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Surface Soil Properties Influence Carbon Oxide Pulses After Precipitation Events in a Semiarid Vineyard Under Conventional Tillage and Cover Crops

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ABSTRACT

In semiarid regions of the Mediterranean basin, a rainfall event can induce a respiratory pulse that releases a large amount of soil carbon dioxide (CO_2) into the atmosphere; this pulse can significantly contribute to the annual ecosystem carbon (C) balance. The impacts of conventional tillage and two different cover crops, resident vegetation and *Bromus catharticus* L., on soil CO_2 efflux were evaluated in a *Vitis vinifera* L. vineyard in La Rioja, Spain. Soil CO_2 efflux, gravimetric water content, and temperature were monitored at a depth of 0–5 cm after rainfall precipitation events approximately every 10 d in the period from May 17 to July 27, 2012, during which the cover crops had withered. Additionally, on June 10, 2012, soil organic C, microbial biomass C, and β-glucosidase activity were determined at soil depths of 0–2.5, 2.5–5, 5–15, and 15–25 cm. The results show that pulses of soil CO_2 were related to the increase in soil water content following precipitation events. Compared to the conventional tillage treatment, both cover crop treatments had higher soil CO_2 efflux after precipitation events. Both cover crop treatments had higher soil organic C, microbial biomass C, and β-glucosidase activity at the soil surface (0–2.5 cm) than the conventional tillage treatment. Each pulse of CO_2 was related to the surface soil properties. Thus, this study suggests that the enhancement of soil organic C and microbiological properties at the soil surface under cover crops may increase soil CO_2 efflux relative to conventional tillage immediately after precipitation events during the dry season.

Key Words: microbial biomass C, β-glucosidase activity, soil CO_2 efflux, soil water content, soil temperature

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INTRODUCTION

Soil respiration is an important process in the biosphere, accounting for up to 25% of global carbon dioxide (CO_2) emissions (IPCC, 1997). Respiration of CO_2 from soils includes autotrophic respiration from plant roots and heterotrophic respiration from soil microorganisms (Ryan and Law, 2005; Inglima *et al.*, 2009). Accurate quantification of soil CO_2 emissions is critical for understanding soil carbon (C) flow and ecosystem resilience (von Lützow *et al.*, 2006). In addition, knowledge of the factors that drive soil CO_2 efflux can help identify appropriate management options in various agrosystems in order to increase soil C sequestration.

Many studies have shown that soil temperature and soil water content can have complex effects on the seasonal dynamics of soil respiration. For example, laboratory experiments by Davidson *et al.* (1998) and Fang and Moncrieff (2001) showed that soil CO_2 efflux dynamics are positively correlated with soil temperature and soil water content. In contrast, based on studies of the dry season in Mediterranean and semiarid ecosystems, Rey *et al.* (2002, 2011) concluded that soil temperature and soil CO_2 efflux are not correlated, although there is a positive linear correlation between soil water content and soil CO_2 efflux.

Semiarid regions are characterized by irregular rainfall events during the dry season that can completely replenish the water content at the soil surface after long periods of drought. These rainfall events can increase the microbial population and activity, as well as substrate availability, resulting in soil CO_2 pulses to the atmosphere (Davidson *et al.*, 1998; Rey *et al.*, 2002, 2005; Jarvis *et al.*, 2007). In general, rainfall events directly affect soil CO_2 efflux through changes in soil water content and soil temperature; they can also have indirect effects on soil organic matter availability and/

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or plant physiological activity (Tang and Baldocchi, 2005; Cable *et al.*, 2008). Some studies have shown that practices related to so-called "conservation agriculture" (practices that use no-tillage, minimum tillage, or cover crop methods) can increase soil organic C in semiarid climatic conditions (Álvaro-Fuentes *et al.*, 2008b; Melero *et al.*, 2009). In vineyard agrosystems under Mediterranean climatic conditions, the utilization of cover crops increased soil organic C (Steenwerth and Belina, 2008; Smith *et al.*, 2008; Peregrina *et al.*, 2010a, b).

