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Estimating heterotrophic and autotrophic soil respiration using small-area trenched plot technique: Theory and practice

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Abstract

The trenching method of root exclusion is generally used to estimate heterotrophic (microbial decomposition) (F_h) and autotrophic (root and associated rhizosphere respiration) (F_a) components of soil respiration (F_0), particularly in forest ecosystems. However, some uncertainties exist on the accuracy and interpretation of the results from such experiments using small-area root exclusion plots. Using field and laboratory measurements as well as simulations using a process-based model of CO_2 production and transport in soil, we show that: (a) CO_2 concentrations at or immediately below the depth of root exclusion in small-area root exclusion plots are similar to those at the same depth in nearby undisturbed soil and (b) the contribution of soil CO_2 flux from below the root exclusion depth to the measured efflux at the surface of a root exclusion plot (F_{0re}) is increased because of the higher concentration gradient at the bottom of the root exclusion layer due to the decreased rate of CO_2 production above this depth. Consequently, F_a, calculated as F_{0c} measured in control (non-disturbed) plots minus F_{0re} measured in root exclusion plots, is underestimated. We describe an analytical model, derived from the soil CO_2 production and diffusion equation, to obtain correct estimates of F_a measured using small-area root exclusion plots. The analytical model requires knowledge of depth distribution of soil CO_2 diffusivity and source strength as inputs.

Keywords: Root exclusion; Soil respiration; Heterotrophic; Autotrophic; Soil CO_2 efflux; Soil CO_2 concentration; Diffusivity

1. Introduction

Because soils contain as much as or more carbon than that contained in the atmosphere and live biomass together (Eswaran et al., 1993), soil CO_2 efflux (F_0) has been widely measured under different ecosystems and environmental conditions. Soil CO_2 is the product of decomposition of plant litter and soil organic matter, the heterotrophic respiration (F_h), and from root respiration including respiration of symbiotic microbes and mycorrhizae that feed on root exudates, the autotrophic respiration (F_a). Although F_0 has received considerable attention in recent decades, much less is known about the relative contributions of F_h and F_a to F_0, and our understanding of how they will respond to global warming is poor. The two components of F_0 can have different responses to temperature and soil water content (Boone et al., 1998; Lee et al., 2003; Lavigne et al., 2004), thus the contribution of these components needs to be understood in order that the implications of environmental change for soil carbon cycling and sequestration can be evaluated (Hanson et al., 2000).

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Estimates of F_h are also required for estimating the net primary productivity (NPP) of an ecosystem from eddy covariance measurement of net ecosystem exchange (NEE), i.e. NPP = −NEE + F_h.

The contribution of F_a to F_0 has been reported to vary from 10% to as much as 90% for both forest and non-forest ecosystems (Hanson et al., 2000; Xu et al., 2001). Part of this variability may be due to differences in ecosystems, species, or developmental stages (Hanson et al., 2000; Hogberg et al., 2001). However, much of the variation has been attributed to problems associated with measurement techniques (Hanson et al., 2000), each with a unique set of limitations (Rochette et al., 1999). Hanson et al. (2000) reviewed methods and observations for partitioning F_0 into F_h and F_a and concluded that more work is required to refine methods and interpretations.

The trenching method of root exclusion has been widely used for separating F_0 into F_h and F_a, particularly in forest ecosystems (Bowden et al., 1993; Kelting et al., 1998; Epron et al., 1999; Hanson et al., 2000). In this method, roots are severed by digging a trench around the plot and the trench is lined with heavy-duty polyethylene sheet, landscape fabric or tarpaulin to prevent growth of roots into the plot. F_a is estimated from the difference between measured CO_2 effluxes at nearby undisturbed locations and in the trenched plots. There are concerns with this technique that have been identified and investigated, e.g. (a) disturbance effect due to trenching (e.g. Edwards, 1975; Blet-Charaudeau et al., 1990; Ewel et al., 1987; Bowden et al., 1993), (b) influence of residual decomposing roots (e.g. Lavigne et al., 2003) and (c) differences in soil water regime between the trenched and control plots (e.g. Edwards, 1975; Hanson et al., 1993; Thierron and Laudelout, 1996). However, one aspect that seems to have been overlooked in all these studies is the increased contribution of CO_2 to the measured efflux in the root exclusion plot from below the root exclusion depth, as explained below.

A review of the literature indicates that depth of root exclusion with trenching has varied among ecosystems, e.g. 30 cm in Balsam fir (Lavigne et al., 2003, 2004), 40 cm in cool-temperate deciduous forest (Lee et al., 2003), and 100 cm in wet tropical forest (Li et al., 2004) and some other ecosystems (Ewel et al., 1987; Bowden et al., 1993; Epron et al., 1999). Also, in most of these studies, the size of the root exclusion plots is relatively small, e.g., 60 cm × 60 cm in Lee et al. (2003), 1.4 m × 1.4 m in Lavigne et al. (2003, 2004), and 1.5 m × 2 m in Epron et al. (1999). None of these studies report on the depth distribution of soil organic matter or roots. Though both roots and soil organic matter are known to decrease with soil depth either exponentially or with a power law function, small amounts of soil organic matter and even fine roots may be present below the trenching depth (Trumbore et al., 1995; Nepstad et al., 1994). These factors, combined with low diffusivity, may result in high soil CO_2 concentrations at these depths.

Also missing in the above-mentioned root exclusion studies is any information on water table depth and depth of soil or any impermeable layer, all of which affect the CO_2 concentration and concentration gradient at deeper depths. High CO_2 concentrations and significant concentration gradients are generally observed below the 50 cm depth in forest soils, e.g. concentrations of the order of 10,000 ppm at the 50 cm depth (Jassal et al., 2005; Suwa et al., 2004; Takahashi et al., 2004; Trumbore et al., 1995) and significant concentration gradients at the 1 m depth (Drewitt et al., 2005; Jassal et al., 2004; Suwa et al., 2004; Takahashi et al., 2004; Trumbore et al., 1995). Root exclusion, especially in small-area trenched plots is not likely to alter the soil CO_2 concentrations at or below the depth of root exclusion, due to lateral diffusion (Susfalk et al., 2002).

Although CO_2 fluxes in soils below 50 cm depth are generally small compared to CO_2 fluxes in the upper layer (Jassal et al., 2004, 2005; Davidson and Trumbore, 1995; Sombroek et al., 1993), we hypothesize that the upward CO_2 flux from below the root exclusion layer in root exclusion plots will be greater than in control plots due to root exclusion decreasing the source strength (rate of soil CO_2 production), which leads to an increased concentration gradient at the bottom of the root exclusion layer (Fig. 1). This may significantly affect the estimate of autotrophic soil respiration obtained by subtracting measured efflux in root exclusion plots from that in control plots. The objectives of this paper are to: (i) show that soil CO_2 concentrations immediately below the trenching depth are nearly the same as that at the same depth in the control plot, (ii) show that the contribution of the upward flux at the depth of root exclusion in small-area root exclusion plots is increased due to decreased source strength in the absence of roots, and that this results in an underestimation of the autotrophic component of soil respiration and (iii) describe a method for correcting heterotrophic and autotrophic soil respiration measured using the small-area trenched plot technique.

2. Theory

Under most field conditions, when changes in barometric pressure are small, transport of CO_2 in soil