Time and type of pruning affect tree growth and yield in high-density olive orchards

Time and type of pruning affect tree growth and yield in Q1 high-density olive orchards

The corrections made in this section will be reviewed and approved by a journal production editor.

E.M. Lodolini[a,*], enricomaria.lodolini@crea.gov.it, S. Polverigiani[b], V. Giorgi[b], F. Famiani[c], D. Neri[b]

[a]Council for Agricultural Research and Economics, Research Centre for Olive, Citrus and Fruit Crops, via di Fioranello 52, Rome 00134, Italy

[b]Department of Agricultural, Food and Environmental Sciences, Marche Polytechnic University, Ancona, Italy

[c]Department of Agricultural, Food and Environmental Sciences, University of Perugia, Perugia, Italy

*Corresponding author.

Abstract

The effect of different strategies and the time of pruning on olive vegetative-reproductive behavior was studied in a 5-year-old high-density orchard (1,250 trees ha−1, cv. 'Ascolana tenera'). The treatments were: a) winter lateral pruning and topping, b) summer lateral pruning and winter topping, c) winter lateral pruning and summer topping and d) summer lateral pruning and topping. Selective spring pruning maintaining a conical shape of the canopy was used as the Control. Topping significantly maintained tree height recorded at the end of the 3-year trial in comparison to the Control (3.84 ± 0.45 m), in particular summer treatments maintained the final tree height at 3.0 ± 0.26 m. Summer topping and lateral pruning significantly reduced canopy volume compared to winter pruning and the Control. There was less vegetative re-sprouting in the control and, on the average, less for summer than for winter pruning in the same year of pruning. There were no significant differences between the treatments regarding the seasonal vegetative growth of 1-year-old mixed shoots. Fruit yield per tree was significantly higher with time-split pruning (part in winter and part in summer) with respect to conical-shape pruning of the canopy. Results suggest that the proposed management of pruning with winter lateral pruning and summer topping contributes to good vegetative-reproductive balance of young trees with high yield and a more compact shape.

Keywords:

Lateral, Topping, Vegetative re-sprouting, 1-year-old mixed shoot, Fruit yield efficiency

Abbreviations

No keyword abbreviations are available

Data Availability

Data will be made available on request.

1 Introduction

Since the 1990s a new model for olive groves has been promoted in Spain. It is defined as super high-density (SHD) and consists of planting the trees with short distances within the row according to a hedge system and using 1,000–2,500 trees ha^{-1} (Tous et al., 2010; Famiani and Gucci, 2011). These SHD orchards have several advantages, including rapid mechanized harvesting and pruning, high crop levels, and early bearing (Tous et al., 2010; Dìez et al., 2016). These features make SHD systems profitable, and thus they are commonly chosen for new plantations, especially in non-traditional olive-growing countries, such as Argentina, Australia, Chile and the USA (Rallo et al., 2013; Connor et al., 2014) as well as many traditional oil-producing countries, such as Tunisia, Morocco, Portugal, France, and Italy. At the global level, olive growers immediately adopted the super high-density system and by 2010, 100,000 hectares were cultivated with this system. This represents about 1% of the world land cultivated with olive trees, half of which is in Spain (Famiani and Gucci, 2011; Rius and Lacarte, 2015). In the last 10 years, the new SHD groves have continued to expand covering currently about 400,000 hectares worldwide (~~Mercacei, 2022~~Mercacei) with different high density orchard plantation approaches and with different propagating materials including micropropagated scions ([Instruction: Remove the internal parenthesis (2020) and add a ',' after the '.'......final result should be: (Neri et al., 2020)]Neri et al. (2020)). Regardless of the system, pruning is the key practice for the success of grove management. The main goals of pruning are to maintain well-lit leaf surfaces, creating the right balance between vegetative growth and reproductive functions, allowing air circulation through the hedge and successful mechanical harvesting (Lodolini et al., 2018). One way is to multiply the number of one-year shoots in the part of the canopy most illuminated where olive fruits are usually produced (Connor et al., 2014). In high-density olive orchards pruning requires a different approach in comparison to traditional low-density models. The single tree is replaced with the hedgerow (Connor et al., 2014) and the canopy evolves from an expanse and in-volume vase to a narrow wall suitable for the dimensions of the tunnel of the over-the-row harvester (Godini et al., 2011; Caruso et al., 2014; Vivaldi et al., 2015). The single tree in the hedgerow must therefore respect a maximum height of 2.5–3.5 m and transversal width of Q2 1–1.5 m.

