Soil Biology & Biochemistry 42 (2010) 1549–1557

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Belowground carbon allocation patterns in a dry Mediterranean ecosystem: A comparison of two models

M. Almagro*, J. López, C. Boix-Fayos, J. Albaladejo, M. Martínez-Mena

Departamento de Conservación de Suelos y Aguas, Centro de Edafología y Biología Aplicada del Segura-CSIC, Campus de Espinardo, P.O. Box 4195, 30100 Murcia, Spain

ARTICLE INFO

Article history:
Received 16 November 2009
Received in revised form
20 May 2010
Accepted 28 May 2010
Available online 9 June 2010

Keywords:
Mediterranean ecosystem
Carbon budget
Total belowground carbon allocation
Litterfall
Litter decomposition
Soil respiration
Water erosion
Root production
Aboveground net primary production
Belowground net primary production

ABSTRACT

Total belowground C allocation (TBCA) accounts for a large fraction of gross primary production, it may overtake aboveground net primary production, and contributes to the primary source of detrital C in the mineral soil. Here, we measure soil respiration, water erosion, litterfall and estimate annual changes in C stored in mineral soil, litter and roots, in three representative land uses in a Mediterranean ecosystem (late-successional forest, abandoned agricultural field, rain-fed olive grove), and use two C balance approaches (steady-state and non-steady-state) to estimate TBCA. Both TBCA approaches are compared to assess how different C fluxes (outputs and inputs) affect our estimates of TBCA within each land use. In addition, annual net primary productivity is determined and C allocation patterns are examined for each land use. We hypothesized that changes in C stored in mineral soil, litter and roots will be slight compared to soil respiration, but will still have a significant effect on the estimates of TBCA. Annual net primary productivity was 648 ± 31.5, 541 ± 42.3 and 324 ± 22.3 g C m^{-2} yr^{-1} for forest, abandoned agricultural field and olive grove, respectively. Across land uses, more than 60% of the C was allocated belowground. Soil respiration (F_S) was the largest component in the TBCA approaches across all land uses. Annual C losses through water erosion were negligible compared to F_S (less than 1%) and had little effect on the estimates of TBCA. Annual changes in C stored in the soil, litter layer and roots were low compared to F_S (16, 24 and 10% for forest, abandoned agricultural field and olive grove, respectively), but had a significant effect on the estimates of TBCA. In our sites, an assumption that $\Delta[C_S + C_R + C_L]/\Delta t = 0$ will underestimate TBCA, particularly in the abandoned agricultural field, where soil C storage may be increasing more rapidly. Therefore, the steady-state model is unsuited to these Mediterranean ecosystems and the full model is recommended.

1. Introduction

Carbon storage in terrestrial ecosystems is governed by the difference that exists between inputs from aboveground and belowground net primary production and outputs through erosion and decomposition of plant material and soil organic matter at both short and long term scales. Dry and semi-arid lands, which are characterized by patches of vegetation and bare soil, are the dominant ecosystems in Mediterranean climates. Slow growth rates, difficult land recovery after degradation and potentially high mineralization rates make them especially sensitive to perturbations resulting from climate change, drought and land-use changes (Domingo et al., 1999; Smith et al., 2000; Asner et al., 2003; Giorgi, 2006).

Vegetation allocates carbon (C) belowground to the production of coarse and fine roots, for root respiration and exudation, and to maintain mycorrhizal activity (Raich and Nadelhoffer, 1989). Total belowground C allocation (TBCA) accounts for a large fraction of gross primary production, it may overtake aboveground net primary production, and contributes to the primary source of detrital C in the mineral soil (Ryan et al., 1994, 1997; Gower et al., 1996; Law et al., 1999). Because of the lack of direct measurements of TBCA, Raich and Nadelhoffer (1989) proposed a conservation of mass approach to estimate TBCA (g C m^{-2} yr^{-1}) in ecosystems where the stocks of soil organic matter, roots, and litter were assumed to be nearly steady:

$$\mathrm{TBCA} = F_S - F_A \quad (1)$$

where F_S is the soil-surface CO_2 efflux (soil respiration) and F_A is the aboveground litterfall.

As the near-steady-state assumption is sometimes uncertain and problematic (for example, disturbed forests, forests established on agricultural land, croplands; Nadelhoffer et al., 1998), Giardina

* Corresponding author. Tel.: +34 968396264; fax: +34 968 396213.
E-mail address: mbonmati@cebas.csic.es (M. Almagro).

0038-0717/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2010.05.031

and Ryan (2002) proposed a similar approach, whereby C outputs from the soil equal C inputs minus any change in the C stored in soil per unit of time (Δt):

$$F_S + F_E = \text{TBCA} + F_A - \Delta[C_S + C_R + C_L]/\Delta t \quad (2)$$

Soil-surface CO_2 efflux (F_S) is the largest output of C in forest soils. Although poorly quantified, the export of C through erosion and leaching (F_E) is very low compared with the other fluxes, and so has relatively little influence on the total soil carbon budget (Edwards and Harris, 1977; Schlesinger, 1977, 1984; Raich, 1983; Giardina and Ryan, 2002; Forrester et al., 2006). At our study-site, the loss of C through leaching is probably negligible because of low soil water-extractable organic carbon concentrations (Martínez-Mena et al., 2008). However, we include the carbon mobilized by water erosion in our TBCA approach because of the importance of this process in the organic C balance of Mediterranean ecosystems (Smith et al., 2007). Soil C inputs include the C allocated belowground by plants for root production and respiration, exudation, and for the maintenance of mycorrhizal activity (TBCA), together with aboveground litterfall (F_A). The major components affecting C storage in soils are mineral soil organic matter (C_S), fine and coarse roots (C_R), and the litter layer (C_L).

