

Continuous measurements of soil respiration with and without roots in a ponderosa pine plantation in the Sierra Nevada Mountains

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Abstract

Continuous measurements of soil respiration and its components help us understand diurnal and seasonal variations in soil respiration and its mechanism. We continuously measured CO₂ concentration at various depths in the soil and calculated surface CO₂ efflux based on CO₂ gradients and diffusivity in a young ponderosa pine plantation in the Sierra Nevada Mountains of California. We determined soil respiration both in a control plot that included roots and in a trenched plot that had no roots. The difference between these plots was used to partition soil respiration into root respiration and heterotrophic respiration. We found that both CO₂ concentration in the soil and surface CO₂ efflux in the control plot were higher than in the trenched plot. The diurnal range of soil respiration in the trenched plot was larger than in the control. We observed dramatic pulses of soil respiration in response to rain events in summer and fall during the dry season. We modeled the seasonal variation in soil respiration without the pulses using soil temperature and moisture as driving variables and simulated soil respiration pulses using an exponential decay function in response to the volume of rain. Daily mean soil respiration peaked at 5.0 μmol m⁻² s⁻¹ in the control and at 2.7 μmol m⁻² s⁻¹ in the trenched plot in June before the rain pulses. Soil respiration increased from 4.9 to 8.2 and to 12.1 μmol m⁻² s⁻¹ after the first and second rain events in the control, and increased from 2.2 to 4.1 and to 6.6 μmol m⁻² s⁻¹ in the trenched plot. After incorporating the pulse effect, the model simulated measured data well. Annual soil respiration in 2003 was estimated as 1184 g C m⁻² y⁻¹. The average ratio of root over total respiration was 0.56 during the growing season and 0.16 during the non-growing season with an annual average of 0.44.

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1. Introduction

Soil surface CO₂ efflux, or soil respiration, has a potential role either to amplify global warming due to its sensitivity to environmental conditions (Cox et al., 2000; Trumbore et al., 1996; Kirschbaum, 2000), or to mitigate climate change due to enhanced soil carbon

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sequestration and reduced CO₂ efflux (Lal, 2004; Goh, 2004). Improved understanding of the mechanisms and quantification of the variations in soil respiration is essential for better managing these potentials. Because of the high temporal and spatial variations in soil respiration (Raich et al., 2002; Rayment and Jarvis, 2000; Law et al., 2001a; Tang and Baldocchi, 2005), high-resolution information on the local scale is necessary for evaluating the soil carbon budget on the global scale.

Soil respiration has been extensively measured using various methods. Chamber-based methods allow measurements of soil respiration on a small scale (e.g. Norman et al., 1992; Meyer et al., 1987). Portable chambers enable investigation of the spatial variation in soil respiration (Tang and Baldocchi, 2005). Automated chamber systems provide continuous and semi-continuous measurements for investigating the temporal variation in soil respiration (Russell et al., 1998; Scott et al., 1999; Goulden and Crill, 1997; Liang et al., 2003; Irvine and Law, 2002; King and Harrison, 2002; Drewitt et al., 2002). However, chamber-based measurements may create sampling biases by disturbing air pressure and altering CO₂ concentration in the soil (Livingston and Hutchinson, 1995; Healy et al., 1996; Davidson et al., 2002). Under-story eddy covariance methods provide an alternative to continuously measure soil CO₂ efflux without disturbing the soil (Baldocchi and Meyers, 1991; Law et al., 1999). However, the component flux from under-story vegetation often limits the use of under-story flux data and stable conditions make eddy covariance measurements in this environment difficult. The recently developed soil CO₂ vertical gradient measurement method provides an opportunity to measure soil respiration with high frequency (minutes to half hour) with minimum disturbance to the natural structure of the soil (Tang et al., 2003; Hirano et al., 2003; Liang et al., 2004; Jassal et al., 2005). This method has not been widely used earlier probably due to instrument limitations and difficulty in calculating soil surface CO₂ efflux from gradient measurements and CO₂ diffusivity in the soil.

Soil respiration has been widely simulated using continuous records of temperature, moisture, and other variables (e.g. Raich and Schlesinger, 1992; Davidson et al., 1998; Epron et al., 1999a; Xu and Qi, 2001; Treonis et al., 2002; Reichstein et al., 2003; Tang et al., 2005b). It has been observed that rainfall causes pulses of soil respiration and ecosystem respiration and that these pulse effects may significantly influence the annual carbon budget (Lee et al., 2004; Xu et al., 2004; Yuste et al., 2003). However, few models have

incorporated the rain pulse effects in estimating the annual sum of soil respiration.

Partitioning soil respiration into root respiration (including associated respiration from mycorrhizae) and heterotrophic respiration helps us understand the mechanisms of soil respiration and aids in development of process-based carbon cycle models. The ratio of root respiration to total soil respiration may vary from 10 to 90% depending on vegetation type and season of the year (Hanson et al., 2000). In situ comparisons between soil respiration and heterotrophic respiration in a continuous and simultaneous way are rare, but are valuable for improving understanding of the different behavior between root respiration and heterotrophic respiration.

In this study, we report continuous measurements of CO₂ concentration gradients in the soil, provide an algorithm to calculate soil surface CO₂ efflux based on these gradients, quantify diurnal and seasonal patterns of soil respiration with roots (soil respiration) and without roots (heterotrophic respiration), and simulate seasonal variations in soil respiration and root respiration that include the rain pulse effects.

2. Materials and methods

2.1. Site description

The study site, a part of the Ameriflux and Fluxnet networks, is located in a young ponderosa pine (*Pinus ponderosa*) plantation (38°53'42.9"N, 120°37'57.9"W, 1315 m) adjacent to the University of California Blodgett Forest Research Station. The stand is dominated by ponderosa pine trees planted in 1990 after clear cutting. Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), giant sequoia (*Sequoiadendron giganteum*), and California black oak (*Quercus kelloggii*) occur sparsely in the overstory canopy. The major understory shrubs were *Arctostaphylos* spp. and *Ceanothus* spp.

The plantation had an original tree density of 1213 stems ha⁻¹. Shrubs were cut during spring 1999 and the plantation was thinned in May 2000 as a forest management practice. About 60% of trees and 30% of total biomass and leaf area including most shrubs were cut down and masticated into detritus (Tang et al., 2005b; Misson et al., 2005). In spring 2003, one-sided leaf area index (LAI) averaged 1.79 for the overstory and 0.7 for the understory shrubs. Stand density was 378 stems ha⁻¹ with mean tree diameter at breast height (DBH) of 12.0 cm, mean tree height of 4.7 m, and basal area of 9.58 m⁻² ha⁻¹ in 2003.

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