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Efficient irrigation management can contribute to reduce soil CO_2 emissions in agriculture

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ABSTRACT

Irrigation water restrictions in the Mediterranean area have created a growing interest in water conservation. Apart from environmental and economic benefits by water savings, regulated deficit irrigation (RDI) may contribute to reduce soil CO_2 emissions and enhance C sequestration in soils, by decreasing microbial activity in response to decreased soil moisture levels. An experiment was established in an orchard for one year to investigate the effects of three irrigation strategies on soil CO_2 emissions, soil C pool dynamics and aggregate content and stability. Three irrigation treatments were assayed: full irrigation (FI), RDI1, irrigated as FI except for the postharvest period where 50% of FI was applied; and severe RDI (RDI2), irrigated as RDI1, except for two periods in which irrigation was suppressed. Soil CO_2 emissions were monitored every 15 d. Soil sampling was carried out every three months. Soil fractionation was also carried out (<50, 50–250, 250–850, 850–2000) to assess the weight, C content and aggregate stability of each fraction. The application of deficit caused a significant decrease in CO_2 emission rates, mainly in RDI2, with rates of, in average, 35 mg CO_2-C m^{-2} h^{-1} lower than that of FI during the period when deficit was applied. Cumulative CO_2-C released for one year showed a total release of 410 g CO_2-C m^{-2} in FI, 355 g CO_2-C m^{-2} in RDI1, and 251 g CO_2-C m^{-2} in RDI2. Soil organic C, recalcitrant C and organic functional groups showed no significant differences among treatments. The labile organic fractions increased under FI in summer, likely due to increments in microbial biomass C and enzyme activities. Irrigation treatments did not have a strong effect on the amount and stability of aggregates, but increased SOC content in the coarse fraction under RDI2. No effect of irrigation was observed in inorganic C content.

1. Introduction

Farmers who grow fruit trees in arid and semiarid regions face the threat of maintaining production and high quality fruits with less irrigation water. In addition, the lower costs for cultivation in emerging countries arise as a challenge for European farmers to become competitive in the global market. Thus, in order to compete in these markets, farmers need to optimize the use of water inputs (Fereres and Soriano, 2007). This can be achieved by adopting efficient irrigation scheduling (de la Rosa et al., 2013). These issues have promoted more research about irrigation systems, technologies and strategies to improve water use efficiency. One of the most promising methods is regulated deficit irrigation (RDI), an irrigation strategy designed to save water with a minimum impact on yield and fruit quality (Romero et al., 2004; Girona et al., 2005; Pérez-Pastor et al., 2009). This is accomplished by imposing water deficits during those phenological stages when trees are relatively tolerant to water stress.

Promoting water conservation using RDI can also contribute to reduce soil CO_2 emissions and has the potential to enhance soil C sequestration. Different volumes and frequencies of irrigation may cause significant differences in water distribution in the soil and, thus may affect soil bio-physicochemical processes differently, especially microbial activity and organic matter dynamics (Li et al., 2010). However, the effects of irrigation strategies on soil C content and distribution have not been systematically studied and are not well understood. It has been widely reported that the most important factor accelerating the breakdown of soil organic matter (SOM) seems to be water availability, especially in dry and arid regions, as moisture promotes microbial and invertebrate activities, thus enhancing SOM decomposition (Butenschoen et al., 2011; Arroita et al., 2013). Thus, application of lower quantities of water should reduce SOM breakdown and then enhance soil organic C accumulation. Some studies have reported decreases in CO_2 emissions and increases in soil organic C contents under limited irrigation (Kallenbach et al., 2010; McDowell and Smith,

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2012). Remoistening of dried soil by irrigation disrupts soil structure and increases substrate availability which further enhances microbial activity and C mineralization (Lamparter et al., 2009; Morugán-Coronado et al., 2011). Thus, continuous dry–wet cycles under irrigation in arid and semiarid environments may lead to greater C losses due to increased soil respiration after rapid rewetting. Full irrigation may also increase microbial activity resulting in higher C sequestration inside aggregates, increasing soil C stability (Gillabel et al., 2007). In fact, examination of the C stabilization capacity in aggregates under irrigation management can help elucidate mechanisms of C sequestration in irrigated systems (Gillabel et al., 2007). There is a feedback mechanism between aggregation and SOM dynamics, and increased SOM can lead to increased aggregate formation which in turn enhances C sequestration by physical protection (Six et al., 2004). The sand fraction particles (>50 μm) are considered to include the most labile portion of soil C, while in the smaller fractions the C has been considered increasingly stable (Sleutel et al., 2006). With regard to inorganic C, a more stable way to sequester C in soils, irrigation with calcite-saturated water generally resulted in a net release of CO_2 from soil; however, irrigation with low electrical conductivity water resulted in net C sequestration by carbonate precipitation (Sanderman, 2012).

Very few studies have dealt with the effect of RDI on CO_2 emissions, SOC dynamics and soil aggregation. We hypothesized that RDI may reduce CO_2 emissions due to lower microbial activity, but may decrease the stability of aggregates owing to increments in the dry/wet cycles during the year. Thus, an experiment was established in a nectarine tree orchard to investigate the effects of three irrigation strategies on soil C dynamics, aiming to: i) investigate if a link between irrigation strategies and soil CO_2-C emissions and C accumulation can be found in an agricultural land; ii) elucidate if irrigation strategies affect soil organic C quality and stability; iii) determine which physical soil size fractions are responsible for any observed soil C differences between irrigation treatments; and iv) assess if irrigation strategy contributes to shifts in aggregate stability.