Soil respiration, particularly its heterotrophic component, is strongly related to soil organic matter decomposition (Hanson *et al.*, 2000) and is influenced by the input of organic C to the soil from crop residues (Fließbach *et al.*, 2007). According to Mariscal-Sancho *et al.* (2010), who examined various soil managements under Mediterranean climatic conditions, soil CO_2 efflux has a relationship with soil organic C and β-glucosidase activity.

In the Rioja winegrowing region, vineyard soils generally have a low organic matter content (< 10 g kg^{-1}) (Peregrina *et al.*, 2010b). Recent studies have reported that cover crops increase soil organic C, labile organic C fractions, and microbiological activity compared to conventional tillage (Peregrina *et al.*, 2014a, b). Changes in labile organic C and soil microbiologic activity can affect soil CO_2 efflux; in a vineyard under Mediterranean climatic conditions, Steenwerth and Belina (2008) found that soil CO_2 efflux is higher in soils with cover crops than in tilled soils. In addition, they found that the higher CO_2 efflux in soils with cover crops is associated with a higher total soil organic C and a higher labile C than in tilled soils. In addition, in vineyards with cover crops under Mediterranean conditions, Steenwerth *et al.* (2010) found that soil CO_2 efflux was positively affected by soil water content and soil temperature. However, these studies do not differentiate between heterotrophic and autotrophic soil respiration.

The objective of this study was to evaluate the influences of soil water content, soil temperature, soil organic C, and soil microbiological properties at the soil surface on soil CO_2 efflux dynamics under different management regimes (conventional tillage and cover crops) in a semiarid vineyard.

MATERIALS AND METHODS

Site description

A field experiment was conducted in a vineyard at the experimental farm "Finca La Grajera", which belongs to the La Rioja regional government (42°26′3418″ N, 2°30′5307″ W), in northern Spain. The vineyard was established in 1996 with *Vitis vinifera* L. cv. "Tempranillo" grafted on rootstock variety 110-R. The planting density was 2 998 vines per hectare, and the vine spacing was 1.15 m × 2.9 m with east-west facing rows. Vines were head-trained.

The climate in the study area is semiarid according to the UNESCO aridity index (UNESCO, 1979), with heavy winter rains and summer drought. The slope of the study area is approximately 10.2% and the fields face east. The soil is a fine-loamy, mixed, thermic Typic Haploxerept according to the USDA soil classification (Soil Survey Staff, 2006) or a Calcaric Cambisol according to the FAO classification (FAO, 2014). The soil properties are as follows: clay, 230 g kg^{-1}; silt, 433 g kg^{-1}, sand, 337 g kg^{-1}, coarse elements, < 2 %, organic matter content, 9.3 g kg^{-1}; carbonates, 149 g kg^{-1}. The soil pH was 8.62 and the electrical conductivity was 0.17 dS m^{-1} in the Ap horizon (0–20 cm).

Experiment procedure

The experimental design was a randomized complete block with soil management regimes as treatments and three replicates per treatment. Each replicate (plot) included three rows and each row (measuring 69 m in length and 5.80 m in width) had 60 vines, with the soil management regimes implemented between rows. Three different soil management regimes were designed: 1) conventional tillage (CT), 2) undisturbed soil with a permanent cover crop of resident vegetation (RV), and 3) undisturbed soil with a permanent cover crop of *Festuca longifolia* Thuill. 'Aurora Gold' (BV). The CT treatment was established from 2004 to 2011 and consisted of tillage to 15 cm depth, as required to control weeds, approximately every 4 to 6 weeks during the grapevine growth cycle from the end of April to mid-November, except the period when the monitoring of soil CO_2 efflux was conducted from May 17 to June 27, 2012. In 2012, the CT treatment involved tillage to 15 cm depth during the second week of February, the second week of March, and the third week of April. The RV treatment was established in 2004, with the resident vegetation cover dominated by annual grasses and forbs common to La Rioja vineyards, including *Bromus mollis* L., *Hordeum murinum* L., *Diplotaxis erucoides* (L.) DC., *Sonchus asper* (L.) Hill, *Sonchus oleraceus* L., *Veronica latifolia* L., *Conyza canadensis* (L.) Cronquist, and *Papaver hybridum* L. In the BV treatment, 50 kg ha^{-1} of *F. longifolia* was sown in October 2004 using a rotary seed drill, with 50 kg ha^{-1} of *Bromus catharticus* L. re-sown