Spatial Variability of Soil CO_2 Flux in a Cornfield

Liukang Xu [1], Rod Madsen [1], Dave Scoby [2], Tim Arkebauer [2], Jon Welles[1] , Tanvir Demetriades-Shah [1], Dayle McDermitt [1]
[1] LI-COR Biosciences, Lincoln, NE, 68504 USA
[2] Department of Agronomy, University of Nebraska, Lincoln, NE, 68583 USA

INTRODUCTION

Although soil respiration is a significant component of the carbon balance for an ecosystem, the environmental (soil moisture, rain event, temperature, etc.) and biological (photosynthesis, LAI, etc.) controls regulating soil respiration remain poorly understood. This limits our ability to understand the carbon budget at the ecosystem level, making it difficult to predict the impact of climate change on soil respiration and its feedback. One of the major reasons for this poor understanding is that there is a lack of continuous long-term soil respiration data at a very fine spatial and temporal scale, due to unavailable robust and reliable automated soil respiration instruments. To meet this need, LI-COR® is developing a new automated multiplexing system, the LI-8100M, for obtaining high spatial and temporal resolution of soil CO_2 flux (F_{CO2}) information. The system has the capability to measure F_{CO2} at up to 16 locations. In this paper we:

(1) present the overview of the multiplexing system, a new way (exponential fit) to compute F_{CO2} to minimize the impact of decreased CO_2 diffusion gradient inside the chamber, and demonstrate that the flux from the linear fit systematically underestimates the F_{CO2} as compared with that from an exponential fit.
(2) present the spatial variability of F_{CO2} in a cornfield using data obtained with our new multiplexing system.
(3) discuss the number of measurements required in order to have reliable mean fluxes based on the spatial variability of F_{CO2}.

MATERIALS & METHODS

1. Multiplexing System Overview

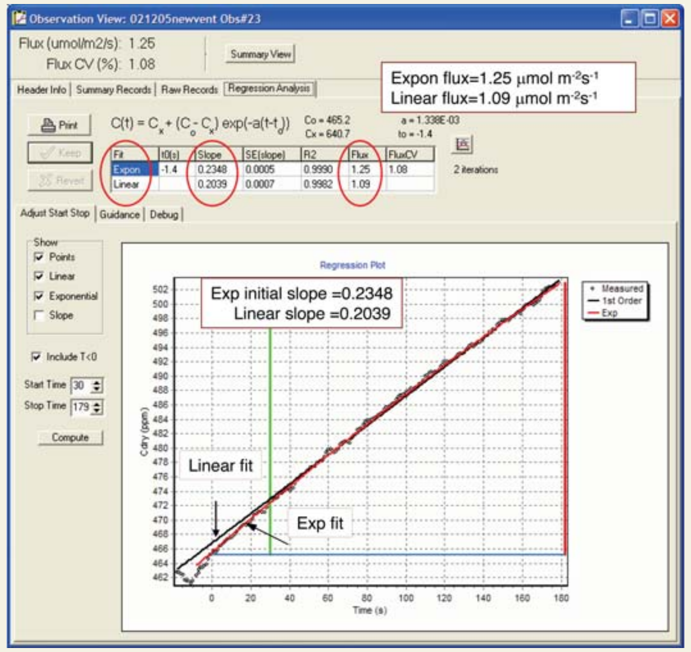
The automated multiplexing system can sequentially measure soil CO_2 flux at up to 16 locations (**Fig. 1**), and covers an area with a radius of 17 m. One full cycle of 16 measurements can be finished in one hour. The LI-8100M can operate at ambient temperatures from -20°C to 45°C. The system has Wi-Fi capability that allows for wireless communication with a Personal Digital Assistant (PDA).

Figure 1. 16-chamber multiplexing system control box. The top two panels show one side of the control box with 8 gas ports and a soil CO_2 flux chamber.

Each chamber has a diameter of 20 cm and a volume of 4.03 liters. The chamber is moved away from the soil area being measured when it is not in the measurement mode, ensuring that the measurement area is subject to normal, undisturbed precipitation, temperature and radiation, etc. Chambers are equipped with a newly designed vent to maintain pressure equilibrium inside the chamber and the ambient air under both calm and windy conditions (Xu et al., 2005; also see poster by McDermitt et al: *Equalizing pressures between a soil CO_2 flux chamber and the ambient air under windy conditions).*

2. Data Analysis

The LI-8100M is a non-steady state, closed-chamber system. The slope of dCO_2/dt is required to compute F_{CO2}. To obtain the slope of dCO_2/dt, the chamber CO_2 concentration must be allowed to rise. Consequently, soil CO_2 flux will be suppressed because of 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: $C(t) = C_x + (C_c - C_x)e^{-a(t-t_o)}$ where C_x is CO_2 concentration in the soil surface layer and C_c 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 (**Fig. 2**).



