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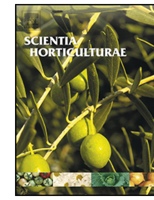

Dynamics of shoot and fruit growth following fruit thinning in olive trees: Same season and subsequent season responses

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ABSTRACT

The need to understand how the balance between vegetative and reproductive growth in olive trees is modified by different crop loads has become more important over the last 20 years due to increasing planting densities and the greater use of irrigation. The objectives of this study conducted in a well-irrigated olive orchard were to: (1) evaluate shoot and fruit growth dynamics following fruit thinning during the same growing season in which thinning was applied and during the next growing season; and to (2) determine crop load effects on bloom, fruit set, and fruit yield over three growing seasons. Hand-thinning of fruit 35 days after full bloom on 9-year-old cv. 'Arauco' trees in an "on" year led to thinning treatments of 24, 48, and 87% with respect to an unthinned control. Apical and lateral shoot elongation were measured every two weeks throughout the growing season, and fruit were sampled to determine fruit weight at the same interval. Apical shoot elongation occurred only early in the season when crop load was medium or high, while apical elongation continued for most of the season when crop load was low. Elongation of laterals contributed significantly to total shoot elongation on fruit-bearing branches in trees with low crop loads after thinning the first season. Individual fruit dry weight was reduced about 40% by high crop loads in both seasons. Differences in relative growth rates of both the shoots and the fruit due to crop load suggest fruit growth was limited by photoassimilate availability early in the season, but shoot growth was limited most of the season under medium and high crop loads. Inflorescence number per shoot was reduced by crop load in the two seasons following the thinning event. Fresh fruit yield was only reduced in one of the two biennia (i.e., periods of 2 years) in the trees that were heavily thinned (87%) the first season. The trees in which about one-half (48%) of the fruit were thinned the first season did not show biennia yield reductions and maintained a low alternate bearing index over three seasons. Thus, chemical thinning could be applied in growing seasons with high flowering. Further studies are needed to better assess competition for resources between shoots and fruit with the ultimate goal of reducing alternate bearing.

1. Introduction

Similar to the Mediterranean region, the expansion of large, intensively-managed olive orchards (>100 ha) with greater planting densities than traditional orchards has resulted in profound changes in olive growing in South America over the past 20 years. Such intensive orchards use high levels of irrigation and fertilizers to improve yields and are often located at warm, subtropical latitudes with long growing seasons (Ayerza and Sibbett, 2001; Gómez del Campo et al., 2010; Searles et al., 2011). Alternate bearing (i.e., "off" versus "on" production years) is fairly common in warm regions when an event such as a hot desert wind or a frost in some mountainous areas eliminates flowering structures, which can lead to vigorous vegetative growth the current season and high yield the next season (Lavee et al., 2007). Once an alternate bearing cycle is initiated, it may continue throughout the life of the tree unless fruit thinning or other management options are explored (Monselise and Goldschmidt, 1982; Lavee, 2006).

In olive, bloom and subsequently fruit number depend on the number of axillary buds formed by shoot growth in the previous season, the induction of these potentially reproductive buds, and

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the accumulation of sufficient winter chilling to break endodormancy (Rallo et al., 1994; Smith and Samach, 2013). Floral induction occurs during the fruit growth period and high crop load may facilitate a hormonal signal that inhibits induction (Fernández-Escobar et al., 1992; Samach and Smith, 2013). Thus, early fruit thinning in an 'on' year can play an important role in increasing return bloom the following season and in reducing alternate bearing (e.g., Dag et al., 2009, 2010). The thinning of flowers or fruit also improves fruit quality in many fruit tree species (Forshey and Elfving, 1989; Guardiola and Garcia-Luis, 2000). In olive, chemical fruit thinning is commercially practiced in table varieties in California (USA) and Israel to increase fruit size (Krueger et al., 2002; Birger et al., 2008). However, it is still quite uncommon in the newer commercial growing regions of South America.

Shoot and fruit growth in olive are largely a function of the crop load in a given season (Rallo et al., 1994; Lavee, 2007). For example, both apical and lateral shoot elongation have been reported to be greater on five year-old, non-fruit bearing branches than on similar fruit-bearing branches (Castillo-Llanque and Rapoport, 2011). When partial fruit thinning is practiced, shoot length is also most often greater at the end of the season (Proietti and Tombesi, 1996). Shoot elongation has been found to have the capacity to increase even when fruit are removed up to 120 days after full bloom (i.e., mid-summer) (Dag et al., 2010). In terms of reproductive growth, both individual fruit weight and pulp-to-pit ratio are consistently greater in olive when crop load is low (Barone et al., 1994; Proietti et al., 2006; Gucci et al., 2007; Trentacoste et al., 2010).

