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Olive tree response to the severity of pruning

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Abstract: Pruning has been seen as a means of improving olive tree productivity. The presumed importance of pruning was described by Columella (born 4 AD), and has persisted in general terms to the present. In this work, the effect of different pruning regimes was assessed from two field trials conducted in Mirandela, NE Portugal, in an olive grove of cv. 'Cobrançosa', rainfed managed. The first trial began after a light crop ("off" year) and received four pruning regimes (hard, moderate, light, and nonpruned control). The second trial started the following year, after a heavy crop ("on" year), and received two pruning regimes (hard and nonpruning). The study was carried out from 2012 to 2016. The accumulated crops of the four harvests performed after pruning in the first experiment did not significantly vary among nonpruning (8754 kg ha^{-1}), slight pruning (8850 kg ha^{-1}), and moderate pruning (8334 kg ha^{-1}) but was significantly lower in hard pruning (6449 kg ha^{-1}). The olive trees showed a high plasticity or tolerance to pruning, since olive yield did not decrease in response to light or moderate pruning regimes. It seems that it is possible to carry out light to moderate pruning to achieve several objectives of orchard management without significant loss of production. The results also showed that if pruning is done under a hard regime it should only be performed after a heavy crop. In addition, if done under a light regime, pruning can also reduce the alternate-year bearing behavior of the olive tree.

Key words: Alternate bearing, *Olea europaea*, olive yield, pruning regime

1. Introduction

Pruning of olive trees has been a subject of lively debate since ancient times. Lucius Junius Moderatus Columella (4–c. 70 AD), the most important writer on agriculture of the Roman Empire, provided the first essay on olive pruning. He reports an old proverb that says "He who ploughs the olive-grove, asks it for fruit; he who manures it, begs for fruit; he who lops it, forces it to yield fruit" (Foster and Heffner, 1941). Several other old pruning texts have been revisited by Gucci and Cantini (2000) in a thorough review of the subject.

In the last few decades, olive pruning has been gaining increasing interest. Important literature published as textbooks on olive growing has devoted important chapters to pruning (Sibbett, 2005; Tombesi and Tombesi, 2007; Vossen, 2007; García-Ortiz et al., 2008; Therios, 2009). Usually they cover several aspects of pruning, such as training systems, tree shape, dates of pruning, methods and tools, and general and specific objectives of pruning. In general terms, all authors agree that pruning is essential to orchard management or even as a means of enhancing profitable fruiting.

Pruning has been advocated for several purposes: in young trees, mainly to build a framework necessary to support fruit load (Vossen, 2007; Gregoriou, 2009; Therios, 2009); in mature trees, pruning is performed to maximize sunlight exposure and to maintain the equilibrium between vegetative and reproductive functions (Sibbett, 2005; García-Ortiz et al., 2008). Other relevant objectives assigned to pruning are to reduce the severity of and/or facilitate pest and disease control (Sibbett, 2005; Tombesi and Tombesi, 2007), to moderate the crop during an "on" year by pruning and to reduce alternate bearing (Vossen and Devarenne, 2007; Gregoriou, 2009), and to adjust the canopy to the training system and method of harvest (Sibbett, 2005; García-Ortiz et al., 2008; Therios, 2009). Older trees can be subjected to rejuvenating and regenerative pruning as a means of controlling tree growth and productivity (Sibbett, 2005; García-Ortiz et al., 2008).

Being a technique with so many recognized benefits and with such good coverage in text books, it is difficult to understand the very limited literature published on the subject in the form of scientific papers. The authors of books and book chapters support their viewpoints

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with personal experience and/or local trials and reports, generally inaccessible to the international scientific community. There are, however, a set of good papers reporting diverse aspects of pruning. With the purpose of studying an alternative method to the expensive and labor-intensive manual pruning, Peça et al. (2002) and Dias et al. (2012, 2014) demonstrated that mechanical pruning can give higher yield than hand-held chain-saw pruning. Studies were also carried out to demonstrate the benefits of regenerative pruning in the recovery of old olive trees (Ben Rovina et al., 2001; Metzidakis, 2002). From a study aimed at determining the effects of mechanical topping and hedging on yield, Ferguson et al. (2002) found that the cost of mechanical harvesting would need to decrease significantly to compensate for the significant decrease in olive yield.

The most pertinent scientific issue concerning pruning, and which is universal to all training systems, is the severity of pruning combined with the pruning regime. Few studies, however, have been devoted to the subject. From a young high density hedgerow olive orchard, Tombesi et al. (2014) reported that unpruned trees proved to be more productive than those subjected to two different pruning regimes. In a book chapter on pruning, García-Ortiz et al. (2008) reported results from their own experiments in which trees kept unpruned for 8 years produced more fruit than trees subjected to many other pruning regimes. Despite these results, the authors do not recommend that pruning should be suspended but that only under irrigation does it seem necessary to reduce the severity of pruning. Tombesi and Tombesi (2007) reported results from an experiment in which crop yields were distinctly higher when trees underwent light pruning as opposed to medium and heavy pruning. Unfortunately, this experiment did not have a control without pruning.

In view of the above, the hypothesis for this work is that productivity cannot be increased by pruning. This does not mean that pruning cannot be done for several good reasons (phytosanitary, adaptation to harvest and other cropping operations, etc.), but that increase in production cannot be the real outcome of pruning. To test the hypothesis, a field trial with four pruning regimes differing in frequency and intensity, including a nonpruning control, was installed in a rainfed olive orchard located near Mirandela, NE Portugal. A second trial was established 1 year later to test if crop load in the year of pruning influences the final result, taking into account the alternate bearing cycle of olive. This second experiment only comprised two treatments, hard pruning and no pruning.

2. Materials and methods

2.1. Study site

The experiment was carried out over five consecutive harvests (Autumn 2012 to Autumn 2016) in a mature ~25-year-old olive orchard (cv. 'Cobrançosa'), spaced at 7 ´ 7 m (~204 trees ha^{-1}) and rainfed managed. The experimental plot is located near Mirandela (41.513946; –7.187348) in the northeast of Portugal. The region benefits from a typical Mediterranean climate, with an annual average temperature of 14.3 °C and a cumulative annual rainfall of 509 mm. The orchard is established in a schist-based soil, sandy-loam textured. Selected soil properties, determined from four soil samples randomly taken from the plot at the beginning of the pruning trial, on 6 November 2012, are presented in the Table.

Table. Selected soil properties determined from soil samples (0–20 cm layer) taken at the beginning of the field trial on 6 November 2012 (mean ± standard deviation).

