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Responses of vegetative growth and fruit yield to winter and summer mechanical pruning in olive trees

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ABSTRACT

Mechanical pruning has become increasingly common in olive orchards, particularly under high tree densities. Large cutting disks make heading cuts at a single canopy depth without discriminating between branch thickness, size, or type of branch. The objectives of this study were to: (i) quantify the responses of vegetative growth over two growing seasons and yield components over three seasons following different intensities and moments of application of mechanical pruning; and (ii) evaluate some leaf morphology and gas-exchange characteristics of the remaining leaves after pruning. Five year-old olive trees with high crop load (cv. Arbequina) were pruned towards the end of the winter (W) or early summer (S). Three intensities of winter pruning representing different distances (0.25, 0.50, 0.75 m) from the outer canopy surface were applied, while there was only a single summer pruning treatment (0.75 m). The vegetative growth variables measured after pruning included new branch number and length, new leaf number, and increase in trunk cross sectional area. Reproductive variables included fruit and oil yield, fruit number, fruit weight, and oil content per fruit. Growth of new branches increased significantly with winter pruning intensity while delaying pruning to early summer reduced regrowth to the level of the unpruned control. Despite differences in yield in individual years between the unpruned control and the winter pruning treatments, the average yield over the three years after the winter pruning event was similar between all trees. Delaying the intense pruning to summer was associated with some reduction in yield, and moderate winter pruning (0.50 m) appeared to partially reduce alternate bearing. When measured shortly after winter pruning, specific leaf mass of the remaining leaves decreased steadily as the level of winter pruning increased, which is consistent with prior shading within the tree. The leaf net photosynthetic rate per unit mass was also different between pruning treatments. In conclusion, our results contribute to filling the gaps in knowledge related to important aspects of olive tree responses to the intensity and timing of mechanical pruning.

1. Introduction

There is a growing trend in the use of mechanical pruning in modern olive groves. The replacement of manual by mechanized pruning is in large part due to the increase in labor costs (Peça et al., 2002; Dias et al., 2012). Mechanical pruning in olive is performed by large cutting disk assemblies mounted onto a tractor or other vehicle. Discs make cuts at a single prescribed canopy depth and angle, which results in a uniform exterior canopy surface, without discriminating between branch thickness, size or type of branch. Such pruning alters the growth and development of individual trees and hedgerows because eliminating the branch apices leads to the reestablishment of hormone and nutrient relationships to the numerous remaining lateral buds on each branch (Génard et al., 1998). However, mechanical pruning can be an advantageous management tool for maintaining an adequate canopy size for commercial harvesters, improving light distribution, and reducing alternate bearing (Connor et al., 2014).

Whether it be manual or mechanical pruning, olive tree pruning is most often conducted during the winter when there are few other management tasks to perform. Although this period does coincide with minimal shoot extension, little information is available for olive trees as to what this choice or the use of different training systems entail for subsequent branch growth and fruit yield (Aïachi Mezghani et al., 2012). Indeed, winter pruning in fruit trees has often been associated with excessive shoot growth (Mika, 1986; ; Sihan et al., 2005). As has been shown in apple, summer pruning may offer some benefits including improved fruit illumination, increased fruit size, reduced vegetative growth, and reduced canopy transpiration under high plant

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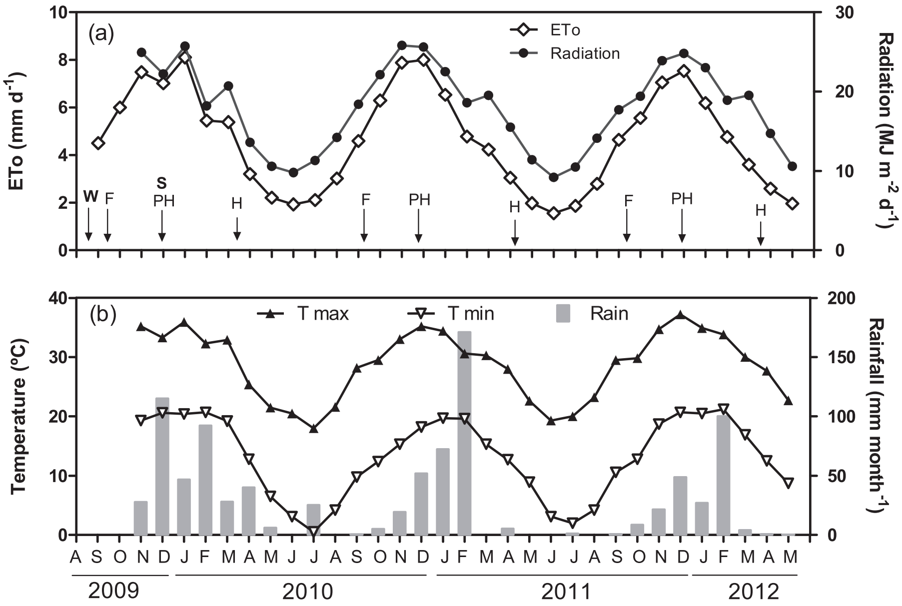

Fig. 1. Reference evapotranspiration (ETo) and solar radiation (a) as well as maximum (Tmax) and minimum (Tmin) temperature and rainfall (b) during the experiment (August 2009–May 2012). The ETo, solar radiation, and temperature values are average daily values for each month, while rainfall values are monthly totals (mm month^{-1}). The arrows indicate the dates of winter (W) and summer (S) pruning, flowering (F), pit hardening (PH), and harvest (H) for each year.

density (Mika, 1986; Forshey and Elfving, 1989; Li et al., 2003a,b). In olive, summer pruning is not a common practice, although eliminating the uppermost canopy growth (i.e., 'topping') from olive hedgerows during the summer before mechanical harvesting is increasingly applied.

