Field litter decomposition rate estimation: Does incubation starting time matter?

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***Abstract*—Litter decomposition rate is one of the most important variables regulating ecosystem carbon and nutrient cycling. However, the current estimation method – fitting an exponential decay curve to data describing litter mass remaining – may produce incorrect results if the litter decomposition rate varies depending on the time of year the field incubation trial is started. Using a computer simulation method, we demonstrated that the trajectory of litter mass remaining varied with different starting times. Although the final litter mass remaining after two years was similar for each starting time, the estimated litter decomposition rate varied significantly in the simulations. Our analyses raised cautions in the estimation and interpretation of field measured litter decomposition rate.**

Keywords-apparent litter decomposition rate; exponential decay function; optimal litter decomposition rate; soil moisture.

I. INTRODUCTION

Due to its importance in ecosystem carbon and nutrient cycling [1~3], litter decomposition has been studied for decades [4~10]. Previous studies have shown that litter decomposition is a quite complex process regulated by many factors including litter quality such as nitrogen content, carbon:nitrogen ratio and lignin content [2, 11, 12] and climatic factors such as soil temperature and moisture [13~16]. However, litter decomposition rate is usually estimated using a simple exponential decay function that is applied to litter mass remaining in litter bags incubated over a certain period of time, without considering the influence of soil temperature and soil moisture [2, 9, 10, 16].

This simple method works well for a variety of litters, especially for the early stage of decay, and it has been widely applied in both laboratory and field studies [5, 14, 16]. In the laboratory, the incubation can be held at constant temperature and moisture, and the estimated litter decomposition rate is an optimal (or maximum) litter decomposition rate, given adequate temperature and moisture. But under field conditions where soil temperature and moisture usually vary seasonally, the estimated litter decomposition rate is the overall outcome of varying litter decomposition rates. This apparent litter decomposition rate is often used in validating ecological models.

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One deficiency of this method for estimating litter decomposition rate under field conditions is that the estimated apparent litter decomposition rate may vary with the experimental starting times. If we use the same leaf litter but start the incubation at different times of the year, the seasonal patterns of soil temperature and moisture may result in different estimates of litter decomposition rate. In this study, we explored this possible influence using a model simulation approach.

II. METHODS

A set of hypothetical data are simulated with different starting times, then litter decomposition rate is estimated for each starting time using the exponential decay function. To simulate the dataset, we assume that we have a plant species with a fixed optimal litter decomposition rate (k_o). We collect leaf litter and start litter bag incubation at different starting times of the year. To simulate climate factor influence, we used the measured soil temperature and moisture in an open-top chamber global change experiment at Oak Ridge National Laboratory [17]. The measurements during October 2003 and October 2005 were used in this simulation. For simplicity and the purpose of just demonstrating the starting time influence, we assumed that soil temperature was not a limiting factor and only considered the influence of soil moisture. We also assumed that soil moisture did not limit litter decomposition when volumetric soil moisture was greater than 0.30, and linearly influenced litter decomposition rate when soil moisture was between 0.30 and 0.05 as:

$$f_{Mi} = \begin{cases} 1 & \text{when } Ms \geq 0.3, \\ 1 - \dfrac{0.30 - Ms}{0.30 - 0.05} & \text{when } Ms < 0.3, \end{cases} \quad (1)$$

where f_{Mi} is the soil moisture influence factor on litter decomposition in the ith month, Ms is the measured soil moisture. Thus, the litter decomposition rate in the ith month can be calculated as:

$$k_i = k_o f_{Mi}. \quad (2)$$

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Litter mass remaining in litter bags was then calculated monthly based on the (3) below. Let Y_i represent the fraction of mass remaining in ith month, mass remaining in $(i+1)$th month Y_{i+1} can be calculated as:

$$Y_{i+1} = Y_i e^{-k_i*1/12} + e_{i+1}, \quad (3)$$

where e_{i+1} is a small random error following a normal distribution (μ=0, σ=0.005).

We simulated eight different scenarios. The first one assumed a constant k_o (ignoring soil moisture influence on litter decomposition rate by assuming k_i=k_o=0.50 year^{-1}). The other seven scenarios started the experiment in Oct. 2003, Jan. 2004, May 2004, Aug. 2004, Dec. 2005, June 2005, and Aug. 2005, respectively. All experiments lasted for 2 years. For those experiments started later than Oct. 2003, the soil moisture measurements from previous years were repeated. This guaranteed that all experiments experienced the same soil moisture condition during the two year experiments. The only difference among experiments was the starting time.

We estimated apparent litter decomposition rate (k_A) using the exponential decay function [4, 18]:

$$Y_i = e^{-k_A*i/12}, \quad (4)$$

and compared the litter decomposition rates among different scenarios. Data analysis was performed using SAS software [19, 20]. PROC NLIN was used to fit the exponential decay function.

