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Effect of varied summer deficit irrigation on components of olive fruit growth and development

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ABSTRACT

The timing, duration, and intensity of summer water restrictions differentially affect overall olive fruit growth and production, based on the underlying fruit developmental processes. For that, the fruit component and tissue morphogenetic response to different irrigation strategies during summer was examined in a hedgerow olive orchard cv. Arbequina. Control trees (CON) were irrigated to maintain the root zone close to field capacity throughout fruit growth. From budburst to 4 weeks after full bloom (WAFB) (Period 1) and from 14 WAFB to harvest (at 23 WAFB) (Period 4) trees of all treatments were irrigated as CON. Two severe water deficit treatments were applied during summer by irrigating 30% CON from 4 to 9 WAFB (Period 2) in DI-P2 or from 9 to 14 WAFB (Period 3) in DI-P3. Moderate water deficit was applied in Periods 2 and 3 by irrigating 50% CON in DI-P2&3. Growth and development of the fruit and its component tissues (exocarp, mesocarp and endocarp), fruit composition, mesocarp cell area and cell number, and epidermal characteristics at the end of each period were evaluated. Water deficits significantly reduced fruit volume at the time when they were applied. Mesocarp size was more sensitive to water deficit than endocarp size and showed a high recovery capacity after rewatering. Although the majority of cells were developed in Period 1, a substantial number of mesocarp cells were also formed later. While mesocarp cell number was unaffected by water reduction in any of the deficit periods, cell size was highly affected but with high recoverability. Endocarp size was reduced when water restriction was applied in DI-P2 and its effect continued until harvest. Fruit oil content at harvest was not significantly affected by the applied water restrictions, whereas water was the fruit component which most responded to both the increases and decreases in irrigation. Cuticle thickness, epidermal cell size and number at harvest appeared to respond to both irrigation regime and fruit expansion pressures.

1. Introduction

Water is becoming one of the most scarce environmental resources and water availability for irrigation will limit agricultural production in dry lands. In the case of olive, although extensive olive orchards have been traditionally grown under rain-fed conditions in the Mediterranean region at low densities, between 100 and 200 olives/ha, olive tree production increases substantially when irrigation is applied (Patumi et al., 1999; Fernández and Moreno, 1999; Moriana et al., 2003). Also, since the early 1990s, hedgerow olive orchards have been spreading worldwide for high production and profitability at densities higher than 1500 olives/ha. In most growing conditions irrigation ensures early, high and constant fruit and oil production, so it is necessary to find irrigation strategies that can reduce water use with low impact on productivity. In fruit tree production, regulated deficit irrigation (RDI) is an irrigation strategy based on the reduction of irrigation doses in certain periods such that final fruit growth and production are least reduced (Chalmers et al., 1981; Fereres and Soriano, 2007). Beneficial results of RDI have been reported in olive (Goldhamer, 1999; Moriana et al., 2003).

Water availability affects a range of plant processes, with that effect depending on both amount and timing. Fruit growth, differentiation and composition may all be affected, either directly or indirectly. Thus the different olive fruit tissues (exocarp, mesocarp and endocarp) and components (water, dry matter and oil) respond

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differently to water stress depending on their different sensitivities in the phases in which deficit irrigation is applied and their capacity to recover once the olive tree is fully irrigated (Gucci et al., 2011).

Early in olive fruit growth both the mesocarp (pulp) and endocarp (pit) increase rapidly in size (Rallo and Rapoport, 2001; Hammami et al., 2011), producing competition for resources which can affect both the pulp-to-pit ratio and pulp size at harvest (Gucci et al., 2009). In this first phase of fruit growth, water stress produces smaller pits (Lavee, 1986), which can lead to higher pulp-to-pit ratios, but may also reduce fruit size and number. Rapoport et al. (2004a) obtained a reduction in fruit size at harvest when water stress was applied in this phase, whereas the number of mesocarp cells was unaffected. These authors also showed that the capacity of the endocarp to recover once stress was relieved was greater than that of the mesocarp, and at harvest endocarp size of the initially stressed plants was similar to the control plants. Under more prolonged stress, however, endocarp size remained smaller (Gucci et al., 2009).

During the next phase, fruit growth increases sharply resulting from the expansion of the mesocarp, which predominantly determines final fruit size (Hammami et al., 2011). In this phase oil biosynthesis in mesocarp parenchymatic cells begins, with accumulation initially at a low rate from 5 WAFB and for about 4 weeks (Tombesi, 1994), followed by intense oil synthesis during approximately two months. Differences in fruit size with irrigation are mainly due to increased cell expansion of the mesocarp (Rapoport et al., 2004a; Gucci et al., 2009), and the amount of mesocarp developed will condition oil production (Lavee and Wodner, 2004). Severe water stress conditions produce smaller fruit with lower oil content (Beltran et al., 2010), however when water restriction is not severe oil production is not reduced (Costagli et al., 2003; Moriana et al., 2003; Rapoport et al., 2004a; Gucci et al., 2007).

