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Improvement of yield and grape and wine composition in field-grown Monastrell grapevines by partial root zone irrigation, in comparison with regulated deficit irrigation

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ABSTRACT

Regulated deficit irrigation (RDI) and partial root zone irrigation (PRI) were compared for four years (2009–2012), each at two different irrigation volumes (110 mm year^{-1} (1) and 78 mm year^{-1} (2)), in field-grown Monastrell grapevines grafted onto 1103P, in South Eastern Spain. The aim was to distinguish the effects of deficit irrigation *per se* from specific PRI effects (placement of water) on yield response and berry and wine quality. Vines grown with PRI-1 or RDI-1 received around 30% of the ETc from budburst to fruit set, 13–15% ETc from fruit set to *véraison* and 20% ETc from *véraison* to harvest. The RDI-2 and PRI-2 vines received around 20% ETc from budburst to fruit set, no irrigation from fruit set to *véraison* and a recovery (21-24% ETc) thereafter. In general, the PRI-2 and RDI-2 vines (the most-severely water-stressed) showed greater yield reduction and lower overall berry and wine quality (including technological and phenolic composition) than the moderately-water-stressed vines (RDI-1 and PRI-1). Compared to RDI-1, PRI-1 improved the yield response—increasing mean yield, cluster number per vine and berry weight and maintaining better bunch health at late ripening and a greater proportion of bigger bunches. In addition, PRI-1 increased the anthocyanin and amino acid concentrations of the berries and altered their composition, improving the phenolic and chromatic characteristics of the wine and enhancing the health-promoting value of the fruit. It was also the option most economically viable under the present conditions of the wine grape market, compared to RDI-1 and the rest of the treatments. In contrast, PRI-2, although it improved some technological quality attributes and phenolic and chromatic characteristics of Monastrell berries and wines compared to RDI-2, did not have a positive effect on yield (yield and cluster and berry weight decreased in some years) and its implementation was economically unviable under these soil and climatic conditions. The significant interaction between irrigation volume (high vs. low) and irrigation placement (PRI vs. RDI) indicate that the response to PRI also depended on the volume of water applied in the wet root zone and the soil total water availability.

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1. Introduction

Some recent studies comparing partial root-zone drying irrigation (PRI) and conventional deficit irrigation techniques (DI) in different crops and experimental conditions (controlled or field conditions) have reported a wide range of PRI-specific responses, some of which may represent a significant improvement in yield, water use efficiency and/or fruit quality. The latter, novel PRI effects (compared with conventional DI plants which received the same amount of water) in different species include: (1) greater fruit growth, fruit fresh weight and/or total fruit dry weight (Dorji et al., 2005; Antolín et al., 2006; Zegbe et al., 2007; Spreer et al., 2007; Topcu et al., 2007; Aganchich et al., 2008; Savic et al., 2008; Talluto et al., 2008; Senyigit and Ozdemir, 2011; Romero and Martínez-Cutillas, 2012); (2) increased soil N availability, improved fertilizer-N use efficiency and plant N nutrition and distribution in the canopy (Wang et al., 2009, 2010, 2012a–c; Wang et al., 2013) and enhanced root nutrient uptake capacity

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(Wang et al., 2012a,b,c); (3) an advancement in fruit maturity (Zegbe et al., 2003; Topcu et al., 2007; Aganchich et al., 2008; Pérez-Pérez et al. unpublished results); (4) greater activation of the antioxidant system (particularly soluble peroxidises and superoxide dismutase) (Aganchich et al., 2007); (5) a reduction in fruit disorders, such as blossom-end rot (BER) in tomatoes (Zegbe et al., 2007; Sun et al., 2013) and hot peppers (Dorji et al., 2005); and (6) a significantly-increased marketable fruit or grain yield and WUE in different crops (Du et al., 2006; Shao et al., 2008; Kirda et al., 2004; Kaman et al., 2011; Wang et al., 2012a,b,c; Pérez-Pérez et al., 2012; Senyigit and Ozdemir, 2011; Affi et al., 2012; Panigrahi et al., 2013; Yactayo et al., 2013; Yang et al., 2013).

Furthermore, PRI-specific effects (compared to conventional DI) on fruit composition include: a greater content of Ca in tomatoes (Sun et al., 2013) and of N in potatoes (Topcu et al., 2007; Wang et al., 2009), increased hexose (glucose and fructose) content (Du Toit, 2005), greater antioxidant activity (Marjanovic et al., 2012) and total phenols (Aganchich et al., 2008), increased water-soluble dry matter content, greater accumulation of water and carbohydrates and higher solute content (Marjanovic et al., 2012; Romero and Martínez-Cutillas, 2012), greater accumulation of soluble cell-wall-bound phenolic compounds (Tahi et al., 2008), higher flesh firmness (Talluto et al., 2008), a greater fraction of marketable and edible parts (Kirda et al., 2004; Spreer et al., 2007; Aganchich et al., 2008; Talluto et al., 2008), increased enzymatic activity in PRI fruits during ripening (Savic et al., 2008) and an improvement in whole plant quality in ornamental plants (Cameron et al., 2008).