Soil properties		Soil properties	
Clay (%)	9.3 ± 0.51	[c]Extract. P (mg P_2O_5 kg^{-1})	22.1 ± 4.70
Silt (%)	16.6 ± 0.90	[c]Extract. K (mg K_2O kg^{-1})	97.0 ± 16.00
Sand (%)	74.1 ± 0.89	[d]Extract. B (mg kg^{-1})	0.9 ± 0.08
Texture	Sandy loam	[e]Exchan. K ($cmol_c$ kg^{-1})	0.3 ± 0.07
pH(H_2O)	5.5 ± 0.15	[e]Exchan. Na ($cmol_c$ kg^{-1})	0.4 ± 0.02
pH(KCl)	4.5 ± 0.13	[e]Exchan. Ca ($cmol_c$ kg^{-1})	3.4 ± 0.13
[a]Oxidizable C (g kg^{-1})	0.6 ± 0.03	[e]Exchan. Mg ($cmol_c$ kg^{-1})	1.0 ± 0.07
[b]Total organic C (g kg^{-1})	1.5 ± 0.04	[e]Exchan. acidity ($cmol_c$ kg^{-1})	0.1 ± 0.04

[a]Walkley–Black; [b]Incineration; [c]Egner–Riehm; [d]Azomethine-H; [e]Ammonium acetate, pH 7.

2.2. Experimental design and orchard management

The study comprised two independent experiments. A main experiment, in which four different pruning regimes were performed, started in 2012 following an "off" year, and a second experiment with two pruning regimes began after the harvest of 2013 after an "on" year. Prior to the beginning of the experiment, the farmer used to prune the trees every 4 years by performing a moderate/hard (50% to 70% of the foliage removed) pruning regime. In the year of the establishment of the main trial, the trees had not been pruned for 4 years and were expected to be pruned again precisely in this year according to the quadrennial pruning cycle in which they had been managed to the present. The trees of the second trial were in the fifth year without being pruned given that the trial began a year later.

The pruning regimes of the main experiment were chosen according to the most common practices in the region: i) hard pruning, with removal of ~75% of the foliage and performed every 4 years (in this experiment once at the beginning of the experiment on 17 January 2013); ii) moderate pruning, with removal of 50% of the foliage and carried out every 3 years (2013 and 2016 in this experiment); (iii) light pruning, performed annually, with 25% of foliage removal [recommended in the regional literature on pruning (Lopes et al., 2009)]; and (iv) no pruning as a control. In this experiment, 10 similar trees (10 replications) per treatment were randomly selected and tagged, and the pruning regimes applied in a completely randomized design. The second experience was greatly simplified. Only two pruning regimes were established: (i) hard pruning, as defined above; and (ii) no pruning as a control. In this case, only five trees per treatment were randomly selected and tagged.

The orchard floor was managed by conventional tillage, performed with a cultivator once a year in early April after the application of fertilizers. A NPK compound fertilizer (10:10:10) was applied annually at a rate corresponding to 30 kg ha^{-1} of N, P_2O_5, and K_2O. Boron was also applied every year at a rate of 2 kg B ha^{-1}. The farmer does not apply pesticides and relevant phytosanitary problems were not observed during the experimental period. Pruning was performed in the resting period of winter, respectively on 17 January 2013, 21 February 2014, 11 February 2015, and 4 February 2016, as is usual in the region. The harvests were held in the autumn of each year, respectively on 6 December 2012, 4 December 2013, 24 November 2014, 25 November 2015, and 25 November 2016. The harvest was performed by using a branch shaker harvesting machine to pull the fruit down, with sheets spread on the floor to recover it.

2.3. Field and laboratory determinations

The pruning wood corresponding to the initial pruning event of 17 January 2013 was weighed both fresh and dry. The objective was to evaluate the amount of foliage removed and subsequently to provide information on nutrient balance. From representative subsamples of all treatments, the prunings were separated into wood, twigs, and leaves. In the year following the first pruning event, suckers and water sprouts were also weighed both fresh and dry and separated into stems and leaves. All the plant parts were carried to the lab, and were oven dried at 70 °C and ground for further laboratory elemental analysis.

In the growing season following the first pruning event, 20 potentially fruitful twigs per tree were randomly selected and tagged with a weightless and colored thread, to count flower clusters and fruit set. In the next autumn, when the growth of the trees ceased due to lower temperatures, the length of the new shoots was measured and the number of leaves counted.

In the resting period of winter and in the summer at endocarp sclerification (by July), a leaf sample per tree was collected for elemental analysis, allowing monitoring of the nutritional status of trees. The leaves were taken from the middle portion of the current season shoots, which were equally distributed around the tree at approximately 1.8 m high.

In the autumn the fruits were harvested and weighed per tree. The harvesting method has already been described. In the harvest of 2013, random samples of 100 fruits were taken per tree and weighed as fresh for fruit size evaluation. Subsamples of these fruits were separated into pulp and pit, oven dried at 70 °C, and analyzed for elemental composition.

Elemental analysis was carried out in all tissue samples. Tissue analyses were performed by Kjeldahl (N), colorimetry (B and P), flame emission spectrometry (K), and atomic absorption spectrophotometry (Ca, Mg, Cu, Fe, Zn, and Mn) methods (Walinga et al., 1989).

Estimates of the chlorophyll content of leaves were recorded by a portable Minolta SPAD-502 plus chlorophyll meter. Thirty readings per tree were taken from the blade of fully expanded young leaves.

A normalized difference vegetation index (NDVI) was estimated by using a Field Scout CM 1000 NDVI meter. The device senses the light at wavelengths of 660 nm and 840 nm, measuring the ambient and reflected light at each of those wavelengths. The NDVI value (–1 to 1) is calculated from the measured ambient and reflected light data [(%Near Infrared – %Red) / (%Near Infrared + %Red)]. Readings are taken by pressing a trigger that activates the targeting lasers and the measuring and calculating mechanism. Readings were taken from the blade of fully expanded young leaves.

2.4. Data analysis

The effect of the different pruning regimes was subjected to analysis of variance (ANOVA). When significant differences among treatments were found, the means were separated by Tukey HSD test (α = 0.05).

3. Results

3.1. Resources removed in pruning wood

Pruning removes valuable resources from the trees. Hard pruning removed 2.7 Mg dry matter (DM) ha^{-1}, from which 600 kg ha^{-1} corresponded to leaves (Figure 1). Nitrogen content in removed leaves in the hard pruning regime amounted to 8.3 kg ha^{-1} and a total of 15.3 kg N ha^{-1} was removed in all pruned plant parts. Minor quantities, but still relevant, were removed of other macronutrients and micronutrients. Potassium removed, for instance, in the hard pruning regime, amounted to 9 kg ha^{-1}.

