A modified soil coring method for measuring fine root production, mortality and decomposition in forests

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ABSTRACT

Fine root (diameter < 2 mm) production, mortality and decomposition have been poorly estimated at ecosystem scales due to technical limitations. The soil coring method can accurately assess fine root biomass and necromass, but the concurrent growth, death and decomposition processes were not reasonably assessed during the sampling period, leading to greatly biased rate estimates. We developed a dynamic-flow method with two variations to address these processes by combining the soil coring method with an improved decomposition experiment. For a certain interval i ($1 \leq i$) in the growing season, the dead fine roots were classified into fine roots dying before the start of interval i (G_{I-i}) and those dying during interval i (G_{II-i}). The decompositions of G_{I-i} and G_{II-i} were separately quantified and integrated into a modified mass balance model to estimate the production, mortality and decomposition. An example study conducted in a secondary Mongolian oak (*Quercus mongolica* Fischer ex Ledebour) forest showed that fine root production, mortality and decomposition were greatly underestimated by conventional soil coring methods failing to address the simultaneous growth, death and decomposition processes but overestimated by the method in which the decompositions of G_{I-i} and G_{II-i} were not separately determined and the decomposition rate was assumed to be constant. The dynamic-flow method greatly improved the accuracy of fine root estimates and can be widely applied to forests.

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1. Introduction

Accurate measurements of fine root production, mortality and decomposition are essential for understanding carbon and nutrient fluxes in terrestrial ecosystems (Woodward and Osborne, 2000). Sequential soil coring, ingrowth core and minirhizotron are major methods for measuring the production, mortality and decomposition but all have their respective advantages and disadvantages (Vogt et al., 1998; Hendricks et al., 2006; Strand et al., 2008). The main deficiencies of the minirhizotron and ingrowth core methods include disturbance of the rooting environment during the installation and that roots grow under an environment which is different from natural soil (Vogt et al., 1998; Strand et al., 2008; Krasowski et al., 2010).

The sequential soil coring approach allows direct measurement of fine root standing mass, thus avoiding the inherent deficiencies associated with the two other methods. However, estimating fine root production, mortality and decomposition based on changes in the standing fine root mass alone could not account for the simultaneous processes of growth, death and decomposition (Persson, 1978; McClaugherty et al., 1982; Fairley and Alexander, 1985; Ostertag, 2001; Yuan and Chen, 2013).

Santantonio and Grace (1987) proposed a compartment-flow method to assess the simultaneous processes in which fine root production ($g(t)$), mortality ($m(t)$) and decomposition ($d(t)$) in a certain interval were evaluated by mass balance equations:

$$dB(t)/dt = dg(t)/dt - dm(t)/dt;\qquad(1)$$

$$dN(t)/dt = dm(t)/dt - dd(t)/dt\qquad(2)$$

$B(t)$ and $N(t)$ were fine root biomass and necromass at time t, respectively. $dm(t)/dt$ was presumed to remain constant. $dd(t)/dt = N(t)\,k$. k was dead fine root decomposition rate which was

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assumed to be constant and described as a function of soil temperature, temperature coefficient and reference rate of fine root decomposition at a mean soil temperature. The production, mortality and decomposition can be solved by integrating the equations above. Mäkelä and Vanninen (2000) developed the compartment-flow model further using the finding that the ratio of fine root necromass to biomass is related to the specific rates of decomposition, mortality and net grow. However, these two approaches have not been widely utilized because they required additional measurement, estimation and modeling of variables other than the decomposition coefficient itself. Osawa and Aizawa (2012) simplified the compartment-flow approach by replacing the complex modeling of the decay coefficient with a litterbag experiment in which the decomposition rate was estimated by an exponential decay function.

Because soil coring method can yield reliable fine root mass estimate, the efficacy of these methods depends on accurate quantification of the decomposition. For a certain interval i ($1 \leq i$, i is an integer) in growing season, all these methods assumed that the decomposition rate remains constant and fine roots dying before the start of interval i (G_{I-i}) and during interval i (G_{II-i}) have the same decomposition rate when using the mass balance equations (Santantonio and Grace, 1987; Mäkelä and Vanninen, 2000; Osawa and Aizawa, 2012). However, the two assumptions could not well reflect the decomposition dynamics. Fine roots are composed of different components. The labile components are degraded first, while the recalcitrant components remain much longer (Dornbush et al., 2002; Fan and Guo, 2010; Li et al., 2010; Lin et al., 2011). As the former disappear and the latter accumulate, the decomposition rate decreases, presumably in a continuous manner (Dornbush et al., 2002; Fan and Guo, 2010; Li et al., 2010, 2013; Lin et al., 2011).

To overcome the limitation above, we developed a new method (dynamic-flow method) in which the temporal change in the decomposition rates of G_{I-i} and G_{II-i} were separately assessed in an improved decomposition experiment, G_{I-i} decomposition was quantified by a new decay equation, the decomposition of G_{II-i}, and the production and mortality were calculated by mass balance equations. The dynamic-flow method has two variations due to difference in the decomposition experiment and equations of the model.

