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Use of a regression method to partition sources of ecosystem respiration in an alpine meadow

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ABSTRACT

The partitioning of ecosystem respiration (ER) into plant respiration (PR), aboveground-part respiration (AGR), root respiration (RR), and microbial respiration (MR) components is crucial for understanding the responses of carbon cycling in terrestrial ecosystems to climate change. Here, we present the ER–PB/AGB regression method, which is a modification of the SR–BGB method (PB, plant biomass; AGB, aboveground biomass; SR, soil respiration; BGB, belowground biomass) and is based on the assumption of a linear relationship between biomass and respiration rate for the partitioning of ER into PR, AGR, RR, and MR. Diurnal measurements of CO_2 flux and biomass analysis were conducted in three *Kobresia* (*Kobresia pygmaea*, *Kobresia humilis*, and *Kobresia tibetica*) meadows on the Qinghai-Tibetan Plateau. We found significant linear relationships between ER and PB/AGB in the three meadows. However, the relationships between measured SR and BGB were either not significant or lower than those between ER and PB/AGB. The relative contributions of respiration components (AGR, RR, MR) to ER decreased consistently in the order AGR > MR > RR in the three *Kobresia* meadows. The contributions of RR and MR to SR calculated by the proposed ER–PB/AGB method differed widely among the three meadows and were consistently higher (RR) and lower (MR) than those by the SR–BGB method in all three meadows. Compared with the SR–BGB technique, our ER–PB/AGB regression method proved capable of determining more accurately the temporal changes in a larger number of respiration components.

1. Introduction

The global balance between photosynthesis and respiration, which are the major biological processes involved in the carbon cycle, regulates the level of atmospheric CO_2. Recent micrometeorological tower observations by the Eddy covariance method in a wide range of terrestrial ecosystems have demonstrated that most ecosystems play important roles as carbon sinks (Flanagan et al., 2002; Li et al., 2005; Jaksic et al., 2006; Kato et al., 2006). Additionally, spatio-temporal variations in net ecosystem CO_2 exchange (NEE) are attributable more to variations in ecosystem respiration (ER) than to variations in gross primary production (GPP) (Cox et al., 2000; Valentini et al., 2000; Barford et al., 2001; Janssens et al., 2001; Saleska et al., 2003; Davidson et al., 2006). It is plausible that strong sensitivity of ER to temperature change is the primary cause of the interannual variation in NEE, whereas GPP would be more sensitive to solar radiation. We need to partition the individual components of ER if we are to improve our understanding of the mechanisms of control of ER by abiotic and biotic factors and improve annual estimates of ER. Although the partitioning of soil respiration (SR) into root respiration (RR) and microbial respiration (MR) is gaining more importance (Kuzyakov, 2006; Subke et al., 2006), there have been only limited studies on the partitioning of ER into its components (Janssens et al., 2001; Davidson et al., 2006).

ER consists of two main components, plant respiration (PR) and MR. PR is subdivided into aboveground-part respiration (AGR) and RR. Because the dynamics of these components are controlled by temperature, water availability, vegetation structure, photosynthetic activity, and plant phenology, improved knowledge of ER partitioning will deepen our general understanding of the mechanisms behind spatio-temporal variations in ER and/or NEE.

Kuzyakov (2006) highlighted a simple method, called the regression method, of using analysis of undisturbed soil to partition SR. The regression technique first, suggested by Kucera and Kirkham (1971), is based on an assumed linear relationship between belowground biomass (BGB) and the amount of CO_2 respired by roots and by microorganisms in the rhizosphere. The amount of CO_2

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derived from decomposition of soil organic matter (SOM) corresponds to the *y*-intercept of the regression line between BGB (independent variable) and the total CO_2 evolved from the soil (dependent variable). Kucera and Kirkham (1971) observed that about 60% of the total SR in tallgrass prairie is SOM-derived. This simple method, which we call the "SR–BGB regression method" here, was applied in later studies (Gupta and Singh, 1981; Behera et al., 1990; Hill et al., 2004; Wang et al., 2005; Jia et al., 2006). However, because the data from application of the SR–BGB regression method are limited to respiration processes in the soil, no relevant information on ER is available. If the variables were to be extended from SR to ER and from BGB to plant biomass (PB) or aboveground biomass (AGB), examination of the intercepts of ER vs. PB/AGB would yield information more detailed than that obtained by SR–BGB regression.

Here, we present an extended regression method, the ER–PB/AGB regression method. In this method, MR corresponds to the *y*-intercept of the regression line between PB (independent variable) and ER (dependent variable), whereas SR corresponds to the *y*-intercept of the regression line between AGB and ER. Our method has at least three important advantages: First, it can partition four respiration components (PR, AGR, RR, and MR)—a greater number than that possible with SR–BGB regression method. Second, unlike the trenching, clipping, and root exclusion approaches, it can be used to determine the four components without any disturbance to the ecosystem. Third, ER and PB, measured as variables of a linear regression system, can be easily determined in grassland ecosystems such as those at the research sites in this study (described below), which have a low vegetation height and shallow distribution of belowground plant parts.