Thus, through conservation of mass, TBCA can be estimated:

$$\text{TBCA} = F_S + F_E - F_A + \Delta[C_S + C_R + C_L]/\Delta t \quad (3)$$

Both TBCA approaches have previously been used for different purposes in mature temperate or tropical forests, and in plantations with high stem density, a considerable litter layer thickness and medium to high mean annual precipitation (Raich and Nadelhoffer, 1989; Davidson et al., 2002; Giardina and Ryan, 2002; Forrester et al., 2006; Newman et al., 2006). However, the steady-state assumption has not been directly tested for dry Mediterranean woodlands or tree-crop fields.

This study focuses on characterizing C pools and allocation patterns along a land-use intensification gradient in a Mediterranean ecosystem (late-successional forest, abandoned agricultural field, rain-fed olive grove). The specific objective of the present work was to compare both C balance approaches to assess how different C fluxes (outputs and inputs) affect our estimates of TBCA within each land use. We hypothesized that changes in mineral C soil, litter and roots would be slight compared to soil respiration, but would have a significant influence on the estimates of TBCA.

2. Materials and methods

2.1. Study area

The study area was located in Cehegín in the northwest of the province of Murcia in S.E. Spain. The climate is dry meso-mediterranean with an average annual precipitation of 370 mm, which occurs mostly in autumn and spring. The mean annual temperature is relatively high, 15.5 °C, and mean potential evapotranspiration (calculated by the Thorntwaite method) is 800 mm yr^{-1}, so the mean annual water deficit is 430 mm. July and August are the driest months. This area is representative of the agricultural, socioeconomic and environmental situation of many dryland farming areas in the Mediterranean region, where the main limitation to agriculture is water shortage. A heterogeneous mosaic of agricultural practices exists in this area. Three sites (1.5 km^2) representative of each land-use type were selected to carry out the study: 1) a circa 150-yr-old forest stand, 2) an abandoned agricultural field which was cultivated with cereal until about 25 years ago, and 3) a rain-fed olive grove without terraces and regularly ploughed along the contour lines. The olive grove was planted with a 10 × 10 m spacing (107 olive trees/ha) and has been cultivated for 100 years. The forest and abandoned agricultural field sites are covered by a typical Mediterranean shrubland with scattered Aleppo pines (*Pinus halepensis*). Although both sites show the same dominant plant species (*Rosmarinus officinalis*, *Quercus coccifera*, and *Juniperus oxycedrus*), the forest presents a more developed vegetation structure, with a total vegetation cover of about 65% compared with the 35% of the abandoned agricultural field. The soils in the study area, with a loamy texture, derived from limestone colluvia (forest and olive grove) and Triasic marl colluvia (abandoned agricultural field), are classified as Petric calcisol (forest and olive grove), and Calcaric regosol (abandoned agricultural field) (FAO, 2006). The three areas are located on a glacis hillslope with a mean height of 640 m a.s.l., and a mean slope of 10–12%, good drainage and a high percentage of surface stones. The forest and olive grove are adjacent, and occupy around 1.8 and 1.2 ha, respectively. The abandoned agricultural field, which has not been exposed to human perturbation since it was abandoned 25 years ago, is located 2 km away and occupies 0.15 ha.

Rather than comparing C pools and fluxes among different land uses, this study focuses on understanding belowground C cycling within the most representative sites in this area. Hence, we chose to intensively study one site in each land-use type rather than attempting to replicate sites across the ecosystem. Although the experimental design of this study may be considered a case of "simple pseudoreplication" (Hurlbert, 1984) for the purpose of comparing C fluxes and pools among different land uses, we feel the approach is suitable for testing the validity of both C-budgeting models to estimate total belowground C allocation.

2.2. Measurements and calculations

2.2.1. Organic carbon pools

For each land use, 24 sampling points at 15 cm depth were distributed in a stratified manner, depending on the number of plant cover types within each land use. A composite sample from each point included a non-disturbed sample (core of 100 cm^3 volume) for bulk density measurements and a disturbed sample for C and N analysis. Soil samples for analyses were air-dried, ground and sieved through a 2 mm sieve. Before soil organic carbon (SOC) and total nitrogen (TN) were analysed, using a N/C Analyzer (Flash 1112 EA, Thermo-Finnigan, Bremen, Germany), soil carbonates were eliminated using 1 M HCl. Soil organic carbon stock (g m^{-2}) was computed as a product of the organic C concentration, bulk density and depth for each sampling point.

Aboveground biomass (AGB) was estimated from plot-based measurements of shrub and tree stem basal diameters. Twenty-four 5 × 5 m plots were located in the forest ($N = 16$) and abandoned agricultural field ($N = 8$), and every single stem basal diameter was measured at the end of the growing season (2006) in order to estimate AGB from species-specific allometric relationships (Baeza et al., 2006; Baeza et al., unpublished data; Barberá et al., unpublished data). In the olive grove, AGB was estimated from trunk basal area measurements ($N = 30$) using an allometric relationship developed using 18 *Olea europaea* L. trees growing in a cropland from southern Spain (Villalobos et al., 2006). Representative biomass samples (stems, twigs, and needles) were dried at 50 °C for seven days, weighed and ground. The C content of AGB was estimated to be 48% of dry weight, hereinafter referred to as ABG-C (g C m^{-2}).

Belowground biomass (BGB) was estimated using the core method (Vogt et al., 1998). Twelve soil cores were collected according to a stratified sampling design at each land-use site in late December 2006. The sampling was repeated in late April 2007. Plant roots were sampled at a mean depth of 15 cm by collecting soil cores 8 cm in diameter. The soil cores were gently rinsed through a series of three successively smaller sieves (5.0,