Agriculture, Ecosystems and Environment 196 (2014) 167–177

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Litter decomposition rates of green manure as affected by soil erosion, transport and deposition processes, and the implications for the soil carbon balance of a rainfed olive grove under a dry Mediterranean climate

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ARTICLE INFO

Article history:
Received 21 March 2014
Received in revised form 25 June 2014
Accepted 26 June 2014
Available online 6 August 2014

Keywords:
Soil erosion
High-intensity rainfall event
Litter decomposition
Soil carbon balance
Mediterranean agroecosystem
Green manure

ABSTRACT

Soil erosion by water promotes the distribution of soil organic carbon (SOC) and nutrients within the landscape. Moreover, soil redistribution may have a large impact on litter decomposition dynamics. There is a current lack of information about the role of soil erosion in the SOC balance of sloping agricultural fields because its magnitude and direction depend on the dominant horizontal and vertical C fluxes at the different landform (eroding, transport and depositional) positions within the hillslope. Therefore, the significance of these lateral fluxes in the local C balance has to be assessed when interactions with vertical C fluxes (e.g., litter decay) are also taken into account. An experiment was designed to increase our understanding of the role of different phases of the soil erosion process in litter decomposition and the resulting impact on the soil C balance of a rain-fed olive grove under a dry Mediterranean climate, in which two or three high intensity-low frequency rainfall events are responsible for the majority of the annual soil erosion. To accomplish this, four replicate plots were installed at three different landform positions, according to erosion criteria (eroding, transport and depositional sites), and two litter types (*Avena sativa* L. or *Vicia sativa* L.) with contrasting initial litter chemistry (high C:N, low C:N) were deployed in the middle of the summer season, before the expected occurrence of rainfall events in the experimental area. Two successive rainfall events led to pronounced patterns of erosion and associated processes of soil transport and deposition, accounting for 99% of total soil loss in the experimental area and leading to the burial of most of the litterbags located at the depositional positions. The results indicate that soil erosion (lateral movement and soil mixing) may be an important mechanism of litter decomposition, as litter mass loss rates were related closely to the amount of soil infiltrated/deposited within the litterbags for both litter types, decay rates at depositional sites being about three-fold higher than at eroding and transport sites. Our results also indicate that soil mobilisation by erosion has significant impacts on C dynamics, causing lateral and vertical fluxes of C similar in magnitude to those induced by changes in land use or management. According to our estimates, soil C losses driven by land-use change could be compensated after 20 years of green manure incorporation in this rainfed Mediterranean olive grove.

1. Introduction

Soils are the largest carbon (C) reservoir of the terrestrial C budget (Batjes and Sombroek, 1997). Therefore, even a relatively small increase or decrease in soil C content due to changes in land use or management practices may result in a significant net exchange of C between the soil reservoir and the atmosphere (Houghton, 2003). Under natural conditions, soil systems are considered to be in equilibrium, as losses through erosion and decomposition of litter and soil organic matter are compensated by inputs from aboveground and belowground net primary production on both short- and long-term scales (Giardina and Ryan, 2002). However, conversion from native to agricultural ecosystems has increased C losses to the atmosphere without enhancing C inputs into soil, and therefore the global C cycle has been drastically altered (DeFries et al., 1999; IPPC, 2007). These C losses, given by previous native vegetation and subsequent annual

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http://dx.doi.org/10.1016/j.agee.2014.06.027
0167-8809/

crop removal, tillage operations and enhancement of soil erosion rates (Lal, 2003; Quinton et al., 2010; Van Oost et al., 2005, 2012), may be compensated by sustainable land management (SLM) practices. In this regard, the incorporation of cover crops such as leguminous species (i.e., green manure) into the soil of a given cropping system is considered a promising sustainable management practice to reduce soil erosion risk (Almagro et al., 2013a; Alliaume et al., 2014; De Baets et al., 2011; Francia Martínez et al., 2006; Gómez et al., 2009) while compensating soil C losses derived from land-use change and tillage in agricultural fields (Gómez-Muñoz et al., 2014; Lal, 2013; Milgroom et al., 2007; Ramos et al., 2010). This is an important issue in Southern Spain, where subsidy policies have induced the expansion and intensification of olive and almond orchards in hilly environments while overlooking erosion-derived problems, and furthermore, an increase in the area suitable for olive production is expected with climate warming (García-Ruiz, 2010; Olesen and Bindi, 2002).

Soil erosion (detachment, transport and deposition) affects not only the distribution of sediments and associated C within the hillslope (Ritchie and McCarty, 2003; Nadeu et al., 2012; Zhang et al., 2006) but also litter decomposition dynamics through several abiotic and biotic mechanisms (Barnes et al., 2012; Berhe, 2012; Hewins et al., 2013; Lee et al., 2014; Throop and Archer, 2009). There are several mechanisms involved in litter decomposition during the process of soil erosion by water along hillslopes. During detachment and transport, soil deposition onto litter (or burial of litter) may not occur but collision with soil particles may be an important mechanism driving litter fragmentation, increasing the surface area available for microbial decomposers transported within the sediments (Barnes et al., 2012; Berhe, 2012; Throop and Archer, 2009). During deposition, besides physical fragmentation by soil abrasion, burial of litter may accelerate decay rates by promoting soil-litter mixing and improving soil moisture and temperature conditions for microbial decomposition (microclimate buffering) (Barnes et al., 2012; Throop and Archer, 2009; Whitford, 2002). Therefore, to understand erosional effects on litter decomposition dynamics the consideration of all three phases (soil erosion, transport and deposition) is necessary.

