Measurements of Soil CO2 Flux


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Introduction

The predominant processes that produce carbon dioxide in soil are respiration of roots and soil organisms and the decomposition of organic matter. In calcareous soils significant amounts of CO2 can also be produced from the action of acidic rain on soil carbonate. The production of CO2 in the soil is strongly correlated with soil temperature and moisture (Kemper et al., 1994). Therefore, soil temperature and moisture data can be useful when interpreting soil CO2 flux measurements. One should also recognize that any experimental protocol that perturbs the soil temperature and/or moisture (e.g., long-term chamber enclosures) will most likely change the soil CO2 flux.

Although the primary mechanism for transport of CO2 from the soil to the atmosphere is diffusion, transport may also be influenced by fluctuations in pressure, wind, temperature, and precipitation. There is a great deal of spatial variability in soil CO2 flux due to its dependence on environmental conditions and the heterogeneity of soil. It may be more difficult for a researcher to recognize when measurements have been compromised by problems in the techniques or methodology when the process being measured has a high degree of variability. This makes it particularly important to rigorously evaluate techniques used for such measurements.

Chamber techniques are probably the most widely used means of measuring gas exchange between the soil and the atmosphere. In this paper we evaluate a new closed-chamber, dynamic system.

Materials and Methods

An LI-6400 portable photosynthesis system (LI-COR Inc., Lincoln, Nebraska) was fitted with a 5.680-l. soil CO2 flux chamber (Figure 1). The system volume (including gas analyzer optical path) is 376 cm3 and the measured soil area is 371 cm2. The CO2 and water vapor analyzers are attached directly to the chamber and mixing in the chamber headspace is achieved with the gas analyzer mixing fan and the associated manifold (Figure 2). During a measurement, a chamber is at rest at the top of the chamber through the analyzer inlet duct and enters the optical path of the gas analyzer. Air is returned from the gas analyzer through the analyzer outlet ducts to the manifold near the soil surface. Soil CO2 flux measurements were made using 3-cm id soil cores inserted 3 to 4 cm into the soil to an interface between the soil and the chamber.

A high resolution pressure sensor (Datastream Barocel type 960, Wilmingtom, MA) was used to monitor the pressure inside the chamber across a range of operating conditions in order to evaluate how operation of the system may influence pressure over the soil during a typical measurement.

The LI-6400 soil CO2 flux system setup. The plumbing circuit highlighted in color is for CO2 scrubber operation. It is only used during the draw down portion of a measurement cycle. During the measurement, mixing in the chamber headspace is achieved with the gas analyzer mixing fan and manifold.

Chamber CO2 Concentration and Soil CO2 Flux

Soil CO2 flux was measured while chamber headspace CO2 concentration was decreasing and allowed to rise (Figure 3). The soil CO2 flux was measured from about 8 mol mol-1 to about 40 mol mol-1 as chamber headspace CO2 concentration rose from 350 mol mol-1 to 1500 mol mol-1

These measurements demonstrate the dependence of soil gas-exchange measurements on the chamber CO2 concentration and confirm Heady et al. (1994) prediction of which analytical and numerical techniques for soil gas diffusion were used to evaluate the influence of chamber headspace concentration on estimates of soil CO2 flux. They predicted that chamber induced perturbations of the concentration gradient between the soil atmosphere and the free air above the soil could cause substantial errors in measured soil CO2 flux, and that errors would be larger with increased chamber deployment time and air filtered proximity of the soil.

The LI-6400 soil CO2 flux measurement system has been designed to minimize perturbations in soil-atmosphere CO2 concentration gradient. Before starting the measurement, the ambient CO2 concentration of the soil surface is measured. Once the chamber is isolated, the CO2 scrubber is used to draw the CO2 concentration in the chamber headspace down below the ambient CO2 concentration. The scrubber is turned off and the soil CO2 flux causes the CO2 concentration in the chamber headspace to rise (Figure 4). Data are logged while the CO2 concentration rises through the ambient level. The software then computes the flux appropriate for the ambient concentration (Figure 5). The LI-6400 performs these calculations automatically for as many iterations as desired.

Figure 2. LI-6400 soil CO2 flux measurement system setup. The plumbing circuit highlighted in color is for CO2 scrubber operation. It is only used during the draw down portion of a measurement cycle. During the measurement, mixing in the chamber headspace is achieved with the gas analyzer mixing fan and manifold.

Chamber Pressure Tests

CO2 Drawdown Mode is initiated by turning on the pump. This causes a positive pressure transient with a maximum of 2.5 Pa above ambient and duration of 0.25 s (FWHM). The pressure then settles down to a steady-state value about 0.17 Pa above ambient while in Drawdown Mode. Turning off the pump initiates Measurement Mode. This causes a negative pressure transient with a maximum about 2.0 Pa below ambient and duration of 0.37 s (FWHM). In Measurement Mode, a steady-state pressure above 0.02 Pa above ambient (NS) is reached within 0.3 s of turning off the pump.

A systematic bias in over the soil surface can cause significant perturbations of gas exchange. Flow-through or "open" systems are problematic because the pressure differences necessary to provide flow can suppress or enhance CO2 emissions. Kemper et al. (1976) measured CO2 flux changes in soil CO2 flux with steady-state pressure changes of 2 to 3 Pa in flow through system. Air turbulence can also cause pressure gradients (Baldwin and Lemon, 1971), and Hanse et al. (1993) found a strong dependence of soil CO2 flux on the mixing fan speed made a chamber. In the closed system reported here, mixing in the chamber headspace is achieved with a manifold and pressure is maintained in dynamic equilibrium with ambient barometric pressure by venting the chamber through a 0.25 m length of 4 mm ID tubing.

The efficacy of these measures is demonstrated by the very small pressure changes measured as the system was used in various operation modes.

Evaluating the influence of chamber CO2 concentration on estimates of soil CO2 flux.

Conclusions

- Chamber headspace CO2 concentration can substantially affect measured CO2 flux rates.
- The soil chamber system reported here measures soil CO2 flux at ambient CO2 concentration.
- Pressure gradients as small as 1 Pa can have substantial effects on measured CO2 flux.
- The soil chamber system reported here operates at very near ambient barometric pressure during the measurement cycle and 0.17 Pa above ambient during draw down cycle. Very brief (0.37 s) FWHM pressure transients occur when the pump is turned on or off.

References

Hanson, F.J. and Walter, J.D. (1980) Seasonal and latitudinal patterns of forest soil CO2 efflux from an upland deciduous forest. Tree Physiology, 1:31-39.