III. Results

Our results showed different trajectories of litter mass remaining for different starting times (Fig. 1). Litter mass remaining was consistently lower in optimal litter decomposition rate scenario than all other scenarios. Among seven different starting times, the initial litter mass remaining decreased faster when started in winter times compared to these in summer times. This was caused by summer drought conditions, which occur frequently in eastern Tennessee. Although the final mass remaining at the end of the two-year experiments was similar for all starting time scenarios, the estimated apparent litter decomposition rates varied significantly among most of the scenarios (Table 1). Estimated apparent litter decomposition rate ranged from 0.346 year^{-1} when incubation started in June 2005 to 0.410 year^{-1} when started in October 2003.

We also tested two other common litter decomposition models for starting time influences. One is the asymptotic nonlinear model with three parameters [21], $Y_i = a + br^t$, where r is the decomposition constant, a and b are parameters with $a + b$ =1. Another is the double exponential model based on the assumption that the litter substrate has two main substrate-quality components with different decomposition rates [22] $Y_i = c_1 e^{-k_1 t} + c_2 e^{-k_2 t}$, in which k_1 and k_2 are decomposition rates for fast and slow decomposition fractions (c_1 and c_2) of the litter, respectively. For both models, we found that trajectories varied among different scenarios, similarly to the simple exponential decay model. The constant decomposition rates scenario in the double exponential model showed faster decomposition than all other scenarios, but the constant r scenario in the asymptotic model showed a mid-range rate. Estimated decomposition rates for both models also varied among different scenarios. Apparent decomposition constant r_A in the asymptotic model ranged from 0.0085 to 0.0169 year^{-1} (optimal decomposition constant r_o was set as 0.05 year^{-1} in the simulation).

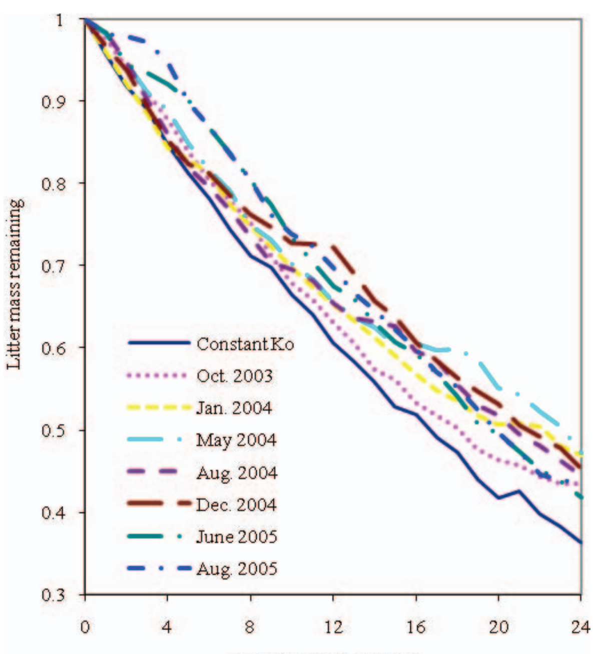

Figure 1. Simulated leaf litter mass remaining under different incubation starting time scenarios.

TABLE 1. Estimated apparent litter decomposition rate and 95% confidence interval under different starting time scenarios.

Scenario	Apparent litter decomposition rate (k_A) [a]	95% confidence interval	r^2 [b]
Constant k_o=0.50	0.499 a	0.495 – 0.503	0.999
Oct. 2003	0.410 b	0.400 – 0.419	0.992
Jan. 2004	0.389 b	0.377 – 0.401	0.984
May 2004	0.347 d	0.339 – 0.354	0.993
Aug. 2004	0.367 c	0.355 – 0.380	0.983
Dec. 2004	0.364 cd	0.353 – 0.376	0.982
June 2005	0.346 d	0.332 – 0.360	0.981
Aug. 2005	0.352 cd	0.335 – 0.370	0.972

a. k_As labeled with same letters indicate no significance between the different scenarios.

b. r^2 is coefficient of determination.

IV. DISCUSSION

The finding that estimated apparent litter decomposition rate varied with the incubation start time has significant implications and raises certain cautions in interpretation of litter decomposition in the field conditions. First of all, it poses a serious question to us when should we start a litter decomposition study. For deciduous forests, the common practice is to collect leaf litter in the previous year(s), and start the experiment next year when leaf starts senescence. While this approach is better than starting the experiment a few months late (after all the litter bags are prepared, for example), interannual variability in both climatic variables and litter quality may influence field litter decomposition rate estimation. For conifer forests and grasslands, it might be hard to decide the starting time since leaf may fall all the time during a year in conifers forests or very small amount of leaf may truly fall on the ground in grasslands. It becomes even more difficulty when the research objective is to compare litter decomposition rate of different species (e.g., among deciduous and coniferous trees and grasses). Secondly, it might be necessary to quantify this variation of litter decomposition of plant species incubated at different start times and in different soil temperature and moisture conditions. This information would be very helpful for ecological modeling. Thirdly, we may need to incorporate soil temperature and moisture effects into models for litter decomposition rate estimation. Quemada [23] reported that replacing time with moisture-adjusted time scales in the exponential decay model improved estimates of biomass decomposition rate. Liao et al. [24] also showed that a model considering temperature effect on litter decomposition fit data even better. As litter decomposition plays a critical role in ecosystem carbon and nutrient cycling, deriving accurate information from the complex litter decomposition process and massive field litter decomposition data remains an important task.

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