between the upper and lower halves of the vent.

Field Testing

The LI-8100 and LI-8150 Multiplexer, fully deployed, can allow the user to obtain high temporal and spatial resolution soil CO_2 flux data in an ecosystem. Figure 5 shows a 2-week testing dataset obtained with the automated 16-chamber multiplexing system. The system was deployed in a dryland cornfield in September 2005 at the Agricultural Experiment Station, University of Nebraska-Lincoln, near Mead, NE. The corn plant was at the end of senescence stage. To study the spatial variability of F_{CO2} in the field, 8 chambers were installed between rows and 8 chambers within rows. From this 2-week experiment, we show:

1. F_{CO2} was significantly higher within row than between rows;
2. A strong diurnal variation in F_{CO2} for both between rows and within row;
3. A rain event occurred on DOY 271, causing a sudden increase in F_{CO2};
4. The diurnal variation in F_{CO2} after the first frost (on DOY 272) became smaller, probably due to a significant decrease in the autotrophic respiration.

Figure 5. Diurnal variation of soil CO_2 flux for between rows and within rows from a dryland cornfield near Mead, NE. Each data point represents the mean and one standard error with the sample number ranging from 4 to 8.



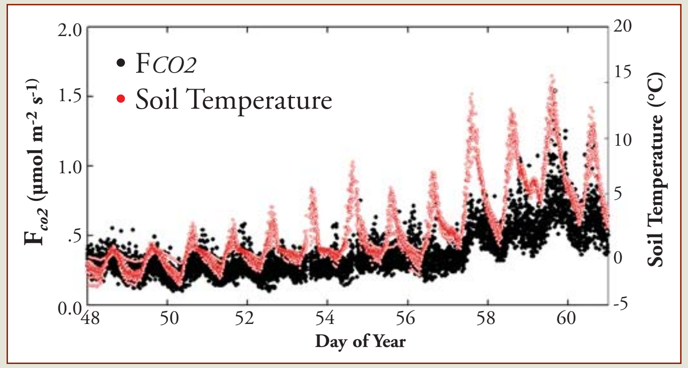
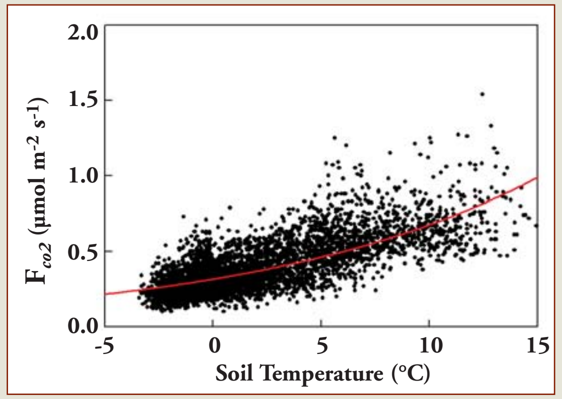


Figure 6. Time series of soil CO_2 flux data obtained with an automated 16-chamber soil CO_2 flux multiplexing system at LI-COR Biosciences research facility in February 2006. Also shown in the figure are the soil temperature data at a depth of 5 cm at each chamber.

Relationship between F_{CO2} and soil temperature (Q_{10})

Figure 6 shows a dataset from testing with the LI-8100/8150 multiplexer at the LI-COR research facility in February of 2006. Because of a warmer than usual Nebraska winter, data were obtained with the 16-chamber multiplexer system at a range of temperatures. Soil temperature at 5 cm depth near each soil collar was also measured via auxiliary input channels at each chamber. Results indicate that the soil CO_2 flux followed soil temperature nicely in a well-known Q_{10} relation. The Q_{10} was 2.1 (Figure 7).

Figure 7. Response of soil CO_2 flux (F_{CO2}) to change in soil temperature at the depth of 5 cm. Same dataset as presented in Figure 6.



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