High-density olive orchards can be pruned mechanically using trimmers or circular saws mounted on articulated bars and operated by a tractor or other self-propelled vehicles that remove branches non-selectively (Lodolini et al., 2006; Vivaldi et al., 2015; Albarracin et al., 2017). There are many advantages for mechanical pruning such as maintaining an adequate size of the canopy to facilitate mechanical harvesters, improving the distribution of light inside the hedgerow and reducing cultivation costs (Génard et al., 1998; Camposeo et al., 2008; Tous et al., 2010). Nonetheless, this practice alters the growth and development of individual trees and hedgerows because of the non-selective removal of the vegetative and mixed shoots in the upper (topping) and lateral (hedging) portions of the canopy, respectively. Furthermore, mechanical pruning reduces fruit production in the year of pruning, as reported for low and medium density olive groves by Ferguson et al. (2002) and Peca et al. (2002), and it takes at least two to three years to bring the plants back to full production (Albarracin et al., 2017). This is a critical disadvantage in the hedgerow systems where Q3 constant yearly fruit production is required to amortize the high plantation costs.

There is still little informationon the physiological response of olive trees in high-density plantations to non-selective mechanical pruning, but the focus on this topic has increased in recent years. A study conducted by Cherbiy-Hoffmann et al. (2012) reported that the fruit yield of olive hedgerows is positively influenced by the amount of photosynthetically active radiation that passes through the canopy and that an improper or excessively intense mechanical pruning, triggering vigorous vegetative growth, increases self-shading of the canopy, reducing flower differentiation and thus fruit yield. Cherbiy-Hoffmann et al. (2012) and Albarracin et al. (2017) showed that vegetative re-sprouting significantly increased with increasing intensity of winter pruning: in particular winter topping. On the contrary, summer pruning reduced vegetative re-sprouting (Albarracin et al., 2017; Lodolini et al., 2018). Furthermore, mechanical pruning should be done at a light to moderate intensity to avoid new water-sprout emissions on older wood and reduction in long-term fruit production (Albarracin et al. 2018). Ottanelli et al. (2019) reported positive results when using an innovative pruning machine equipped with directional air jets that were able to prevent flexible mixed shoots from being cut and thus enabling fruit production to be quadrupled in comparison to traditional pruning machines.

Several studies have reported that correct mechanical pruning should be integrated with selective manual pruning during perennial cycles to avoid the risk of reducing fruit yield and quality over long periods (Lodolini et al., 2006; Dias et al., 2012; Albarracin et al., 2017).

A study conducted by Lodolini et al. (2019) showed that light pruning in early spring (after bud break) does not reduce fruit set when compared to heavy pruning. Trees heavily pruned gave a lower fruit yield because of significant vegetative growth with considerable water-sprout emission when applied in early spring, while vegetative vigor was reduced with late spring pruning (after full bloom). The combination of pruning intensity, time and position of pruning in the canopy seems to be essential in guiding the vegetative-reproductive balance and controlling canopy size, especially in olive orchards with increasing plant density.

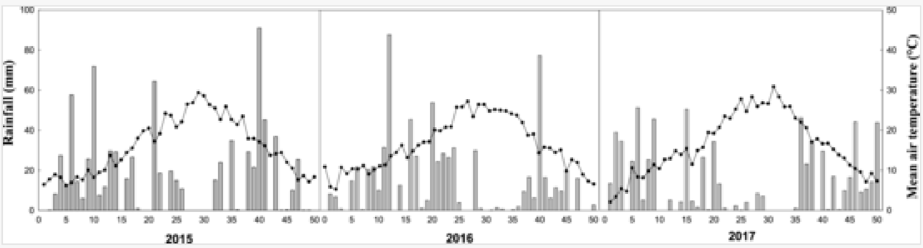
Presently, there is little information about the influence of pruning time (early: after winter or late: in summer) and the position in the canopy, and their interaction to control the vegetative-reproductive balance and canopy size in olive. The objective of the present field study was to identify an appropriate strategy for pruning management in olive hedgerow systems during different phenological periods and in different parts of the canopy, by studying the response of the trees in terms of vegetative-reproductive balance in a three-year period.