The exocarp or epicarp is the thin, most external protective layer of the fruit, formed principally by the epidermal cells and their cuticle, with the addition of none or a few subepidermal cell layers (Roth, 1977). The olive fruit cuticle, a continuous layer external to the epidermal cells, consists of pectopolysaccharides (pectin, cellulose and hemicellulose), cutin and wax layers (Mafra et al., 2001). Patumi et al. (2002) noted that not only is the olive cuticle important for fruit-environment interactions, but can also influence oil extraction. Those authors found an apparent increase in olive cuticle thickness related with seasonal reductions in water supply, however neither periodic deficits, nor exocarp cell size and number have been studied.

Different experiments have demonstrated that the less susceptible period to water reduction in the olive tree occurs in summer (Goldhamer, 1999; Lavee et al., 2007). In this period fruit drop has finished, pit hardening occurs and oil synthesis is low. However, the timing, duration and intensity of summer water reduction can influence final fruit size and weight (Gucci et al., 2007), which derive directly from the timing and interaction of fruit developmental processes. The objective of this work was to evaluate the effects of RDI applied in different summer periods and intensities on 'Arbequina' olive fruit growth and development, with the aim of shedding light on which processes were affected, and the degree of the effect at the time of water limitation on fruit maturation and cuticle and exocarp development. We evaluated fruit and tissue (exocarp, mesocarp and endocarp) size, mesocarp cell size and number, epidermal characteristics, and fruit composition (water, oil, dry matter) during the deficit periods, and the capacity of the fruit to recover by harvest two months later. Two severe water deficit treatments were applied, one between 4 and 9 weeks after full bloom (WAFB), and another between 9 and 14 WAFB, and a moderate irrigation deficit treatment from 4 to 14 WAFB. Production and its component response to these deficit irrigation treatments have already been published by Gomez-del-Campo (2013a).

2. Materials and methods

2.1. Orchard site and design

The experiment was conducted in a 45 ha commercial orchard planted in 1997 with cv. Arbequina at a spacing of 4 × 2 m (1250 olive/ha), rows oriented 20 N of EW, in Puebla de Montalbán, Toledo, Spain (latitude 39°48′N; longitude 04°27′W; altitude 516 m). The hedgerow was 2.3 m high and 1.1 m wide. The soil was clay loam (Haploxeralf typic) with an effective rooting depth of 0.60 m.

2.2. Irrigation treatments

Four irrigation treatments (CON, DI-P2, DI-P3 and DI-P2&3) were maintained during 2009 in an area of 5600 m^2 in a randomized complete block design with three replications (blocks). Each replicate comprised 36 trees (12 trees in each of 3 adjacent rows). The central 10 trees in the central row of each replication were used for measurement. Each row of trees was irrigated from a single line with drip emitters of 3 L/h spaced 0.50 m apart.

CON (control) trees were irrigated according to continuous readings of 6 Watermark^{TM} sensors located in pairs at 0.3 m depth and 0.3 m from emitters adjacent to trunks of 3 representative trees and connected to a data logger (Irrometer, CA, USA). Irrigations of 6 h duration were applied when sensors indicated a mean soil water potential of −0.03 MPa from spring until 15 August and −0.06 MPa from then until end of the irrigation season. Detailed measurements at two sites revealed that this irrigation duration wetted the soil to a 0.6 m depth, and therefore the potential effective rooting depth, without excessive drainage (Gomez-del-Campo, 2013b).

The irrigation season was divided into four periods: Period 1, from budburst (10/03) until end of fruit drop (18/06) at 4 weeks after full bloom (WAFB); Period 2, from mid-June (19/06) until end of July (21/07, at 9 WAFB); Period 3, from end of July (22/07) to end of August (24/08, at 14 WAFB); and Period 4, from end of August (25/08) until harvest (30/10, at 23 WAFB). Periods 2 and 3 occupy the higher water demand period. Full bloom occurred at 24/5.

All treatments were irrigated as CON during Periods 1 and 4. DI-P2 was irrigated with 30% of the water applied to CON during Period 2. DI-P3 was irrigated with 30% of water applied to CON during Period 3. DI-2&3 was irrigated with 50% of CON during Periods 2 and 3. Those irrigation treatments, that were applied from 2007 to 2009, significantly modified relative extractable water of the soil and stem water potential in the periods in which they were applied (Gómez-del-Campo, 2013b). In Period 2, DI-P2 and DI-P2&3 relative extractable water showed significantly lower values (0.29) than CON and DI-P3 (0.63). In Period 3 the lowest values were observed in DI-P3 and DI-P2&3 (0.22) and the highest in CON (0.64). These differences in soil water deficit produced differences in plant water status. In Period 2 the lowest values of stem water potential were observed in DI-P2 and DI-P2&3 (−2.7 MPa) and the highest in CON and DI-P3 (−1.4 MPa). In Period 3 DI-P3 and DI-P2&3 showed lower values (−3.4 MPa) than CON and DI-P2 (−1.7 MPa).

2.3. Fruit preparation and measurements

At the end of Period 1 (4 WAFB), end of Period 2 (9 WAFB), end of Period 3 (14 WAFB) and end of Period 4 (23 WAFB), three subsamples of 25 g of fruits from mid height of the south sides of hedgerows were weighed fresh and again after oven-drying at 105 °C to determine fresh and dry fruit weight; fruit water content was calculated