Our objectives were (1) to partition the four respiration components of ER; (2) to determine the diurnal changes in the components by using our new ER–PB/AGB regression method; and (3) to compare our method with the SR–BGB regression method. The study site was located on the Qinghai-Tibetan Plateau, where about 30% of the total area was covered with three types of sedge meadow, dominated respectively by *Kobresia pygmaea*, *Kobresia humilis*, or *Kobresia tibetica* (Tang, 2004). Although the *Kobresia* species belong to the same taxon, the three meadows are distributed at different sites along a topographical gradient accompanied by changes in environmental factors such as soil water content. Because the three meadows were likely to have differing microbial, root, and shoot respiration patterns as a result of their differing environmental conditions, we considered these locations suitable for our study.

2. Materials and methods

2.1. Proposed regression method

Our regression method can partition ER into PR, AGR, RR, and MR. We assumed that ER had a linear relationship with PB at a given time (during which there were no temporal changes in the controlling factors such as temperature) and in a given plant community (where there were no spatial changes in controlling factors such as soil water and nutrients); this assumption was based on the results of studies of the kinetics of plant metabolic reactions (West et al., 1997; Enquist et al., 2003; Reich et al., 2006; Enquist et al., 2007). We delineated 20 plots in each of the three types of meadow, and we measured ER, PB (both AGB and BGB), temperature, and soil water content. The linear regression between ER and PB yields a *y*-intercept that can be used to estimate MR in the absence of plants (Fig. 1), and that between ER and AGB yields a *y*-intercept that can be used to estimate SR in the absence of the aboveground parts of the plants (Fig. 1). Then RR = SR − MR, and AGR = ER − SR.

2.2. Site descriptions: K. pygmaea, K. humilis, and K. tibetica meadows

Carbon flux and environmental factors were measured at Haibei Alpine Meadow Ecosystem Research Station, Northwest Plateau Institute of Biology, Chinese Academy of Science (lat 37°36′N, long 101°18′E; 3250 m a.s.l.). The research station is located in a large valley oriented northwest–southeast on the Qinghai-Tibetan Plateau; it is surrounded on all sides by the Qilian Mountains. The average altitude of the mountains is 4000 m a.s.l. and that of the valleys is 2900 m a.s.l. The landscape is characterized by large mountain ranges, with steep valleys and gorges interspersed with relatively flat and wide inter-mountain grassland basins.

The climate at Haibei Station is characterized by low temperatures and limited precipitation. The annual average temperature and precipitation between 1981 and 2000 were −1.7 °C and 561 mm. Plentiful sunshine and rainfall (80% of the annual total) during the growing season (May–September) allow plants to grow effectively (Li and Zhou, 1998).

The soil is a clay loam to an average depth of 65 cm. The surface (0–10 cm) horizons, which are classified as Mat Cry-gelic Cambisols in accordance with the Chinese National Soil Survey classification system, are wet and rich in organic matter (Li and Zhou, 1998).

2.3. Chamber measurement of ER

A closed static chamber system was used to measure ER. This system had two parts: a base ring and a chamber. The PVC base ring (10 cm high and 7 cm in diameter) was inserted into the ground to a depth of approximately 5 cm. Since any soil disturbance can influence ER measurement, one of our precautions was to set the base rings into soil 24 h before ER measurement. The live plants surrounded by the base rings were left intact so that the measurements represented the total ER. The chamber consisted of a 25-cm tall PVC cylinder (7-cm diameter, 962-cm^3 volume) with a lid, a CO_2 probe (GMP343, Vaisala, Helsinki, Finland), a data-logger (Thermic Model 2300A, Eto Denki, Tokyo, Japan), and an acid storage battery (12 V). A small fan was fixed to the chamber wall to circulate the air within the chamber. The CO_2 emission rate was determined from the increase in CO_2 concentration in the isolated air.

ER was measured in each plot for 3 min; this translated into 1 h for all 20 plots. To determine the daily changes in ER and its components, ER in the 20 plots was measured hourly from 08:30 to 16:30 (a total of 8 times) on 16 July, 23 July, and 30 July in the *K. humilis*, *K. tibetica*, and *K. pygmaea* meadows, respectively.

2.4. Measurement of SR (aboveground plants removed)

To compare the proposed new regression technique with the more often used SR–BGB regression technique, we clipped the aboveground parts of the plants in the 20 chambers and measured SR on the day after the ER measurements with the same chamber system. The measurements in each of the 20 plots were taken hourly from 08:30 to 10:30 and 13:30 to 16:30 (5 times) on 17 July; 08:30 to 11:30 and 14:30 to 16:30 (5 times) on 24 July; and 08:30 to 11:30 (3 times; it rained from 11:30) on 31 July in the *K. humilis*, *K. tibetica*, and *K. pygmaea* meadows, respectively.

2.5. Measurement of plant biomass

After the SR measurements, the belowground parts of plants were harvested to a depth of 20 cm; this depth was based on data from previous work at Haibei Research Station, which showed that