Olive trees always have a high amount of latent buds, causing a lot of suckers to arise from below ground and water sprouts to emerge from the trunk following a pruning event. This corresponds to an inefficient allocation of resources, since these shoots will be withdrawn the following year. In the hard pruning regime, 258 kg DM ha^{-1} and 2.3 kg N ha^{-1} were removed in suckers and water sprouts in the year following the first pruning event (Figure 2). In the control treatment, for instance, only 28 kg DM ha^{-1} and 0.3 kg N ha^{-1} were removed in suckers and water sprouts.

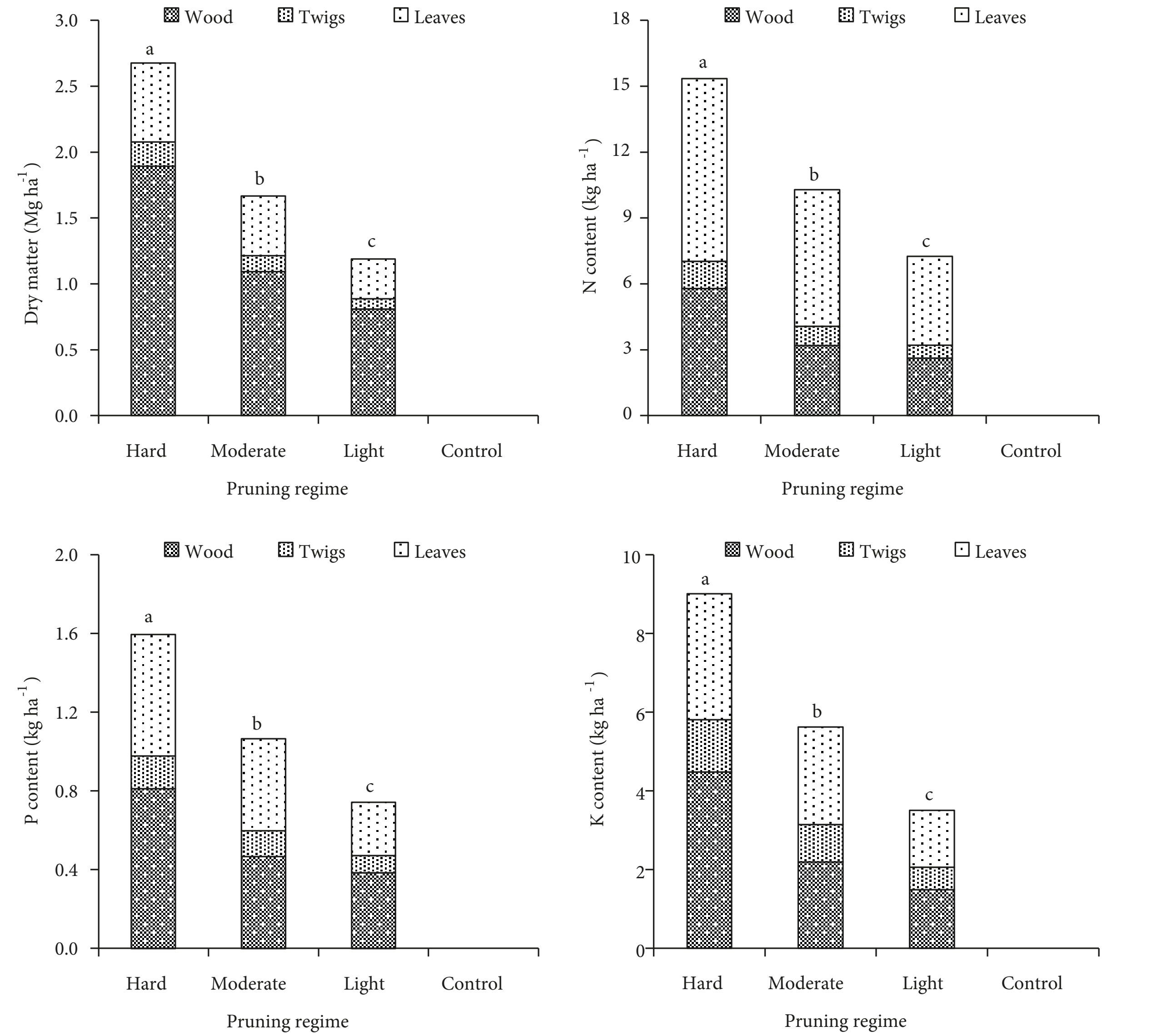

Figure 1. Dry matter removed and N, P, and K content in prunings in the first pruning event of 2013 after having been separated into wood, twigs, and leaves from the four different pruning regimes: hard pruning (75% foliage removed), moderate pruning (50% foliage removed), light pruning (25% foliage removed), and control (no pruning). Different letters above the columns mean significant differences by the Tukey HSD test (α = 0.05).