Flux (umol/m2/s): 1.25
Flux CV (%): 1.08

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

$C(t) = C_x + (C_o - C_x)\exp(-a(t-t_o))$
Co = 465.2
Cx = 640.7
a = 1.338E-03
to = -1.4

Fit	t0(s)	Slope	SE(slope)	R2	Flux	FluxCV
Expon	-1.4	0.2348	0.0005	0.9990	1.25	1.08
Linear		0.2039	0.0007	0.9982	1.09	

2 iterations

Show
☑ Points
☑ Linear
☑ Exponential
☐ Slope
☑ Include T<0
Start Time 30
Stop Time 179

Exp initial slope =0.2348
Linear slope =0.2039

Figure 2. LI-8100 approach to measure the F_{CO2} at ambient CO_2 concentration. In this example, the measurement lasts for 2 min with a dead band of 30 s. This example shows that F_{CO2} calculated from the linear fit underestimated the flux by 13.2% as compared with that from the exponential fit.

RESULTS

1. Underestimation of F_{CO2} When Using Linear Fit

This underestimation becomes more problematic on a lighter soil or forest soil with a lot of organic matter, because of high conductance at the soil surface. As demonstrated in **Fig. 2**, F_{CO2} will be underestimated if using linear fit. See **Fig. 3** for a comparison of underestimation between a heavy clay soil and light sandy soil. The data for the heavy clay soil was obtained at the Agricultural Experimental Station at the University of Nebraska-Lincoln near Mead, NE, and data for the light sandy soil was from the Starker Forest of Professor Bev Law's site at Oregon State University. Both datasets were obtained with automated multiplexing systems with a measurement period of 2 min. Overall, the underestimation for the heavy clay soil was normally less than 15%, while for the light sandy soil, the underestimation was in the range of 10-40%, suggesting a strong suppression of F_{CO2} due to a decreased CO_2 diffusion gradient.

Using a period longer than 2 min for measurements could further increase the magnitude of the underestimation of the flux if the linear fit is used. At LI-COR, we conducted a simple experiment with a LI-8100 Automated Soil CO_2 Flux System to measure F_{CO2}. We set the measurement duration to 20 min. Chamber CO_2 concentration was recorded continuously. From the slope of dCO_2/dt, F_{CO2} can be estimated at any time during the 20-min period. **Fig. 4** clearly shows that F_{CO2} continues to drop. By the end of the 20-min period, the flux decreased by more than 27%. This result is consistent with the conclusion drawn by Healy et al., (1996) who used analytical and numerical models of gas diffusion to evaluate the impact of altered chamber headspace CO_2 concentration on estimated F_{CO2}. They found that chamber-induced perturbation of the CO_2 gradient could result in substantial underestimation of F_{CO2} (6 to 34% for a 30-min measurement).

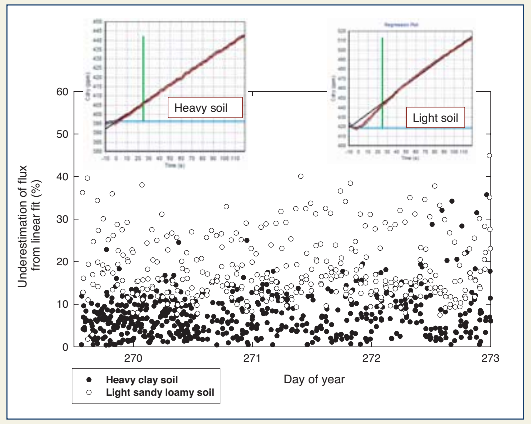
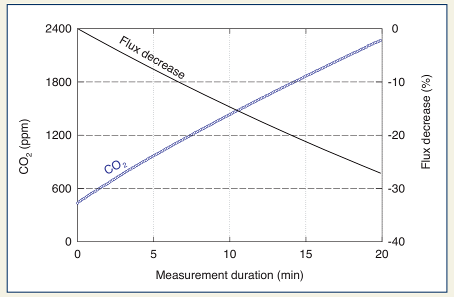


Figure 3. Comparison of underestimation of F_{CO2} when using linear fit for a heavy clay soil and a light sandy soil. The dataset for heavy clay soil was from the University of Nebraska-Lincoln Agricultural Experimental Station, and the dataset for light sandy soil was from Professor Bev Law's Starker forest site.