2 Materials and methods

2.1 Plant material and experimental design

The field study was carried out from 2015 to 2017 in a commercial high-density olive grove (1250 trees ha^{-1}, 4 m x 2 m) planted in 2011 and located in Central Italy, Marche Region (latitude 43°06′05.62″N; longitude 13°39′29.52″E; altitude 200 m a.s.l.). The soil management consisted of a permanent, natural green cover to prevent soil erosion, with periodical mowing (three times per year) to control weed development. Mineral fertilizers were distributed yearly on the soil at vegetative re-sprouting (end of winter season) according to the estimation of nutrient removal. The climate is wet Mediterranean. Weekly mean temperatures and total rainfall at the site, recorded during the experimental period, are reported in Fig. 1 (Servizio Agrometeo ASSAM, Regione Marche).

Fig. 1



Mean weekly temperature and rainfall recorded at the research site (from ASSAM agrometeorological service, Marche region, Italy). Horizontal axis refers to the weeks of the year. Bars and points indicate rainfall and mean temperature, respectively.

The olive orchard was drip-irrigated and water was supplied as supplementary irrigation from June to August. The variety used was ‘Ascolana tenera’, a double purpose cultivar characterized by high vigor, upright growth habit and high canopy density. In January 2015, fifty homogeneous trees were selected according to size (total tree height: 3.14 ± 0.22 m; trunk diameter 200 mm from the ground: 56.12 ± 5.60 mm; canopy diameter longitudinal to the row: 1.83 ± 0.16 m; canopy diameter perpendicular to the row: 1.64 ± 0.22 m; and calculated canopy volume: 2.03 ± 0.45 m^3). A completely randomized experimental design was established with 5 treatments and 10 replicates (trees) per treatment.

2.2 Pruning treatments

The treatments consisted of combinations of timing and pruning type along the sides of the hedgerow (Lateral) and on the apical portion of the canopy (Topping): a) winter lateral and topping (WLT), b) summer lateral and winter topping (SLWT), c) winter lateral and summer topping (WLST), and d) summer lateral and topping (SLT). Treatments were performed manually, using hand-held tools from the ground. Lateral pruning (L) consisted in a selective hand elimination (thinning) of the longest, less flexible, or broken branches protruding toward the inter-row on the lateral portion of the canopy, while topping (T) consisted in a non-selective hand cutting at a height of 2 m from the ground, simulating a mechanical pruning. For the three years of study, summer and winter pruning treatments (topping and/or lateral) were performed in July and February, respectively.

As a Control, pruning was performed manually in spring (April), maintaining the conical shape of the canopy with a central leader head-back cutting and selective elimination of lateral branches.

2.3 Vegetative growth and canopy density

Total tree height, height of the canopy from the ground and longitudinal (along the row) and transversal (perpendicular to the row) canopy diameters were measured for all the trees at the beginning and the end of the three-year trial. The canopy volume was calculated assuming a conical shape of the canopy for the Control and a parallelepiped for the pruning treatments.

Trunk diameter was recorded on the same dates at 20 cm from the ground and used to calculate the Trunk-Cross Sectional Area (TCSA).

Two methods were used to evaluate canopy density. Photos were taken on July 26, 2016 on ten trees per treatment using a portable camera (ST66, Samsung Electronics LTD, Hanja, Korea) from the ground facing upwards close to the trunk and 30 cm from the trunk along the row. Photos were then processed with ImageJ software (National Institutes of Health, Bethesda, Maryland, USA) to calculate the percentage% of shaded area. PAR intercepted by the canopy at different distances from the trunk and Leaf Area Index (LAI) were measured using an AccuPAR Ceptometer model LP-80 (Decagon Devices, Inc., Pullman, WA, USA) on 12 trees per treatment on the west-side of the tree along the row on August 9, 2016.

2.4 Pruning material, yield and efficiency

The pruning material was collected yearly (2015–2017) for each tree and weighed separately for lateral and topping. Cumulated pruning weight was calculated as the sum of the 3 years.

To assess the vegetative growth of the trees, the number and length of water-sprouts newly produced on the primary branches per tree were determined at the end of the growing season (December) of 2015 and 2017. The vegetative growth of five 1-year-old mixed shoots per tree (total 50 shoots per treatment) randomly selected from the external surface of the canopy was also measured.

Total fruit yield per tree was recorded at harvest each year and expressed as fresh weight. The yield efficiency was calculated yearly and is expressed as fruit production (kg) over the Trunk-Cross Sectional Area (cm^2) according to Gucci et al. (2007) and Moutier et al. (2011). To determine the effect of the pruning treatments on the fruit yield efficiency, the ratio between fresh fruit production and fresh pruning material (yield to pruning mass ratio or Ravaz index) was also calculated for each year and as the cumulated value for each pruning treatment (Silvestroni et al., 2018).