2. Materials and methods

2.1. Study site and experimental design

The study was performed during 2012 in a commercial orchard located in Murcia, SE Spain (38° 8′ N; 1° 13′ W). The experimental plot had an area of 2 ha of nectarines trees (*Prunuspersica*) cv 'Viowhite' grafted onto Puebla de Soto 101 plum tree rootstock at a spacing of 6.0 m between rows and 3.5 m between trees within the same row. The climate is semiarid Mediterranean with a mean annual temperature of 17 °C and mean annual rainfall of 230 mm. The potential evapotranspiration rate surpasses 900 mm $year^{-1}$. The soil is a Petric Calcisol (IUSS, 2014),with sandy clay loam texture, pH 8.2, 0.34 dS m^{-1} electrical conductivity (EC), 56% $CaCO_3$, 8.50 $cmol_+ kg^{-1}$ cation exchange capacity, 1.42 g cm^{-3} bulk density and 1.85% soil organic matter (SOM). Usual cultural practices (e.g., weed control, fertilization, pruning, fruit thinning and banding) were carried out by the technical department of the commercial orchard.

A drip irrigation system was installed, with two lines per tree row and 9 pressure-compensated emitters (1.6 L h^{-1}) per tree placed at every 75 cm. Irrigation was scheduled weekly at nights. The frequency of irrigation varied according to the evaporative demand which was 1 times per week in winter, 2 to 7 times per week in spring and autumn, and 7 times per week in summer. The EC of the irrigation water varied between 1.5 and 2.5 dS m^{-1}, depending on the source used (irrigation canal, well water or a mixture of both), with maximum levels of chloride and sodium around of 12.6 and 13.4 meq L^{-1}, respectively.

The study included three different irrigation treatments: full irrigation (FI), irrigated to maintain the total crop water needs; a regulated deficit irrigation (RDI1), irrigated as FI except for the post-harvest period (from 16 June to 28 October), which was irrigated at 50% FI; and a severe regulated deficit irrigation (RDI2), irrigated as RDI1, except for two periods when irrigation was suppressed (from 7 June to 6 July and from 21 July to 17 August), with the aim of not surpassing the threshold of the stem water potential (Ψ_{stem}) of −2 MPa. The total crop water needs were estimated as the product of reference crop evapotranspiration (ET_0) and the crop coefficients (between 0.25 and 0.55) proposed by the Agricultural Information System of Murcia (www.siam.es) for this area, adjusted for tree size (Fereres and Goldhamer, 2003), and an additional leaching fraction applied due to the irrigation water salinity. The experiment was set as a randomized design with three replications per treatment. Each replicate had three adjacent tree rows and 15 trees per row. All measures and samplings were carried out in the central row. Consumption of water during the experimental period was 694 mm, 457 mm and 326 mm for FO, RDI1 and RDI2, respectively.

2.2. Measurements

Hourly meteorological data were measured using an automatic weather station located in the orchard. Soil temperature (T) was measured using a Hydra Probe II multi-parameter soil sensor (Stevens Water Monitoring Systems, USA), with three sensors per treatment installed at a 15 cm depth.

Soil CO_2 emissions were determined using an ACE Automated Soil CO_2 Exchange system station (ADC, BioScientific Ltd). Measurements were carried out at open mode with ambient reading. When the 2.6 L chamber was sealed, ambient air was passed through the chamber at a controlled flow rate. The process of the system is as follows. The CO_2 concentration in the chamber increases and then gradually settles to a value which is dependent on the flux of CO_2 from the soil and the set flow of the pump. Measurements were made continuously every 10 s to determine when stability was reached. Once the value of the CO_2 flux is stabilized, it is automatically recorded. The net soil CO_2 concentration is calculated from the difference between ambient and soil CO_2 concentration. The CO_2 measurements were carried out for 30 min periods at each measurement spot along the drip irrigation lines, since this time proved to be suitable to obtain accurate results. Measurements were made every two weeks in all replicated treatments from 19 January 2012 to 9 January 2013. Only one ACE Automated Soil CO_2 Exchange system station was used, which was moved to every treatment, in a location close to the Hydra Probe II multi-parameter soil sensor. Average CO_2-C emissions were calculated and the cumulative soil respiration for each treatment was estimated by numerical integration. To determine gravimetric soil moisture, a soil sample (0–20 cm depth) was collected adjacent to the measurement location.

2.3. Soil sampling and analytical methods

Soil sampling (0–30 cm) was carried out at each treatment replication location (at the drip irrigation line) every three months (19 January (winter), 19 April (spring), 12 July (summer) and 17 October (autumn) 2012), to determine the evolution of total organic, recalcitrant, soluble and inorganic carbon, aggregate stability, microbial biomass carbon, enzyme activities, and organic functional groups. Samples were air-dried at room temperature to constant weight and carefully sieved through a 2-mm mesh. Coarser materials were discarded and the remaining fine-earth fractions were gently mixed until it appeared to be homogeneous. Biochemical properties were also measured in air-dried samples since biochemical properties from Mediterranean semiarid soils are stable in air-dried samples for at least six months, and it is not necessary to measure them in field-moist soil samples (Zornoza et al., 2009a). Sub-samples of each sample were separated into four size fractions of <50, 50–250, 250–850 and 850–2000 μm to assess the weight, aggregate stability and carbon content and quality of each size fraction in terms of the irrigation treatments. Separation was carried out by