



## Partitioning of ecosystem respiration in winter wheat and silage maize—modeling seasonal temperature effects



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### ABSTRACT

The response of agroecosystem carbon (C) respiration fluxes to environmental changes needs to be better understood as respiration subcomponents may respond differently to management and seasonal weather dynamics, which is important for soil organic matter (SOM) modeling. Respiration measurements at two different spatial and temporal scales (eddy covariance (EC) and soil chambers) were used to ascertain the relationship between temperature and CO<sub>2</sub> flux of different ecosystem respiration components (ecosystem ( $R_{eco}$ ), soil and root combined, and soil). Further, different model approaches (static versus dynamic reference CO<sub>2</sub> rate ( $r_b$ ) and activation energy type parameter ( $E_0$ ) with an Arrhenius-like function) in order to partition  $R_{eco}$  into above- and belowground autotrophic ( $R_{A\_above}$ ,  $R_{A\_below}$ ) and heterotrophic respiration ( $R_{H\_SOM}$ ) were tested. Canopy level CO<sub>2</sub> fluxes in winter wheat and silage maize were measured by EC stations and soil surface CO<sub>2</sub> flux by a handheld chamber analyzer in arable fields in Southwest Germany over a period of three growing seasons (2009, 2010, and 2012). Additionally, successive bare fallow plots were installed at the beginning of each growing season to partition soil respiration between autotrophic and heterotrophic sources (including “labile” soil C (newest bare fallow) as the difference to the oldest bare fallow). Stepwise model building was tested with keeping  $r_b$  and  $E_0$  constant (static method) and then by varying  $r_b$  and  $E_0$  each individually or together by time period (dynamic method) over the whole growing season (15, 10 or 7 days for  $R_{eco}$ , measurement periods for soil chamber measurements). The dynamic models were superior as measured by Aaike Information Criteria (AIC) and coefficient of determination (average  $R^2$ , 0.15 for the static model and 0.50 for the dynamic model). In the best fitting model for each crop-year (lowest AIC),  $r_b$  was successfully estimated in each time period (relative standard error <50%), while seasonally variable  $E_0$  estimates were found in half of the crop years. Estimated  $Q_{10}$  values were between 1 to 6.01 between different components and seasons. Estimated  $R_{eco}$  components during 2012, autotrophic above ground respiration accounted for the largest component during the intense measurement periods under both winter wheat (50%) and maize (60%), with root respiration accounting for 19% and 21%, respectively. Additionally under winter wheat 31% of  $R_{eco}$  was estimated as heterotrophic respiration, with 15% from labile soil C. The results highlight the need to apply individual temperature response functions when using temperature as a driving force for ecosystem respiration components (autotrophic and soil heterotrophic).

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### 1. Introduction

Knowledge of carbon (C) fluxes in ecosystems, especially agroecosystems, at different temporal and spatial scales is a prerequisite to understand the response of these systems to different types of management and climate (Gregorich et al., 2005).

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For example, small gains or losses in soil organic carbon (SOC) as a result of management are often difficult to detect with SOC stock inventories (Smith et al., 2010) due to soil heterogeneity and measurement error (Conant et al., 2011). Therefore, more detailed seasonal accounting of the entire C budget via fluxes, including losses via autotrophic and heterotrophic respiration, can be a more rapid indicator of either short-term soil C sequestration or loss (Hollinger et al., 2005).

Agroecosystems are diverse in terms of crops grown, rotation, management, soil types, and climatic conditions, making it difficult to directly upscale results from individual fields to larger scales such as a regional basis (Smith et al., 2010). Thus, an improved process-based understanding at the plot and field level often has to be used for parameterization and validation of ecosystem models, which are then combined with detailed spatial datasets (e.g., land-use management, soil type, climate) to be extrapolated to larger scales (Smith et al., 2010). In agroecosystems, the eddy covariance method (EC) is commonly used for measuring net ecosystem exchange ( $NEE$ ) and deriving ecosystem respiration ( $R_{eco}$ ) and gross primary productivity (e.g., (Gilmanov et al., 2010)). While the EC method allows a high temporal resolution integrating  $CO_2$  fluxes over an entire field, separation of  $R_{eco}$  components (e.g., above-, belowground, heterotrophic, autotrophic) is not usually possible unless isotopic enrichment (Lin et al., 1999) or pulse-labeling is used (Riederer et al., 2015). Accounting for the components of ecosystem C fluxes is important as the drivers and effects on one component may differ from another one and may cancel each other out if only the sum is quantified (Heinemeyer et al., 2012b) and may vary with crop type and environmental conditions even at the same site (Zhang et al., 2013). For  $R_{eco}$  component partitioning, further measurements such as soil chamber measurements at the plot level need to be combined with EC method. Components of  $R_{eco}$  (plant above and below ground and respiration from soil organic matter (SOM) decomposition) have been previously estimated using a combination of EC measurements (night-time respiration extrapolated to daytime), and soil chamber methods (for both root respiration and SOM respiration) (Suleau et al., 2011; Loubet et al., 2011; Wu et al., 2013).

