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Partitioning carbon fluxes in a Mediterranean oak forest to disentangle changes in ecosystem sink strength during drought

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ABSTRACT

Net carbon flux partitioning was used to disentangle abiotic and biotic drivers of all important component fluxes influencing the overall sink strength of a Mediterranean ecosystem during a rapid spring to summer transition. Between May and June 2006 we analyzed how seasonal drought affected ecosystem assimilation and respiration fluxes in an evergreen oak woodland and attributed variations in the component fluxes (trees, understory, soil microorganisms and roots) to observations at the ecosystem scale. We observed a two thirds decrease in both ecosystem carbon assimilation and respiration (R_{eco}) within only 15 days time. The impact of decreasing R_{eco} on the ecosystem carbon balance was smaller than the impact of decreasing primary productivity. Flux partitioning of GPP and R_{eco} into their component fluxes from trees, understory, soil microorganisms and roots showed that declining ecosystem sink strength was due to a large drought and temperature-induced decrease in understory carbon uptake (from 56% to 21%). Hence, the shallow-rooted annuals mainly composing the understory have a surprisingly large impact on the source/sink behavior of this open evergreen oak woodland during spring to summer transition and the timing of the onset of drought might have a large effect on the annual carbon budget. In response to seasonal drought R_{eco} was increasingly dominated by respiration of heterotrophic soil microorganisms, while the root flux was found to be of minor importance. Soil respiration flux decreased with drought but its contribution to total daily CO_2-exchange increased by 11.5%. This partitioning approach disentangled changes in respiratory and photosynthetic ecosystem fluxes that were not apparent from the eddy-covariance or the soil respiration data alone. By the novel combination of understory vs. overstory carbon flux partitioning with soil respiration data from trenched and control plots, we gained a detailed understanding of factors controlling net carbon exchange of Mediterranean ecosystems.

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1. Introduction

The carbon balance of ecosystems is controlled by inputs via photosynthetic assimilation, storage in various pools (e.g. plant biomass, soil carbon) and loss of carbon by autotrophic and heterotrophic respiration as well as leaching, physical demineralization of inorganic soil carbon, erosion and forest fires (e.g. Schulze et al., 2000; Law et al., 2002; Trumbore, 2006). Carbon cycling in forest ecosystems involves complex interactions between numerous C-pools, which vary both spatially and temporally and may also be differentially affected by environmental variables (e.g. Schimel et al., 2001; Law et al., 2002; Valentini et al., 2003). In order to understand large scale effects of global warming on ecosystem productivity a process-based understanding of carbon sequestration is needed.

Partitioning net carbon fluxes into assimilatory and respiratory components provides an important tool for analyzing abiotic and biotic processes driving carbon cycling. Various methods for measuring and modeling the opposing fluxes emerged within recent years. One common method uses eddy-covariance data in empirical models which apply temperature corrections to the nighttime CO_2-fluxes to calculate ecosystem respiration (R_{eco}) and to partition daytime fluxes (e.g. Aubinet et al., 2000; Reichstein et al., 2002b; Reichstein et al., 2005).

The interplay between ecosystem primary productivity and respiration processes determines the source/sink capacity of an ecosystem for atmospheric CO_2. Although many terrestrial ecosystems (e.g. forests) are net carbon sinks, changes in climate and phenology can result in a transformation of ecosystems to net carbon sources (Lindroth et al., 1998; Valentini et al., 2003; Ma et al., 2007; Pereira et al., 2007). It has been shown that ecosystem respiration (R_{eco}) is a main determinant of carbon balance in most ecosystems (e.g. Valentini et al., 2000; Rambal et al., 2004), particularly in low productive ecosystems such as the studied Mediterranean oak woodland (Pereira et al., 2007).

