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Fruit growth, yield and oil quality changes induced by deficit irrigation at different stages of olive fruit development

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ABSTRACT

Experiments were performed in a high-density olive orchard to compare the effect of regulated deficit irrigation (RDI) at two different phenological stages with fully-irrigated trees (FI) over two years. Stress was imposed either prior to pit hardening (RDI 1) or after endocarp sclerification during the initial phase of oil accumulation (RDI 2). Fully irrigated trees received 2277 and 1648 $m^3 ha^{-1}$ in 2012 and 2013, respectively, RDI 1 ones 76 and 53% of those volumes in 2012 and 2013, respectively (RDI 2 trees 48 and 67%). There were no differences in fruit set or return bloom due to the irrigation regime. At harvest differences in fruit size between FI and RDI treatments were significant only in the first year. The fruit yields of RDI 1 and RDI 2 trees were 70 and 81% of FI ones, respectively (means of two years), but the yield efficiency was similar across all treatments. The phenolic concentration in RDI 1 fruits was higher than that in fruits from trees subjected to the other water regimes. Verbascoside, 3–4 DHPEA-EDA, and oleuropein of RDI 1 fruits were higher in 2012 (only verbascoside in 2013). Oleuropein and 3–4 DHPEA-EDA of RDI treatments were higher than those of FI in 2013. Higher concentrations of biophenols were measured in oils from RDI 1 trees in both years, whereas FI and RDI 2 showed similar values. An early water stress was more effective to increase the phenolic concentration of olive oil compared with a late deficit or full irrigation.

1. Introduction

Deficit irrigation (DI), that is supplying less water than the volume actually required to compensate for evapotranspirative losses during the irrigation season, is a common practice in orchards (Behboudian and Mills, 1997; Fereres et al., 2012). While early studies focused on the control of tree vigour induced by deficit irrigation (Chalmers et al., 1981), the saving of water and beneficial effects on fruit quality have been more recently emphasized (Caruso et al., 2014; Fereres et al., 2012; Gelly et al., 2003; Roccuzzo et al., 2014). Several effects on fruit quality have been described. In peach moderate water deficits applied during stage II of fruit development improved fruit colour, firmness and total soluble solids (Gelly et al., 2003, 2004). Intrigliolo and Castel (2010) reported that some degree of water stress imposed during early stages of fruit growth increased soluble solids and firmness of plum fruits as long as the stem water potential was maintained above −1.4 MPa and stress was relieved at least one month before harvest. In almond there were no differences in the chemical composition of kernels between fully- and deficit-irrigated trees, but kernel dry weight was decreased by the most stressed treatments (Egea et al., 2009).

Deficit irrigation usually improves water use efficiency (Behboudian and Mills, 1997; Cui et al., 2009; Iniesta et al., 2009; Roccuzzo et al., 2014). Unlike annual crops, a decrease in biomass production for many fruit trees does not necessarily lead to a parallel reduction in fruit yield because of changes in biomass partitioning between the different organs (Behboudian and Mills, 1997; Cui et al., 2009; Roccuzzo et al., 2014). As a result, no reductions in yield have been reported for peach (Gelly et al., 2003), plum (Intrigliolo and Castel, 2010), almond (Stewart et al., 2011), pear-jujube (Cui et al., 2009), apricot (Perez-Pastor et al., 2014), and olive (Lavee et al., 2007), when the stress applied during the irrigation season was moderate.

On the other hand, one of the problems in deficit irrigation of perennial crops may be the prolonged effects of stress that last longer than the current season and often become detrimental in the following years. For instance, Goldhamer et al. (2006) showed that the yield of almond trees declined most if a post-harvest water deficit was imposed, whereas a sustained DI was the most productive strategy. In sweet cherry fruit growth is short and sensitive to water deficit; when post-

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harvest DI was used it did cause reductions in fruit set and crop load the following year unless the post-harvest stress was maintained at values of stem water potential above -1.5 MPa (Marsal et al., 2010). In peach it has also been shown that post-harvest DI affected fruit set the following year (Girona et al., 2004).

Different strategies of deficit irrigation can be developed for fruit crops depending on environmental and cultural conditions. Sustained DI consists in applying a constant volume of water that is less than the evapotranspirative demand during the entire irrigation season. In this case trees usually uptake water from the soil reservoir, which is then gradually depleted as the growing season progresses (Fereres et al., 2012). Regulated DI, instead, imposes stress at definite phenological stages while fully supplying water during the rest of the irrigation season (Fereres et al., 2012); this latter strategy is particularly useful in areas where water is drastically restricted during the summer because of severe drought or priorities for urban uses.

In olive trees the water volume can be reduced well below the level of full satisfaction of water needs with limited or no effects on fruit yield and oil yield (Gómez del Campo, 2013; Gucci et al., 2007; Lavee et al., 2007; Moriana et al., 2003). Moderate restrictions of irrigation accelerated fruit maturation, increased pulp-to-pit ratio, and maintained oil yield of olive trees over 80% that of fully-irrigated trees (Caruso et al., 2013; Gómez del Campo, 2013; Gucci et al., 2009). In a previous paper we reported that the oil yield of deficit irrigated olive trees of cv Frantoio was 82% that of well irrigated ones over four years, while the saving of water applied was about 50% (Caruso et al., 2013). In a hedgerow olive orchard of cv. Arbequina the drastic cut of irrigation by 70% in July allowed to save 16% of the total irrigation water and decrease oil production by only 8% compared to fully-irrigated trees (Gómez del Campo, 2013).