We applied the dynamic-flow method to a secondary Mongolian oak (*Quercus mongolica* Fischer ex Ledebour) forest to illustrate its use (Li et al., 2001). Fine root production, mortality and decomposition in this forest were also determined by the continuous inflow method (Osawa and Aizawa, 2012) which addresses the simultaneous processes and methods including decision matrix (Fairley and Alexander, 1985), new decision matrix (Yuan and Chen, 2013), maximum—minimum (McClaugherty et al., 1982), summation of increments in fine root mass (SIR) (Persson, 1978), and the sum of fine root decompositions and biomass changes (SRD) (Ostertag, 2001) which are unable to address the simultaneous processes (Table 1). The efficacy of the dynamic-flow method was evaluated by comparing the predicted biomass with that measured by the coring method.

2. Materials and methods

2.1. Model

2.1.1. Model 1

Fine root growth, death and decomposition are simultaneous and compensating processes occurring continuously during the growing season. For calculation, the growing season is divided into n intervals ($1 \leq n$). Note that it is not required to determine the

timing of growing season in non-seasonal forests. For a given interval i ($1 \leq i \leq n$), dead fine roots are classified into two groups: fine roots which die before the start of interval i (G_{I-i}) and in interval i (G_{II-i}).

The production ($g_i(t)$) and mortality ($m_i(t)$) from the start of interval i ($1 \leq i \leq n$) to any given time (t) in it can be calculated by the following equations,

$$g_i(t) = B_i(t) - B_i(0) + m_i(t) \tag{1-1}$$

$$m_i(t) = N_{II-i}(t) - N_{II-i}(0) + d_{II-i}(t) \tag{1-2}$$

where $B_i(0)$ and $B_i(t)$ represent fine root biomass in soil cores sampled at the start and time t of interval i, respectively. $N_{II-i}(0)$ and $N_{II-i}(t)$ are the mass remaining of fine roots dying during interval i at the start and time t of that interval, respectively. $N_{II-i}(0) = 0$ as there are no fine roots dying at the start of interval i. $d_{II-i}(t)$ is the decomposition of G_{II-i} from the start to time t in interval i. t is a variable (year).

Fine root necromass in soil cores collected at the start and time t of interval i are termed as $N_i(0)$ and $N_i(t)$, respectively. Thus, the decomposition of G_{I-i} from the start to time t of interval i ($d_{I-i}(t)$) can be calculated as follows:

$$d_{I-i}(t) = N_{I-i}(0) - N_{I-i}(t) \tag{1-3}$$

$$N_{II-i}(t) = N_i(t) - N_{I-i}(t) \tag{1-4}$$

where $N_{I-i}(0)$ and $N_{I-i}(t)$ are the mass remaining of G_I at the start and time t of interval i, respectively. $N_{I-i}(0) = N_i(0)$, because there are no G_{II-i} at the start of interval i.

$B_i(t)$, $B_i(0)$, $N_i(t)$, $N_i(0)$, $N_{II-i}(t)$, $N_{II-i}(0)$, $N_{I-i}(t)$, and $N_{I-i}(0)$ have the unit g m^{-2}.

It is impossible to determine the decomposition dynamics for each fine root in G_{I-i} because most of them die at different time points and are therefore at different decomposing stages. To overcome this problem, we take all fine roots in G_{I-i} as a single pool by mixing them together and the decomposition dynamic of the mixture can be assessed using the litterbag method. This decomposition experiment, termed as ExperimentI-i ($1 \leq i \leq n$), is conducted at the start of interval i and till the end of the growing season.

The decomposition dynamics of the fine roots in G_{II-i} is determined by Experiment II-i ($1 \leq i \leq n$) which is conducted at the start of interval i till the end of the growing season. The newly senesced fine roots are used as decomposition materials and the decomposition dynamics is assessed using the litterbag method again.

A decay model which takes into account a time-dependent decay parameter is adopted to simulate the decomposition rates of both G_{I-i} and G_{II-i}. The decomposition rates are conceptualized as being highest at the beginning and monotonously decreasing over the course of the growing season. Since a particular simple parametric representation of this behavior with only two parameters shows an exponential decrease and gives best fit to experimental data in the first growing season, we can model the decomposition rate as a differential equation:

$$\frac{dy(t)}{y(t)} = \lambda e^{-k\,t} dt \tag{1-5}$$

where $y(t)$ is the amount of fine roots at time t, $\lambda e^{-k\,t}$ is the decay rate, and λ and k are parameters with a unit of year^{-1}.

As fine root decomposition is a mass loss process, the changing rate of a given amount of fine roots equals its negative decomposition rate. Inserting the negative and integrating Eq. (1-5), the