Temporal variation in ecosystem respiration was observed to be substantial in various studies across different biomes (e.g. Baldocchi, 1997; Valentini et al., 2000; Xu et al., 2004; Reichstein et al., 2005). This variability is mainly due to concomitant temporal changes in driving climatic factors such as temperature and soil moisture (e.g. Huxman et al., 2003; Xu et al., 2004; Davidson et al., 2006b; Jarvis et al., 2007). Autotrophic respiration of leaves and roots as well as mychorrizal respiration depends mainly on photosynthetic assimilation whereas heterotrophic respiration of soil microorganisms and fungi is a function of the amount of labile soil carbon (Scott-Denton et al., 2006; Subke et al., 2006). Consequently, different respiration sources have different temporal dynamics. Autotrophic soil respiration follows periods of growth- and carbon-assimilation cycles throughout the year, whereas heterotrophic soil respiration also depends on pulse-like carbon inputs, such as litterfall, priming and other processes (e.g. Kuzyakov and Cheng, 2001).

The complex interplay between assimilatory and respiratory sources and their responsiveness to abiotic changes such as drought and temperature remain poorly understood. Hence, there is a need to disentangle component fluxes for a better comprehension of changes in source/sink behavior of ecosystems in response to climate. Increasing scientific effort was made to partition ecosystem carbon fluxes into all major component fluxes (e.g. Goulden et al., 1996; Lavigne et al., 1997; Law et al., 1999, 2001; Davidson et al., 2006a; Ma et al., 2007).

Due to marked annual dynamics in their source/sink behavior and a simple two-layer structure, Mediterranean oak woodlands (*montado*) are very suitable for studying climate impacts on ecosystem and component carbon fluxes. They represent one of the most typical land use types in south-west Europe (Joffre et al., 1999). Slow growth rates and difficult land recovery after degradation make them especially vulnerable to global climate change (Giorgi, 2006). In these winter rain climate ecosystems, the upper layer is an open tree canopy (savanna-type), consisting mostly of deep rooted evergreen oaks standing over a low vegetation understory consisting largely of shallow-rooted herbaceous annuals that vanish by the end of spring when soil water in the upper soil layers has been depleted. Summer drought constitutes a period of high evaporative demand and low soil water availability (e.g. Tenhunen et al., 1990). Increasing frequency and severity of drought as well as changes in the precipitation pattern can cause large reductions in ecosystem carbon exchange of these ecosystems (Ciais et al., 2005; Giorgi, 2006; Granier et al., 2007; Pereira et al., 2007). The change from the productive spring period to summer drought is generally very rapid and turns the Mediterranean woodland from a carbon sink into a carbon source within only a few weeks. Since most of the annual net carbon assimilation in the Mediterranean occurs between March and June (Allard et al., 2008), timing and length of this event might strongly influence the annual carbon budget (Werner et al., 2006; Ma et al., 2007; Pereira et al., 2007; Allard et al., 2008).

In this partitioning study we took advantage of this rapid transition period to identify the factors driving changes in ecosystem source/sink behavior in the Mediterranean oak-savanna in southern Portugal. We aimed at identifying (i) changes in sink strength in a short-term response to drought; (ii) the component fluxes responsible for these changes and (iii) their dependencies on environmental factors. We hypothesized that some ecosystem components would be more sensitive to water deficits and rising temperature than others and thus, are likely to significantly influence ecosystem carbon budgets under future climate scenarios.

2. Materials and methods

2.1. *Field site and environmental conditions*

The experimental site Mitra is located near Évora in southern Portugal, at 38° latitude N and 8° longitude W and is part of the CarboEurope-IP project (see Pereira et al., 2007). The climate is typically Mediterranean, with a hot and dry summer. More than 80% of annual precipitation occurs between October and April. The long-term (1961–1990) mean annual temperature is 15–16 °C and average annual precipitation is ca. 669 mm. The site is on the ‘‘Alentejana’’ plain, with low altitude (220–250 m) and gentle slopes with soils derived from granite rock. It is in the middle of a homogeneous landscape dominated by