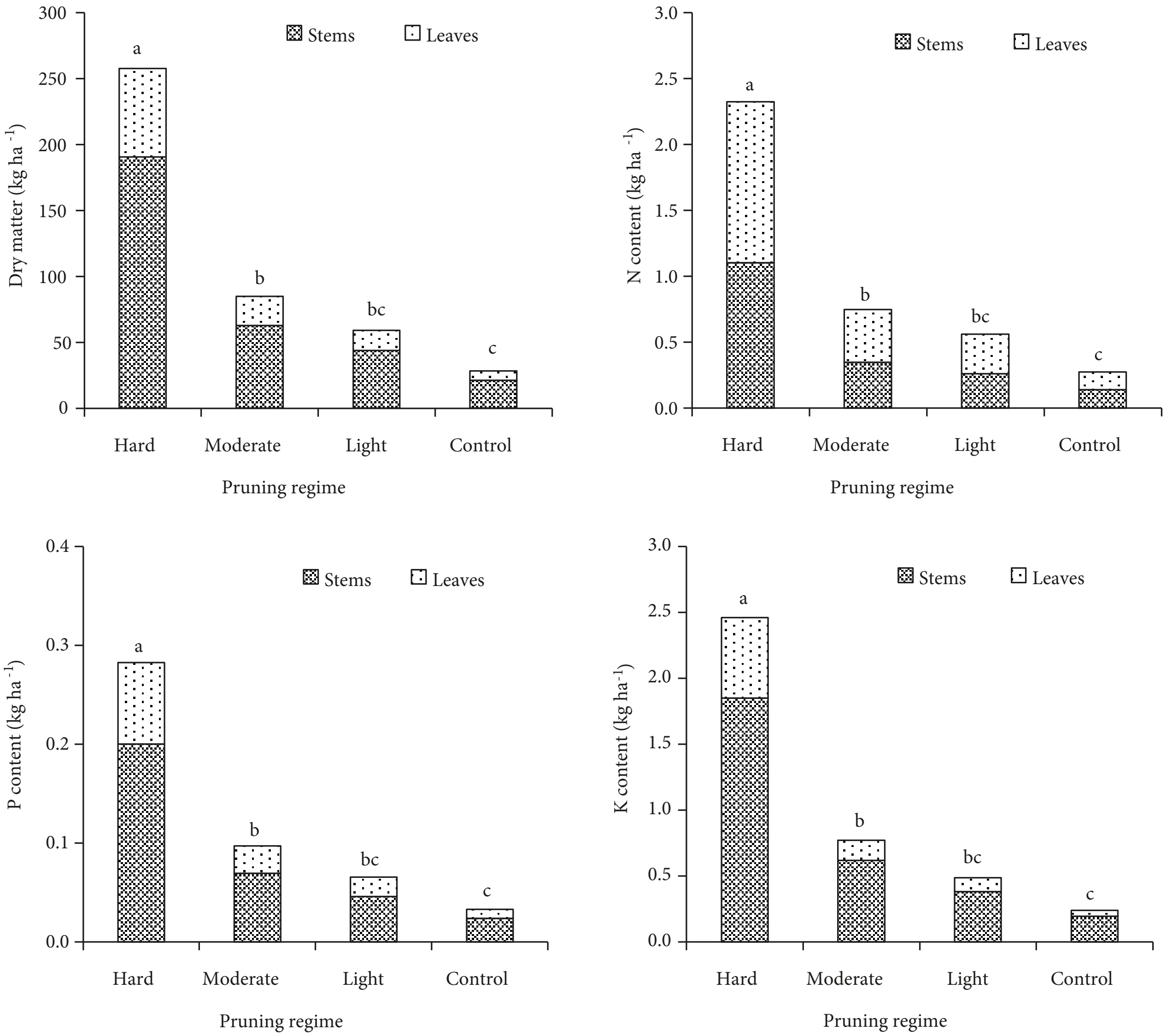

Figure 2. Dry matter removed and N, P, and K content in suckers and water sprouts after the first pruning event of 2013 separated into stems and leaves, from the four different pruning regimes: hard pruning (75% foliage removed), moderate pruning (50% foliage removed), light pruning (25% foliage removed), and control (no pruning). Different letters above the columns mean significant differences by the Tukey HSD test (α = 0.05).

3.2. Shoot growth, fruit set, and tree nutritional status

At the end of the growing season following the pruning event of 2013, the length of the 1-year-old shoots and the number of leaves in them varied according to the severity of pruning (Figure 3). The average length of shoots was 12.1, 8.7, 7.8, and 3.2 cm and the average number of leaves was 14.3, 11.9, 11.3, and 7.3, respectively, in hard, moderate, light, and no pruning regimes.

In the second pruning experience, the effects of pruning on number of flower clusters and fruit set per twig in the current growing season were also assessed. The number of flower clusters was not significantly affected by pruning regime, probably because floral differentiation had already occurred at the time of pruning. In addition, the number of fruits per twig also did not vary with the pruning regime (Figure 4).

Pruning regime caused a significant effect on leaf N concentrations of the olive trees (Figure 5). In the first experiment, the effect lasted for three leaf sampling dates. Hard-pruned plants displayed significantly higher leaf N concentration than unpruned trees. In the second experiment the results were quite similar but the differences were only statistically significant for two sampling dates following pruning. For the other nutrients, the changes

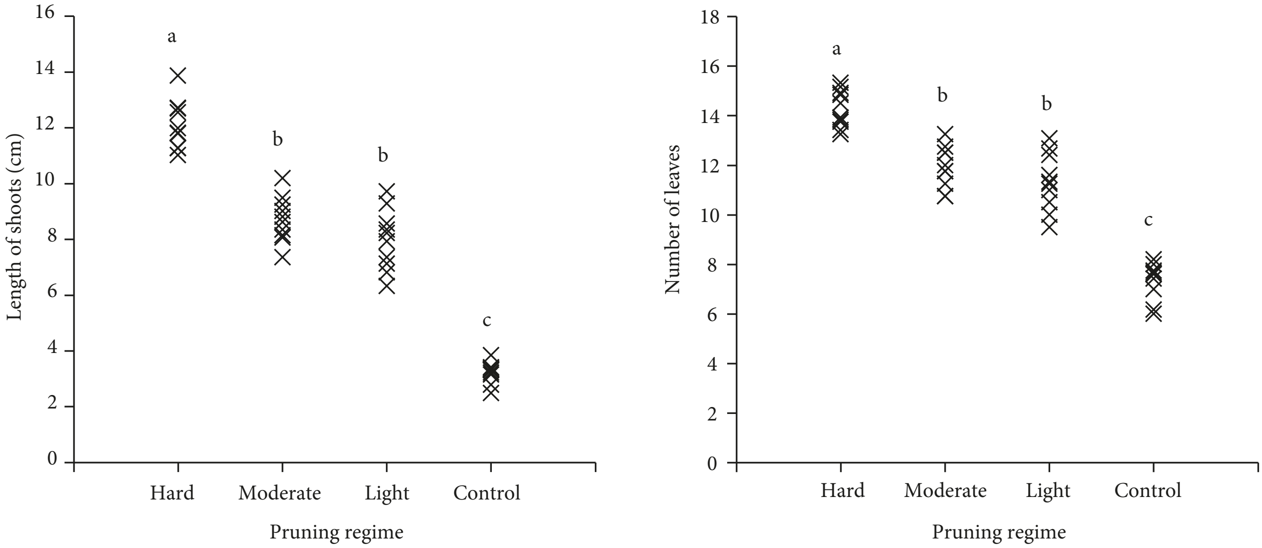

Figure 3. Average length of 1-year-old shoots (left) and average number of leaves in 1-year-old shoots (right) in response to the four different pruning regimes: hard pruning (75% foliage removed), moderate pruning (50% foliage removed), light pruning (25% foliage removed), and control (no pruning). Different letters above each set of data mean significant differences by the Tukey HSD test (α = 0.05).