Temperature has been determined as a main driving factor for  $R_{eco}$  (e.g., (Reichstein et al., 2005)). When calculating a temperature response of  $R_{eco}$  or components, commonly a single function (e.g., exponential, Arrhenius) has been applied for the entire year (Hollinger et al., 1994; Law et al., 1999), or a varying reference respiration parameter (respiration at a certain reference temperature) used (Falge et al., 2002). More recently, approaches allowing both reference respiration and temperature response to vary during the year have gained importance (Reichstein et al., 2005; Heinemeyer et al., 2012a,b). The latter approach has the advantage of incorporating more flexibility into the model (Reichstein et al., 2005) and minimizes effects such as changes in plant growth and soil moisture (Curiel Yuste et al., 2004) which can confound and affect the relationship between temperature and respiration when using just a single temperature response function during the growing season. It would be advantageous to apply this approach to model temperature responses of individual respiration components as it can be expected that the previously mentioned dynamic environmental conditions also affect the temperature response of  $R_{eco}$  sub-components (root and soil respiration).

Combining results from both EC and chamber methods allow the assessment of individual component fluxes and to account for differing component magnitudes and temperature sensitivities. If only a measurement of  $R_{eco}$  is obtained, then the resultant temperature sensitivity is a composite of all individual components. Estimates of autotrophic ( $R_A$ ) and heterotrophic ( $R_H$ ) components of soil respiration has been accomplished via root exclusion treatments (e.g., (Zhang et al., 2013; Suleau et al., 2011;

Moyano et al., 2007; Heinemeyer et al., 2012a,b). Suleau et al. (2011) found lower temperature sensitivity of  $R_A$  than  $R_H$  under potato, winter wheat, and sugar beet, while Zhang et al. (2013) found higher temperature sensitivity for  $R_A$  than  $R_H$  under both winter wheat and maize each during one season. Both of these studies used a single growing season temperature response and reference respiration function to model respiration components, possibly concealing within season changes of respiration temperature sensitivity.

Mueller et al., (1997, 1998) established bare fallow plots with and without addition of crop harvest residues to partition between relatively labile (recently added organic matter) and more stable (SOM) substrate sources for soil respiration in a modeling study. If bare fallow plots are established at different time points, then this may even represent a gradient in amounts of labile carbon as opposed to newly established bare fallow plots, as it is assumed that relatively labile carbon will be lost from the older bare fallow plots compared to the newer bare fallow plots. Comparing these time series plots, the temperature response of predominantly labile and more stable SOM can then be studied as different stabilities of SOM with hypothesized different temperature sensitivities (Davidson and Janssens, 2006). To our knowledge, such a study is lacking in which within growing season temperature sensitivity is investigated over multiple growing seasons and crops to separate not only above and below-ground autotrophic respiration, but also labile and more stable SOM in croplands. This is needed as trends in a single crop-season may be strongly influenced by management and/or weather conditions.

We hypothesized that modeling of ecosystem respiration can be improved by accounting for the seasonal variation of the magnitude and temperature sensitivity of different  $R_{eco}$  components (total, root and SOM-derived). The main objective was to partition  $R_{eco}$  into its subsequent components of above- ( $R_{A\_above}$ ) and belowground ( $R_{A\_below}$ ) autotrophic respiration as well as heterotrophic contributions of "labile" ( $R_{H\_labile}$ ) and "old" ( $R_{H\_SOM}$ ) SOM. The specific objectives were to (a) measure main growing season  $R_{eco}$  via night-time EC fluxes under two crops (winter wheat and silage maize) coupled with soil surface  $CO_2$  flux measurements under cropped plots (winter wheat and silage maize) and in bare fallow plots of different ages to estimate dynamics of reference respiration and temperature sensitivity, (b) partition ecosystem respiration into component fluxes, (c) estimate growing season fluxes using the two model approaches, (d) and finally discuss the benefits of the different modeling approaches for upscaling.

## 2. Materials and methods

The study site was in Southwest Germany, state of Baden-Württemberg close to the city of Pforzheim (48° 55.7' N, 8° 42.2' E). Three farmer's fields (denoted as Field 1 (14.9 ha), 2 (23.6 ha), and 3 (15.8 ha), situated west to east) were selected for installation of eddy covariance (EC) stations, one in each field. The soils were classified as Stagnic Luvisols (IUSS Working Group WRB, 2007) with a texture of 2.3% sand and 17.7% clay. Pre-site selection was carried out to ensure relatively flat terrain and adequate area of homogeneous crop cover for each EC footprint. Each EC station was placed in the field center with the distance to the field edge between 170 and 290 m. The contribution of the target field to the footprint of the EC stations was >=98% as determined by the Lagrangian footprint model (Wizemann et al., 2015). The height of the EC towers was set at 2 m above the ground surface during fallow periods and was adjusted during the growing season to the crop canopy height. In case of wheat the maximum installation height at maximum canopy height varied between 2.5 and 2.95 m. In case of maize this maximum height ranged between 3.85 and 4.4 m. Crop and management details during the three seasons are

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