2. Temporal and Spatial Variation of F_{co2} for a Cornfield

An automated16-chamber multiplexing system was deployed in September 2005 in a dryland cornfield at the Agricultural Experiment Station, University of Nebraska-Lincoln, near Mead, NE, for about 2 weeks. The cornfield 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 two-week experiment (**Fig. 5**), we show that:

Figure 4. Longer measurement periods can further underestimate the soil CO_2 flux when using a linear fit. Data shown are time series of chamber CO_2 concentration and percentage of flux decrease for a 20-min measurement period. Data were obtained with the LI-8100 Automated Soil CO_2 Flux System at LI-COR.



1. F_{CO2} was significantly higher within rows than between rows;
2. A strong diurnal variation in F_{CO2} for both between and within rows;
3. A rain event that occurred on DOY 271 caused 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.

Paired-t test indicates that more than 85% of F_{CO2} data points presented in **Fig. 5**, within row and between rows, were significantly different at a confidence level higher than 0.1.

Photo by Dr. Dave Billesbach,
University of Nebraska-Lincoln

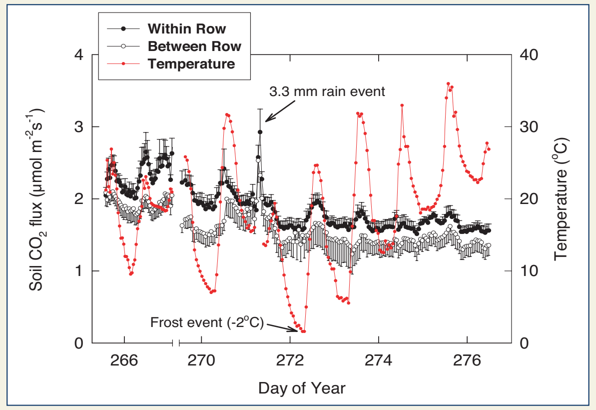
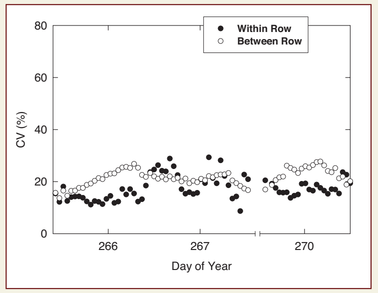


Figure 5. Diurnal variation of soil CO_2 flux for between rows and within rows from a dryland cornfield near Mead, Nebraska. Each data point represents the mean and one standard error, with the sample number ranging from 4 to 8.

From inforrmation of CV, we can determine the samples needed for reliable site mean flux values. For a population with normal distribution, there is a 95% probability that the true mean of the entire population μ lies within the range of $\bar{y} \pm \frac{2\sigma}{\sqrt{n}}$.

Figure 6. Coefficient of variation (CV) for soil CO_2 flux from a cornfield. This dataset was obtained with a 16-chamber automated multiplexing system with 8 chambers deployed between rows and 8 chambers within rows. CV varied from 9 to 29% during the experiment period. CV from between rows seemed more stable over the course of the experiment than that from within rows. In addition, we did not see any significant differences in CV from within row and between rows.



Where $\bar{y}$ is the sample mean and n is the sample size. Generally, we wish to keep $\frac{2\sigma}{\sqrt{n}} \leq \mu \times err$. So $\sqrt{n} \geq \frac{2\sigma}{\mu \times err}$. With the definition of CV being equal to σ/μ, we have the following equation: $n \geq \left(\frac{2 \times CV}{err}\right)^2$

For example, if the CV of a field is 10%, 4 measurements at different locations are needed in order to have a sample mean deviate not more than 10% from population mean. If CV of a field is 20%, then 16 measurements are needed.

ACKNOWLEDGEMENTS

Our thanks to Dr. Jon Martin from Professor Bev Law's group at Oregon State University for collecting a portion of the data presented in Fig. 3. We also thank Dr. Dave Billesbach of the University of Nebraska-Lincoln for the cornfield photograph.

REFERENCES

Healy, R. W., R. G. Striegl, T. F. Russell, G. L. Hutchinson, and G. P. Livingston. 1996. Numerical evaluation of static chamber measurements of soil-atmosphere gas exchange: Identification of physical processes. *Soil Sci. Soc. Am. J.*, 60, 740-746.

L. Xu, M. Furtaw, R. Madsen, R. Garcia, D. Anderson, D. McDermitt. 2005. On maintaining pressure equilibrium between a soil CO_2 flux chamber and ambient air. *J. Geophys. Res. Atm.*, Accepted.

www.licor.com
LI-COR® Biosciences