As a result of ongoing global climate change, and the increasingly acknowledged importance of the role of abiotic factors in comparison to biotic factors in litter decomposition dynamics in dry ecosystems (King et al., 2012; Throop and Archer, 2009), much effort is being devoted to improving our understanding of the abiotic factors driving litter decomposition dynamics and subsequent soil C storage. Although the importance of photodegradation as an abiotic mechanism in litter decomposition has been highlighted recently (Austin and Vivanco, 2006), accounting for the liberation of 1–4 g C m^{-2} yr^{-1} (Brandt et al., 2009), the role of soil erosion has been overlooked in most litter decomposition studies. Most of these studies have been conducted on flat landscapes and little is known about how litter decomposition rates vary along dynamic hillslope environments experiencing lateral soil distribution with soil erosion, despite the fact that these hilly environments account for more than 60% of the terrestrial Earth surface (Staub and Rosenzweig, 1992). Although recent studies have shown that soil erosion can be a significant driver of litter decomposition in arid, semiarid and Mediterranean ecosystems (Almagro and Martínez-Mena, 2012; Berhe, 2012; Hewins et al., 2013; Throop and Archer, 2007), the magnitude, direction and mechanisms (physical fragmentation or microbial decomposition facilitation) behind litter decomposition by soil water erosion remain largely unexplored. To the best of our knowledge, this is the first study to examine the roles of the different phases of soil erosion in litter decomposition rates (but see Berhe, 2012) and their implications for the soil organic carbon (SOC) balance along a dynamic hilly Mediterranean agroecosystem.

The main purpose of this study was to assess whether the process of soil erosion plays a significant role in the soil C balance of this dry Mediterranean agroecosystem, when its interaction with litter decomposition is considered. More specifically, the objectives were: (1) to understand the role of the different phases (erosion, transport and deposition) of soil erosion in the short-term litter decomposition of two contrasting species, common oat (*Avena sativa* L.) and vetch (*Vicia sativa* L.); (2) to identify the factors controlling litter decomposition rates during the different phases of the soil erosion process; and (3) to assess the contribution of green manure incorporation to the soil C balance of a rainfed olive grove under dry Mediterranean climate in Southeast Spain. We hypothesised that soil erosion is an important driver of litter decomposition and that, therefore, litter decomposition would increase along the hillslope driven by a complex interplay of different factors across landform positions. We also hypothesised that green manure incorporation would account for a significant C gain within the soil C balance of this rainfed olive grove, significantly improving its belowground C sequestration capacity.

For the purposes of our study, we define erosional effects on litter decomposition as the direct effect of physical fragmentation by soil abrasion during the detachment and transport of soil particles and any indirect effect derived from the breakdown and burial of litter (such as an increase in litter surface availability, soil-litter mixing and microclimate buffering) that facilitates microbial decomposition.

2. Materials and methods

2.1. Study area

This study was conducted in an agricultural field situated in Cehegín in the Northwest of the province of Murcia, in Southeast Spain (38°3′N, 1°46′W). It was carried out in a 100-year-old organic rainfed olive grove without terraces, which was regularly ploughed along the contour lines and planted with a 10 × 10 m spacing (107 olive trees ha^{-1}). The olive grove (170 m long by 70 m wide) is located on a convex–concave hillslope facing Southeast, with a mean slope of 10–12%, altitudes ranging from 600 to 650 m.a.s.l., good drainage and a high percentage of stones on the surface.

The climate is dry sub-humid Mediterranean, with a mean annual precipitation of 370 mm and mean annual temperature of 15.5 °C. The mean monthly rainfall ranges from 8 mm (July) to 50 mm (October), following a bimodal distribution with two rainy seasons (autumn and spring) and a dry period in summer. However, high rainfall variability between and within years is very common in the study area. Monthly temperatures oscillate from 0 °C or below 0 °C (December and January) to 40 °C (July and August). The mean annual potential evapotranspiration (calculated by the Thornthwaite method; Thornthwaite, 1948) reaches 800 mm yr^{-1}, so the annual water deficit is 430 mm.

The soil in the study site has a loamy texture, is derived from limestone colluvia and is classified as Hypercalcid calcisol, according to soil taxonomy (FAO, 2006). Overall, the soil in the study site is shallow, has a low organic matter content and high percentage of carbonates (Martínez-Mena et al., 2008).

Two successive rainstorms, which occurred in the field on 13th and 19th August 2010, led to the erosion of a significant amount of soil material, eroded mainly by rill and inter-rill erosion from the hillslope. The spatial configuration of the ridges, perpendicular to the slope, allowed the delineation of a set of elongated sections along the slope, in which the different phases of the soil water erosion process (erosion, transport and deposition) can be observed (Fig. 1). It can be assumed that all the eroded soil within each section was trapped behind the furrows, as these ridges remained entirely intact after the rainstorm.