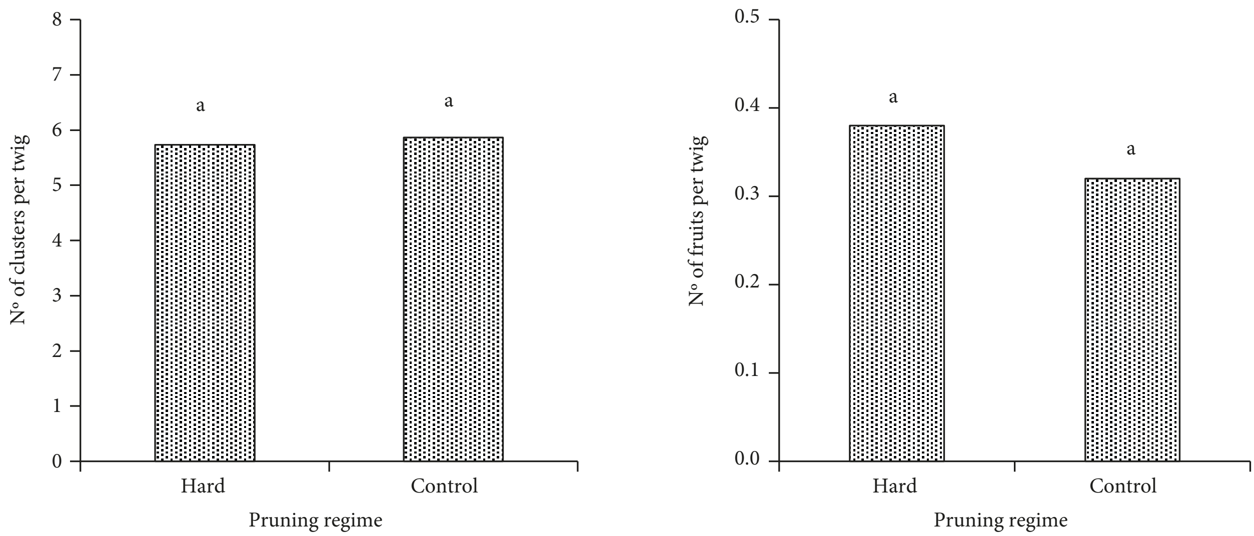

Figure 4. Number of flower clusters (left) and number of fruits (right) per shoot in the spring/summer after the trees had been pruned in two different pruning regimes: control (no pruning) and hard pruning (75% foliage removed). Different letters above the columns mean significant differences by the Tukey HSD test (α = 0.05).

were small and significant differences among pruning treatments were not usually found. No coherent pattern was identified for any of the other nutrients analyzed as a function of the pruning regime (data not shown).

SPAD readings and NDVI showed significant differences among pruning regimes. A consistent decrease was found from the trees severely pruned, followed by the trees moderately and lightly pruned, the lower values recorded being for nonpruned trees (Figure 6).

Fruits of the first harvest on 4 December 2013, following the first pruning event, were also analyzed for elemental composition after they had been separated into pulp and pit. The results of pulp and pit nutrient concentration presented little variation among pruning regimes. The concentrations of K and B in pits showed a consistent decrease from hard-pruned trees to the control but the differences were not statistically significant at $P < 0.05$ (data not shown).

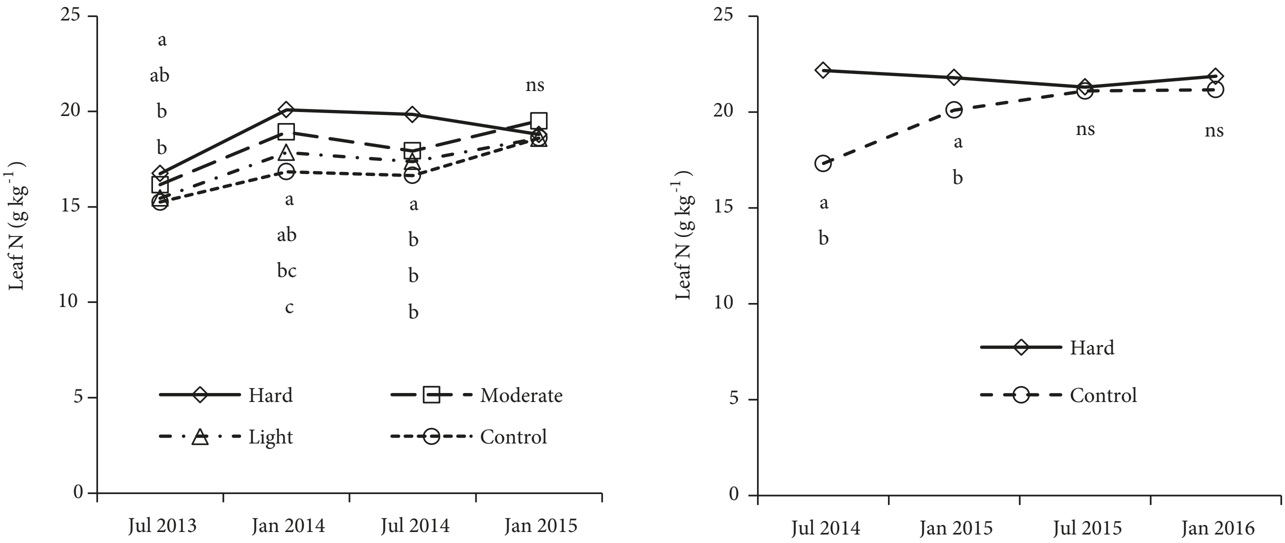

Figure 5. Leaf nitrogen concentrations in the first (left) and second (right) pruning experiments from the first four sampling dates following pruning as a function of pruning regime: hard pruning (75% foliage removed), moderate pruning (50% foliage removed), light pruning (25% foliage removed), and control (no pruning). Different letters associated with each sampling date mean significant differences by the Tukey HSD test (α = 0.05) and ns, not significant.

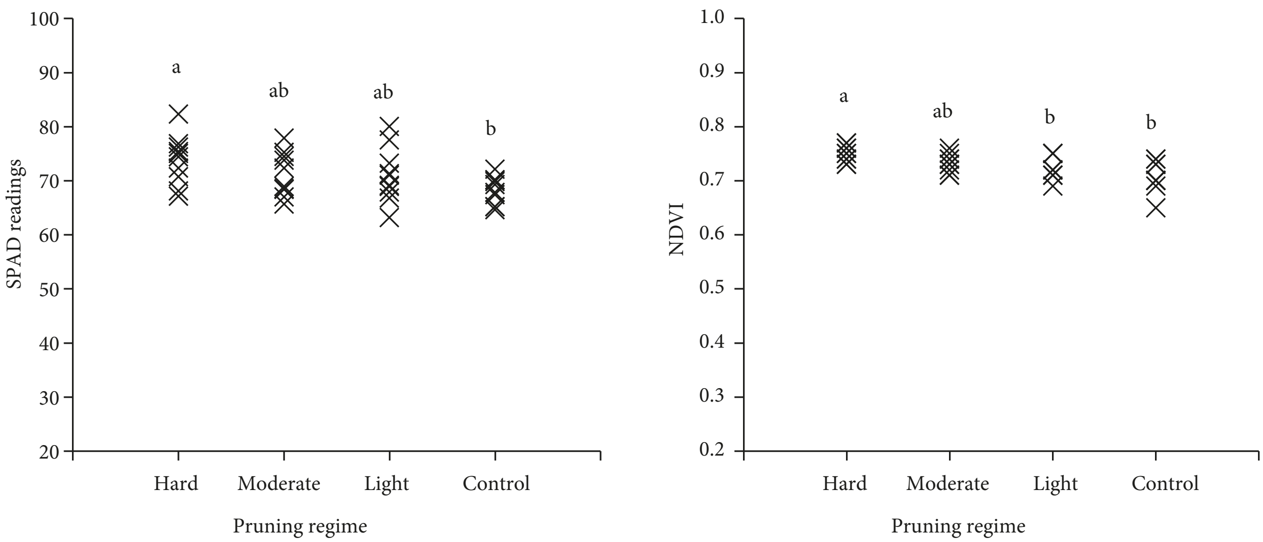

Figure 6. SPAD readings (left) and NDVI (right) in the summer following the first pruning event in response to the four different pruning regimes: hard pruning (75% foliage removed), moderate pruning (50% foliage removed), light pruning (25% foliage removed), and control (no pruning). Different letters above each set of data mean significant differences by the Tukey HSD test (α = 0.05).