Because bloom occurs early in the season, vegetative and reproductive growth in fruit trees occur simultaneously for several months during the season, which can lead to competition for resources among the various plant organs (Forshey and Elfving, 1989; DeJong, 1999; Wünsche and Ferguson, 2005). In peach, analysis of growth dynamics indicates that both shoot elongation and fruit growth may be limited by resources (i.e., photoassimilates) during some periods (Grossman and DeJong, 1994). For example, shoot elongation in peach was often limited by resources for a short period early in the season likely due to the re-establishment of leaf area in this deciduous species, while fruit growth was limited for a longer period early in the season and again just before harvest (Pavel and DeJong, 1993; Grossman and DeJong, 1995a,b,c). Resource limitations have also been observed in other deciduous fruit trees such as apple as reviewed by Wünsche and Ferguson (2005).

In evergeen olive trees, less knowledge is available concerning how the seasonal dynamics of shoot and fruit growth are modified by different crop loads and when source-limited periods may occur. Rallo and Suarez (1989) observed that leaf length, number, and area as well as the dry weight of fruit-bearing branches increased rapidly in the spring with a plateau being reached approximately 60–100 days after bloom and little or no growth the rest of the season. Trunk growth may also slow sharply at about the same time (Cuevas et al., 2010), probably due to competition for assimilates with the fruit, which may be strong sinks after pit hardening (50–60 d after bloom). In contrast, Connor and Fereres (2005) have suggested that shoot elongation and leaf expansion may be maintained from spring to autumn if sufficient irrigation is provided. Studies with different crop loads could provide much needed information to more explicitly assess the observations and assumptions mentioned above.

The objectives of this study conducted in an intensive, well-irrigated olive orchard in Northwest Argentina (La Rioja) were to: 1) evaluate shoot and fruit growth dynamics in cv. 'Arauco' olive trees following fruit thinning during the same growing season in which thinning was applied and during the next growing season; and to 2) determine crop load effects on bloom, fruit set, and fruit yield over three growing seasons. It should be noted that fruit thinning was only performed the first season, and that many of the fruit and shoot growth responses in subsequent seasons were thus considered to be indirect responses to the single thinning event.

2. Materials and methods

2.1. Experimental orchard

The study was conducted in a commercial olive orchard (*Olea europaea* cv. 'Arauco') located near Bañado de Los Pantanos in the Province of La Rioja, Argentina (28.4°S, 66.8°W, 805 m above sea level) over three growing seasons. The cv. 'Arauco' has large fruits, high vegetative vigor, and is considered to be unique to Argentina (International Olive Oil Council, 2000). The trees were 9 years-old at the start of the experiment with a spacing of 6 m within rows × 8 m between rows (208 trees ha^{-1}) and an east-west row orientation. Tree canopy volume was initially 13 ± 3 m^3 and was approximately spherical in shape due to its being trained as a free-vase with little branch thinning in the internal part of the canopy (Gucci and Cantini, 2000). The trees were not pruned during the experiment in order to better assess responses to crop load.

The soil was gravelly sand in texture, deep (>1 m), and classified as typical Torripsamentes using the USDA soil classification system. Main annual rainfall in the area is approximately 90 mm with most rainfall occurring between November and March (i.e., late spring – summer). Due to the coarse soil texture and low rainfall, crop evapotranspiration requirements (100% ETc) were covered by irrigating 3–4 times weekly over the entire year using a drip irrigation system. A crop coefficient (Kc) of 0.7 was employed most of the year based on previous results in a neighboring orchard (Correa-Tedesco et al., 2010), and a reduction factor (Kr) was used to correct for crop ground cover. Fertilization with N, P, K and Mg was provided through the drip system based on periodic foliar nutrient analyses at a commercial laboratory (La Buena Tierra, Catamarca ARG). If any deficiencies were detected, supplemental fertilization was provided to the experimental trees.

Temperature data were obtained from an automatic weather station (Davis Instruments, CA USA) located in a neighboring orchard at the same height above sea level. Daily maximum and minimum temperatures indicated a wide range of temperature conditions during the experimental period (Fig. 1). Freezing temperatures (<0 °C) were recorded on an average of 35 days during the winters of 2008–2010, while maximum daily temperatures were often above 35 °C during the summer.

2.2. Fruit thinning treatments

Twenty-four trees were selected in early October 2007 at full bloom. Thinning was performed on 18 of the trees approximately five weeks after full bloom on November 13–14, 2007 by manually removing different percentages (33, 66, or 95%) of fruit from the entire tree canopy. The remaining 6 trees were used as controls and were not thinned. The experimental design was a randomized complete block design with one tree from each of the experimental four groups assigned to a given block and there were 6 blocks (i.e., 4 trees per block × 6 blocks = 24 trees).

The various thinning treatments were applied to the entire tree canopy by removing from each branch one of every three fruit (33%), two of every three fruit (66%), or 19 of every 20 fruit (95%). The number of thinned fruit was quantitatively assessed by dividing the fresh weight of all thinned fruit per tree by the weight of a sub-sample of 50 thinned fruits. After the final harvest, the percentage of thinned fruits could then be calculated as the number of thinned fruits divided by total fruit number. Total fruit number included the thinned fruit, fruit sampled during the course of the