Changes in oil quality due to water deficit have also been reported for many olive cultivars (Caruso et al., 2014, 2017; Gómez del Campo and García, 2013; Gómez-Rico et al., 2007; Servili et al., 2007; Tovar et al., 2001). Most of these studies have shown that phenolic concentrations in the oil were inversely correlated with the amount of water applied, whereas the irrigation regime had negligible or no effects on other parameters (free acidity, peroxide values, spectrophotometric indices and fatty acid composition). There is evidence that the increase in the oil phenolic concentrations of trees subjected to water deficit is due to enhanced synthesis of these compounds in the fruit (Alagna et al., 2012; Artajo et al., 2006), but recent findings suggest that the catabolism of phenolic substances in the fruit is likely influenced by water stress too (Cirilli et al., 2017). The sensory profile of oils has also been reported to be affected by soil water availability during fruit development (Benelli et al., 2015; Berenguer et al., 2006; Servili et al., 2007; Tovar et al., 2002).

Optimizing DI implies reaching the best balance between yield, oil quality and water saving issues. In particular, the period when stress is applied appears crucial to achieve the best compromise. Given the strong effect of tree water status on oil phenolic concentrations (Caruso et al., 2014; Servili et al., 2007) and the fact that the transcriptional regulation of phenolic biosynthesis in olive fruits appears to be time dependent (Alagna et al., 2012), we hypothesize that the timing of RDI would affect phenolic concentrations in the fruit and the oil.

The objective of the present work was to compare the effect of RDI at two stages of fruit development with the performance of fully-irrigated trees (FI). Stress was imposed either prior to pit hardening (RDI 1), or after endocarp sclerification during the initial phase of oil accumulation (RDI 2). In both cases the level of maximum stress was moderate to severe since stem water potential reached minima of −3.3–3.8 and −3.2–4.6 MPa, respectively. We investigated the effects on fruit set, growth of the mesocarp and endocarp, yield components, and oil quality parameters at harvest over two consecutive growing seasons in a high-density olive orchard.

2. Materials and methods

2.1. Plant material and climatic conditions

Experiments were conducted using mature trees, planted at a 5 × 3.9 m distance and trained to a free vase system, in an olive (*Olea europaea* L., cv. Frantoio) orchard at the experimental farm of the Department of Agriculture, Food and Environment of the University of Pisa at Venturina, Italy, over two consecutive years. The soil was a sandy-loam, consisting of 60% sand, 15% clay and 25% silt (Caruso et al., 2013). The orchard was divided into three blocks, each consisting of three randomly distributed irrigation treatments (three plots per treatment). Each of the nine plots included 12 trees arranged in three rows of four trees. To avoid border effects only the central rows were used and all measurements and samplings were carried out on the inner two trees of the central row. The same trees were used throughout the experiment. The canopy volume and tree height were about 23 m^3 and 3.4 m, respectively.

Fertilizers (55 and 45 g of N, P_2O_5, and K_2O per tree) were supplied via the irrigation system in spring, before irrigation treatments were put into action. Pesticides were sprayed at standard concentrations to protect the crop against the olive fruit fly (*Bactrocera oleae* Rossi) and diseases.

The climatic conditions over the study period were monitored using a weather station installed on site. Annual precipitation was 820 and 915 mm in 2012 and 2013, respectively (Fig. 1). Effective precipitation (EP), calculated as 75% of the daily rainfall (individual rains less than 4 mm were excluded), was 576 and 635 mm in 2012 and 2013, respectively. Summer precipitation was 45 and 23 mm in 2012 and 2013, respectively; temperatures were similar in both years (22.4 and 22.3 °C, respectively). The maximum daily average temperature reached 27.0 (28 August) and 28.6 °C (8 August) in 2012 and 2013, respectively. Potential evapotranspiration (ET_0), calculated according to the Penman-Monteith equation, was 931 and 909 mm in 2012 and 2013, respectively (Fig. 1).

2.2. Irrigation and tree water status

Water was supplied using subsurface drip lines (2.3 l h^{-1} pressure-compensated drippers spaced at 0.6 m) running on the South side of the

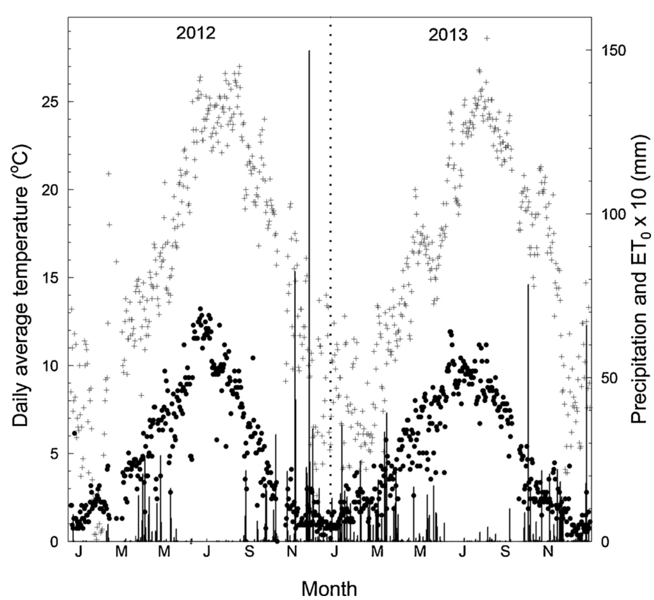

Fig. 1. Daily values of mean air temperature (+) (°C), evapotranspiration (•) (ET_0, mm x 10) and precipitation (histograms) (mm) at the experimental site in 2012 and 2013.