3.3. Olive yield

Hard pruning produced significantly lower crop yields than the other pruning regimes (Figure 7). Among the moderate, light, and no pruning regimes, the differences were not statistically significant. The average accumulated olive yields in the four harvests performed after the trial started amounted to 8754, 8850, 8334, and 6449 kg ha^{-1}, respectively, in the control, light, moderate, and hard pruning plots. The control treatment seems to accentuate the alternate bearing cycle of olive, with more pronounced "on" and "off" years, in comparison with light pruning.

In the second experiment, which started following an "on" year, the control gave significantly higher average olive yields than hard pruning (Figure 8). The average

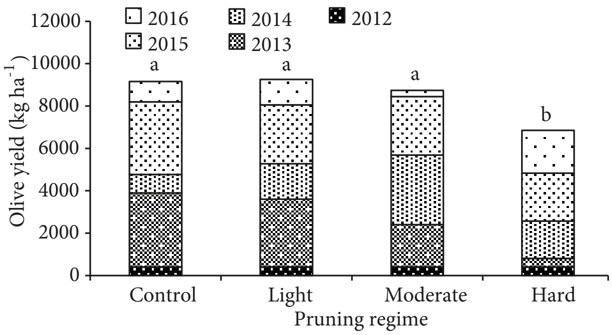

Figure 7. Olive yields in the year before the experiment had started (2012) and four years (2013–2016) after the trees had been pruned under four different pruning regimes: control (no pruning), light pruning (25% foliage removed), moderate pruning (50% foliage removed), and hard pruning (75% foliage removed). Different letters above the columns mean significant differences by the Tukey HSD test (α = 0.05).

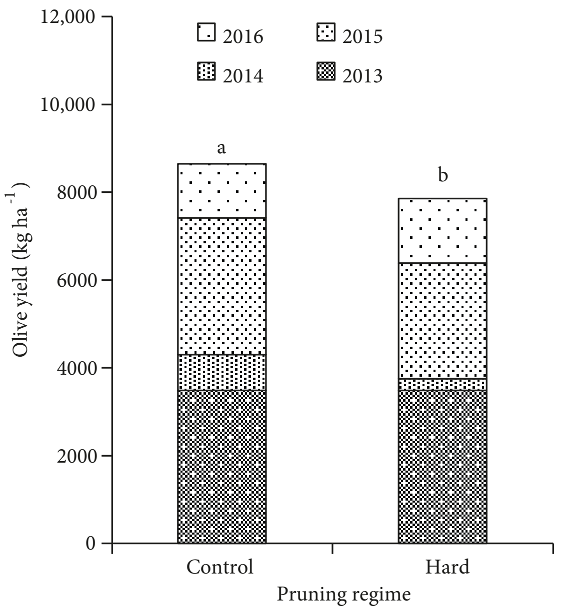

Figure 8. Average olive yields in the year before the experiment had started (2013) and in the following three years (2014–2016) after the trees had been pruned under two different pruning regimes: control (no pruning) and hard pruning (75% foliage removed). Different letters above the columns mean significant differences by the Tukey HSD test (α = 0.05).

accumulated olive yields in the 3 years following the pruning event reached 5161 and 4370 kg ha^{-1}, respectively, in the control and hard pruning plots.

The size of the fruits was also assessed through their weight from a sample taken in the harvest of November 2013, following the first pruning event. The size of the fruits significantly decreased from the hard pruning plot to the control (Figure 9). The result is exactly the opposite of that found in olive yields if only the crop of 2013 is taken into account (Figure 7).

4. Discussion

Hard pruning represented a significant loss of stored energy in plant tissues while also removing potentially carbohydrate-producing parts. Under the conditions of this experiment, hard pruning removed 2.7 Mg DM ha^{-1}, of which 600 kg ha^{-1} was leaves. In total prunings (wood and leaves) 15.3 kg N ha^{-1} and 9 kg K ha^{-1} were also removed from the trees. Sibbett (2005) and Vossen (2007) have clearly referred to pruning as an effective loss to the trees. Many other writers, however, continue to refer to pruning mainly as a mean of maintaining the equilibrium between the vegetative and reproductive functions (Gregoriou, 2009; Therios, 2009; Tombesi and Tombesi, 2009). In the hard pruning treatment of the first experiment, after the first growing season 258 kg DM ha^{-1} and 2.3 kg N ha^{-1} were removed as suckers and water sprouts, which represents an inefficient resource allocation in nonproductive plant parts. Other authors have previously drawn attention to this aspect, when mentioning that pruning if severe results in unfruitful vegetative growth (Sibbett, 2005; Tombesi and Tombesi, 2007).

Pruning did not influence the number of flower clusters per 1-year-old shoot nor did fruit set in the blossom that followed the first pruning event. In olive, floral induction

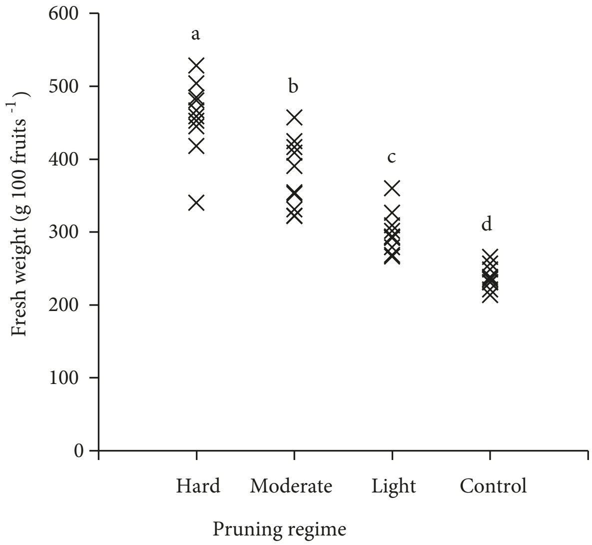

Figure 9. Fresh weight of 100 olives in the harvest of 2013 in response to the four different pruning regimes: hard pruning (75% foliage removed), moderate pruning (50% foliage removed), light pruning (25% foliage removed), and control (no pruning). Different letters above each set of data mean significant differences by the Tukey HSD test (α = 0.05).