In woody species, it is generally assumed that increasing the pruning intensity will result in more shoot growth following the pruning event. For example, Zeng (2003) observed that increasing the leaf area removed by pruning in *Ficus*, *Cinnamomum*, and *Pinus* favored biomass partitioning to leaves with pruned trees reaching leaf areas similar to those of unpruned trees one year after pruning. Additionally, new shoot elongation in peach increased with winter pruning intensity when pruning was conducted for three consecutive years (Siham et al., 2005). In olive, descriptive information suggests that post pruning vegetative growth responds strongly to pruning intensity (Gucci and Cantini, 2000), but quantification of the number and length of new shoots is needed over multiple growing seasons to design long-term pruning protocols in high density orchard systems.

The net carbon fixed by whole trees after pruning likely depends on factors such as the amount of leaf area removed, the photosynthesis of the remaining leaves, and canopy shape. In apple, the carbon fixed decreased proportionally with leaf area removed (13–64%) after summer pruning (Li et al., 2003a). Pruning of low branches in managed forest stands of *Eucalyptus* increased the net leaf CO_2 assimilation rate of the remaining branches after a winter pruning that was attributed to an increase in leaf conductance (g_l) (Pinkard et al., 1998; Pinkard, 2003; Medhurst et al., 2006). Using a modelling approach in olive, Fernández et al. (2008) have proposed that pruning olive trees from a spherical shape to truncated spheres (i.e., removing the top of the crown) may increase net carbon gain because it would increase the proportion of leaves exposed to sunlight. However, this would be affected by the photosynthetic characteristics of the remaining leaves under greater light levels, which are likely related to the canopy depth of the leaves prior to pruning (Larbi et al., 2015).

Studies focused on the quantitative responses of fruit tree species to mechanical pruning are scarce, although significant progress has been made recently in grapevines concerning the maintenance of training systems through mechanical pruning using specialized machinery (reviewed by Poni et al., 2016). In avocado and olive, studies of mechanical pruning are limited to yield comparisons between pruned trees and an unpruned or manually-pruned control (Morris and Cawthon, 1981; Giametta and Zimbalatti, 1997; Thorp and Stowell, 2001; Poni et al., 2004; Dias et al., 2012). In this regard, there is no information available in olive trees on the intensity or timing of mechanical pruning for maintaining canopy size without too adversely affecting yield and its components.

Thus, the objectives of the study were to: (i) quantify the responses of vegetative growth over two growing seasons and yield components over three seasons following different intensities and moments of application of mechanical pruning; and (ii) evaluate some leaf morphology and gas-exchange characteristics of the remaining leaves after pruning.

2. Materials and methods

2.1. Experimental site and pruning treatments

The experiment was conducted from August 2009 to April 2012 in a commercial olive orchard (*Olea europaea* cv. Arbequina) located 20 km north of the city of La Rioja, Argentina (lat. 29° 17′ S, long. 66° 45′ W; 444 m above sea level). The trees were 5 years-old at the beginning of the experiment with a north-south row orientation. The tree spacing was 6 m within rows and 8 m between rows (208 trees ha^{-1}). The soil was sandy loam in texture with a deep homogenous profile.

The orchard was within the Arid Chaco phytogeographic region and the climate is generally characterized by fairly mild, dry winters and very hot summers when torrential rainfall events often occur (Searles et al., 2011). The average daily reference evapotranspiration (ETo) values during the experimental period ranged from 1.6 mm d^{-1} during the winter to 8.1 mm d^{-1} during the summer months (Fig. 1a) for an annual ETo of about 1700 mm y^{-1}. The average maximum daily temperature ranged from 18.0 °C during the winter to 37.2 °C during the summer months with average minimum temperatures between 0.5 °C and 21.2 °C (Fig. 1b). Rainfall was about 340 mm y^{-1} and was concentrated mainly in the summer months.

We employed fairly young, mid-sized trees for simulating mechanical pruning in this study because detailed measurements of very large, 5-m-tall hedgerows grown at low tree densities (200–400 trees ha^{-1}) are impractical for a large number of trees (Cherbiy-Hoffmann et al., 2012), and higher tree density hedgerow orchards were not yet available in our region. At the beginning of the study prior to pruning, the average canopy depth and diameter were 2.7 m and 2.2 m, respectively. Canopy depth was defined as the tree height minus the skirt-to-ground distance. Canopy diameter measurements were made every 0.50 m in height above ground level in the E-W and N-S directions to calculate the average canopy diameter. The initial canopy volume was estimated to