In the recent years, the beneficial effects of the regular consumption of moderate amounts of wine have been a great focus of interest in grape and wine industry research due to the potential effects on health (Guilford and Pezzuto, 2011). The observed effects of PRI on fruit quality and composition might also enhance the health-promoting aspects of the fruit, based on nutrition, flavour and 'healthfulness'. Thus, in grapevines, increased berry growth and sugar content (Santos et al., 2003) and greater skin anthocyanins and polyphenols contents in PRI berries (compared to DI with the same water amount) have been reported (Martín-Vertedor et al., 2004; Valdés et al., 2004, 2005; Antolín et al., 2006, 2008; Bassoi et al., 2007; Chaves et al., 2007; Santos et al., 2007). Some studies related the improvement in berry quality with changes in abscisic acid (ABA) physiology, especially ABA levels in berries and free polyamine production at the onset of *véraison* induced by PRI (Antolín et al., 2006, 2008), while others related it with a reduction in vine vigour, mainly regarding the canopy density—altering the canopy microclimate in the fruit zone and increasing the amount of light reaching the bunch zone in a more-open canopy (Dry et al., 2000a,b).

In addition, further advances indicate that the benefits of PRI – relative to DI – also depend on (1) genotypic variation in root distribution and the proportion of root biomass exposed to drying soil (Martín-Vertedor and Dodd, 2011; Kaman et al., 2011) and (2) the soil water content maintained in the wet root zone (Hu et al., 2011; Hutton and Loveys, 2011; Romero et al., 2012; Romero and Martínez-Cutillas, 2012; Wang et al., 2012a–c; Einhorn et al., 2012; Romero et al., 2014)—this is determined by irrigation management (frequencies and volumes). Recently, Romero et al. (2014) reported that PRI produced different physiological responses in field-grown grapevine (*Vitis vinifera* cv. Monastrell), in comparison to regulated deficit irrigation (RDI), and that these responses were due to both the placement of irrigation and reductions in irrigation volumes. However, we have not yet evaluated whether these distinct PRI-specific physiological changes alter the yield response, berry composition and wine quality. In addition, it is also necessary to assess the economic effects of these DI strategies on crops and to verify whether they make the wine grape production viable and profitable (García-García et al., 2012).

In this work, two different irrigation techniques (conventional RDI and PRI) were compared at the same irrigation volumes (the moderate and low amounts of water usually used by growers to irrigate wine grapes in SE Spain) and with the same controlled DI strategy. The aim was to distinguish the effects of DI *per se* (water volume) from any specific PRI effects (placement of water). Differences between RDI and PRI in bunch microclimate, berry growth, water, sugar and polyphenols accumulation during ripening, berry hormones content, yield, water use efficiency, berry composition and wine quality were studied in field-grown Monastrell wine grapes, in a four-year experiment in a semi-arid environment. The interactive effects of irrigation volume (high vs. low) and placement of water (PRI vs. RDI) on cluster microclimate, yield and grape quality components were also evaluated. In addition, we compared several financial indices, using cost–benefit analysis, to determine the profitability of producing Monastrell wine grapes under RDI and PRI in the semi-arid conditions of SE Spain.

2. Materials and methods

2.1. Field conditions, plant material and irrigation treatments

The experimental design has been described in detail in Romero et al. (2014). Briefly, this research was carried out in a 1-ha vineyard at the CIFEA experimental station in Jumilla, Murcia (SE Spain, Lat: 38° 2′; Lon: 1° 58′, 395 m a.s.l.). The grapevines were 13-year-old Monastrell (syn. Mourvedre), grafted onto 1103 Paulsen rootstock (an invigorating and drought-tolerant rootstock). The training system was a bilateral cordon trellised to a three-wire vertical system. The vine rows ran N–NW to S–SE and the planting density was 2.5 m between rows and 1.25 m between vines (3200 vines ha^{-1}). The experiment involved four different DI treatments that were applied during four consecutive years (2009–2012) (Table 1). These DI strategies were initially designed to control excessive early-season vegetative development, reduce berry size and yield (by using moderate or severe pre-*véraison* water deficits) and stimulate berry accumulation of sugar, anthocyanins and other phenolic compounds (using a moderate post-*véraison* water deficit). The soil characteristics and climate parameters at the experimental site, annual water application for each treatment, reference evapotranspiration and Kc (crop coefficients) values and the fertilisation have been described in Romero et al. (2014).

2.2. Bunch microclimate and degree of exposure

The diffuse light intensity (PAR, 400–700 nm), air temperature and relative humidity in the cluster zone were measured inside the canopy, close to fruiting positions, on sunny days, in specific periods before and after *véraison* in 2011 and 2012. Readings were taken in eight vines per treatment every 5 min, on the face of clusters facing east-west, using HOBO RH/Temp/Light/External sensors with four channels (Onset Computer Corporation, Cape Cod, MA, USA). During post-*véraison* (in 2010), the visible clusters and clusters exposed, partially exposed and non-exposed to direct sun were counted visually at mid-day (12:00–14:00) in 20 vines per treatment and the percentages of sun-exposed and non-exposed clusters were calculated.

2.3. Berry growth and development and sugar and water accumulation

During the berry development period (from early June to mid-September), 12 to 16 fruits (depending on the year) that had been labelled previously were used to make weekly measurements of

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