occurs in summer/autumn of the previous year (Pinney and Polito, 1990; Fernández-Escobar et al., 1992; Martin et al., 2005) and floral bud differentiation starts late in winter after winter chilling releases previously initiated flower buds from dormancy (Rallo and Martin, 1991; Martin et al., 2005). Thus, the number of flower clusters cannot be related to pruning. However, there also appears to have been no significant increase in fruit set by pruning. Fruit set depends in part on the quality of the flowers, since in the olive tree there are many staminate (imperfect) flowers due to pistil abortion (Cuevas et al., 1999; Fernández, 2014). In the few weeks following full bloom, a massive abscission of flowers and young fruits is observed (Rallo et al., 1981). The inflorescence behaves as a unit of fruitfulness, where the competition for reserves among the developing fruits seems to be the main factor in regulating final crops (Rallo and Fernández-Escobar, 1985; Cuevas et al., 1995). Under the conditions of this experiment, pruning was performed in winter and blossom occurred in May. The trees resume relevant photosynthetic activity only after the winter cold, usually in April. Seemingly, pruned trees, although benefiting from an increased root/shoot ratio, would not be in a better condition in terms of available energy to display significantly higher rates of fruit set.

Pruned trees invested their resources in restoring photosynthetic capacity. The more severe the pruning the greater the length of new shoots and the number of leaves per shoot, which in turn are the structures that ensure the crop in the following year. In the Mediterranean environment and in rainfed managed orchards, available water is the main constraint to the vegetative expansion of the tree. Olive can cope with such stressful environments through leaf-level morphological and structural adaptations to reduce water loss (Bacelar et al., 2004) and diverse physiological and biochemical responses to water stress (Bacelar et al., 2009). Pruning reduces the aerial biomass of the tree, which increases the root/shoot ratio. The water conditions of the remaining foliage are enhanced, which allows the increase in the length of the 1-year-old shoots in pruned trees. On the other hand, the fruit load in the growing season after pruning was lower in the more severely pruned trees, with reduced sink points favoring vegetative expansion. It is well stated that in the biennial bearing cycle of olive the massive production of flowers and fruits in a given year reduce the growing of new shoots by competition for assimilates (Martin, 1990; Fernández, 2014).

Pruning significantly influenced some parameters of tree nutritional status. Leaf N concentration, SPAD readings, and NDVI significantly decreased from hard pruning to control. Considering that N is usually a limiting factor in agricultural soils and the plants have the ability to absorb and accumulate it in their tissues, the increase in the tree N nutritional status as the pruning intensity increased is likely due to the distribution of a limited resource over less foliage. It is a common phenomenon of nutrient concentration. Previously Sibbett (2005) has stated that pruning induces new growth by increasing the amount of N available to each remaining point.

Hard pruning significantly reduced olive yield in comparison to the other pruning treatments, including nonpruning. The increase observed in the length and number of leaves in 1-year-old shoots, which potentially increases the number of flowers and potential fruits per shoot, did not compensate for the reduced number of fruiting shoots in the pruned trees. The result shows that pruning cannot increase olive yield in comparison to nonpruning. However, the olive trees showed a great deal of plasticity in relation to pruning, that is, the trees seem to tolerate light to moderate pruning without losing production potential, likely due to the ability to rapidly restore the canopy by increasing the length of the fruitful 1-year-old shoots. This thesis will be valid for at least rainfed conditions, where the main limiting factor is available water and the resource can be used efficiently even if the tree loses part of the photosynthetic apparatus. Probably in irrigated orchards, where leaf area index and intercepted radiation are likely to be the main limiting factors for plant growth and yield, pruned trees may have greater difficulty in displaying the productive potential of unpruned trees. The literature on pruning usually highlights the merits of pruning, including its ability to improve productivity (Sibbett, 2005; Tombesi and Tombesi, 2007; García-Ortiz et al., 2008; Gregoriou, 2009; Therios, 2009). However, as far as we know, there are no published results based on experimental work showing that pruning increases production relative to nonpruning. García-Ortiz et al. (2008) reported several long-term experiences in Spain where nonpruning resulted in higher yields than pruned regimes. However, the authors conclude only that it seems necessary to reduce the intensity of pruning. In a pruning experiment carried out in a young high density hedgerow olive orchard, Tombesi (2013) found that unpruned trees were more productive than two different pruning regimes (removal of basal canopy and removal of basal canopy + hedging). He concludes that minimal pruning operations have to be applied in these kinds of orchards. Tombesi and Tombesi (2007) reported an experiment where crops were distinctly higher when the trees underwent light pruning as opposed to medium or heavy pruning. Unfortunately, the experiment did not include an unpruned control, but the lighter the pruning the bigger the crop.

Nonpruning seems to accentuate biennial fruiting in comparison to light pruning. Due to the bigger size of canopy, unpruned trees can respond with a heavy crop load in a given year, resulting in a lighter one in the following year. This plant probably evolved to maximize the number of seeds in the long term to the detriment of a better interannual balance. In the face of a good opportunity, the plant responds with a heavy crop, resulting in less production the following year. Alternate bearing is a well-known phenomenon in olive groves and is likely due to the overlap of two consecutive production cycles, either because the induction of flowering is inhibited by growing fruits (Fernández-Escobar et al., 1992) or by competition for the resources between flowering and fruit growth with new shoot growth, which determines the crop in the following year (Martin, 1990; Fernández, 2014).

Hard pruning caused less yield loss when done after an "on" year. According to the alternate bearing cycle of olive, after a good crop there will be a lighter one and thus the difference between unpruned and pruned trees will be of minor importance. Hence, if done in an "on" year, pruning can only aggravate what would naturally be a poor crop. In contrast, pruning in an "off" year prevents what would probably be a high crop in the following year, with a heavier penalty for pruned compared to unpruned trees.

Severe pruning gave rise to larger fruits. The result was likely more a consequence of few fruits on the trees and less to a direct effect of pruning itself. With fewer fruits, they tend to be of greater size since there are fewer sink points on the tree for the available resources.

In summary, the results from this work showed that pruning cannot increase olive yield. Without pruning, the trees grow larger, particularly in height, making it difficult to implement several cultural practices. Harvesting, whether manual or mechanical, can be greatly hindered or even impossible in unpruned trees. Dense canopies may favor some pests and diseases and hinder the penetration of spray treatments for their control. The trees, at least if rainfed grown, seem to present high pruning plasticity if applied under light to moderate regimes, without significant yield reduction. This indicates that trees may be pruned and the pruning regime adjusted to meet several purposes other than increased production. Light to moderate pruning regimes can be used to implement a given training system, to reduce alternate bearing, to reduce the density of the canopy, or to adjust the tree to the method of harvest. Hard pruning should be avoided. If done, it is preferable to perform it after an "on" year, since the next year's crop will probably be poor with or without pruning. If the objective is to regulate alternate bearing, light to moderate pruning should be done after "off" years. It also seems appropriate to adjust N fertilization to the pruning regime. After pruning, the N fertilizer rate can be reduced, and conversely, as the period without pruning increases, N fertilization can also be increased.

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References

Bacelar EA, Correia CM, Moutinho-Pereira JM, Gonçalves BC, Lopes JI, Torres-Pereira JMG (2004). Sclerophylly and leaf anatomical traits of five field-grown olive cultivars growing under drought conditions. Tree Physiol 24: 233-239.

Bacelar EA, Moutinho-Pereira JM, Gonçalves BC, Lopes JI, Correia CM (2009). Physiological responses of different olive genotypes to drought conditions. Acta Physiol Plant 31: 611-621.

Ben Rovina B, Omri A, Trigui A (2002). Effect of a hard pruning on trees vigor and yields of old olive orchards. Acta Hort 586: 321-323.

Cuevas J, Pinney K, Polito VS (1999). Flower differentiation, pistil development and pistil abortion in olive (*Olea europaea* L. 'Manzanillo'). Acta Hort 474: 293-296.

Cuevas J, Rapoport HF, Rallo L (1995). Relationship among reproductive processes and fruitlet abscission in 'Arbequina' olive. Adv Hort Sci 9: 92-96.

Dias AB, Peça JO, Pinheiro A (2012). Long-term evaluation of the influence of mechanical pruning on olive growing. Agron J 104: 22-25.

Dias AB, Pinheiro A, Peça JO (2014). Fifteen-year evaluation of the influence of mechanical pruning on olive yield. Acta Hort 1057: 335-340.

Ferguson L, Krueger WH, Reyes H, Metheney P (2002). Effect of mechanical pruning on California black ripe (*Olea europea* L.) cv. 'Manzanillo' table olive yield. Acta Hort 586: 281-284.

Fernández JH (2014). Understanding olive adaptation to abiotic stresses as a tool to increase crop performance. Environ. Exp Bot 103: 158-179.

Fernández-Escobar R, Benlloch M, Navarro C, Martin GC (1992). The time of floral induction on olive. J Amer Soc Hort Sci 117: 304-307.

Foster ES, Heffner EH (1941). Lucius Junius Moderatus Columella, On Agriculture II (Book V. IX. 13-16) (with a recension of the text and an English translation). In: Page TE, Capps E, Rouse WHD, Post LA, Warmington EH, editors. Harvard University Press, USA: The Loeb Classical Library.

García-Ortiz A, Humanes J, Pastor M, Morales J, Fernández A (2008). Poda. In: Barranco D, Fernández-Escobar R, Rallo L, editors. El Cultivo del Olivo. Madrid, Spain: Coedición Junta de Andalucía (Consejería de Agricultura Y Pesca) & Mundi-Prensa, pp. 389-433.

Gregoriou C (2009). Tree training and pruning methods. In: Olive GAP Manual: Good Agricultural Practices for the Near East & North Africa Countries. Association of Agricultural Research Institute in the Near East and North Africa. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Gucci R, Cantini C (2000). Pruning and Training Systems for Modern Olive Growing. Collingwood, Australia: CSIRO Publishing.

Lopes JI, Pinto J, Rodrigues MA (2009). Condução e poda. In: Rodrigues MA, Correia CM, editors. Manual da Safra e contra Safra do Olival. 1st ed. Bragança, Portugal: Instituto Politécnico de Bragança, pp. 69-78.

Martin GC (1990). Olive flower and fruit population dynamics. Acta Hort 286: 141-153.

Martin GC, Ferguson L, Sibbett GS (2005). Flowering, pollination, fruiting, alternate bearing, and abscission. In: Sibbett GS, Ferguson L, editors. Olive Production Manual, 2nd ed. Oakland, CA, USA: University of California, Agriculture and Natural Resources, Publ. 3353, pp. 49-54.

Metzidakis I (2002). Effect of regeneration pruning for the recovery of olive productivity and fruit characteristics in ten olive cultivars. Acta Hort 586: 333-336.

Peça JO, Dias AB, Pinheiro A, Santos L, Morais N, Pereira AG, Souza DR (2002). Mechanical pruning of olive trees as an alternative to manual pruning. Acta Hort 586: 295-299.

Pinney K, Polito VS (1990). Flower initiation in 'Manzanillo' olive. Acta Hort 286: 203-205.

Rallo L, Martin GC (1991). The role of chilling in releasing olive floral buds from dormancy. J Amer Soc Hort Sci 116: 1058-1062.

Rallo L, Fernández-Escobar R (1985). Influence of cultivar and flower thinning within the inflorescence on competition among olive fruit. J Amer Soc Hort Sci 110: 303-308.

Rallo L, Martin GC, Lavee S (1981). Relationship between abnormal embryo sac development and fruitfulness in olive. J Amer Soc Hort Sci 106: 813-817.

Sibbett GS (2005). Pruning mature bearing olive trees. In: Sibbett GS, Ferguson L, editors. Olive Production Manual, 2nd ed. Oakalnd, CA, USA: University of California, Agriculture and Natural Resources, Publ. 3353, pp. 55-59.

Therios I (2009). Olives. Crop Production Science in Horticulture, 18. Oxfordshire, UK: CABI International.

Tombesi A (2013). Advances in harvesting and pruning of olive trees. La Rivista di Scienza dell'Alimentazione (J Food Sci Nutr) 1: 97-103.

Tombesi A, Tombesi S (2007). Olive production and training. In: Production Techniques in Olive Growing. Madrid, Spain: International Olive Council, pp. 45-81.

Tombesi S, Farinelli D, Molfese M, Cipolletti M, Visco T (2014). Pruning technique in young high density hedgerow olive orchards. Acta Hort 1057: 385-390.

Vossen P, Devarenne A (2007). Pruning olive trees: how to minimize alternate bearing and improve production. Newsletter of olive oil production and evaluation. Vol 2, Nº3, University of California Cooperative Extension. University of California.

Vossen PM (2007). Site, varieties, and production systems for organic olives. In: Vossen PM, editor. Organic Olive Production Manual. Oakland, CA, USA: University of California, Agriculture and Natural Resources, Publ 3505, pp. 3-12.

Walinga I, van Vark W, Houba V, van der Lee J (1989). Soil and Plant Analysis: Part 7 - Plant Analysis Procedures. The Netherlands: Wageningen Agricultural University.