2.5 Statistical analysis

All data were tested using a one-way ANOVA. Tukey's (HSD) test was used for means separation whenever the ANOVA indicated significance of a factor. All statistical analyses were performed using JMP 10 (SAS Institute Inc., Cary, NC).

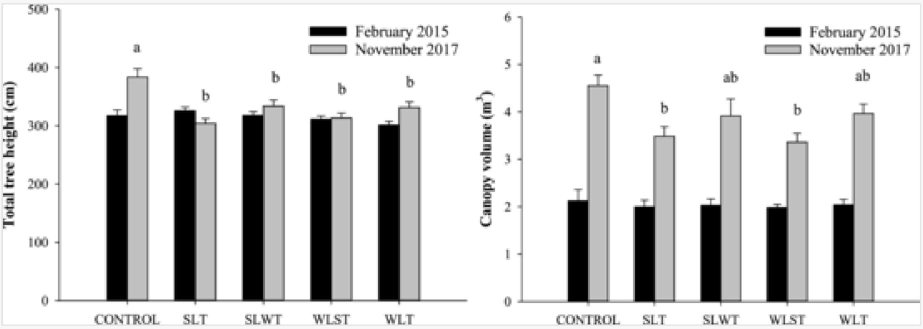
3 Results

Tree response to pruning revealed interesting results. Tree height and canopy volume recorded at the beginning and end of the trial (Fig. 2) showed that all pruning treatments enabled good control of canopy size with an average value of 333.3 cm ± 42.0 for tree height at the end of the experiment, and therefore suitable for over-the-row harvesting machines. In particular, SLT and WLST gave the lowest tree height at the end of the experiment. Only the Control trees were significantly taller (383.8 cm ± 44.8) compared to the pruning treatments.

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 2

Fig. 2



Tree height (left) and canopy volume (right) measured at the beginning (February 2015) and end (November 2017) of the 3-year trial. Columns represent mean ± standard error of 10 replicates. Different letters indicate significant differences between treatments at the same date according to Tukey (HSD) test, $p < 0.05$.

The canopy volume was significantly greater for the Control trees compared to SLT and WLST at the end of the trial. There were no significant differences among the pruning treatments.

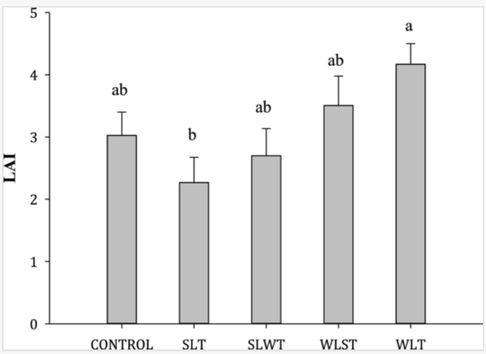
Trunk dimension expressed as TCSA (Ttrunk-cCross Ssectional Aarea) was not influenced by pruning treatments, the overall TCSA average was 39.1 ± 5.79 cm2 at the beginning of the first year (2015) and 57.8 ± 9.16 cm2 at the end of third year (2017).

The different pruning combinations and times influenced LAI (Fig. 3). Winter lateral and topping pruning (WLT) produced a significantly higher LAI compared to summer treatments (SLT). All the other pruning treatments gave intermediate values.

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 3

Fig. 3



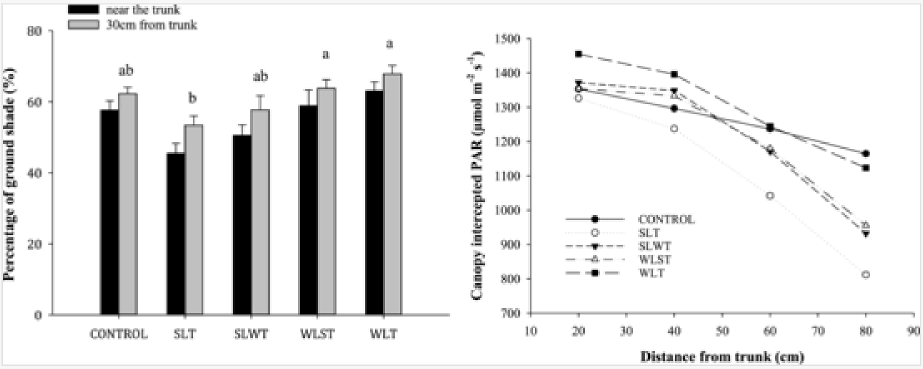
Leaf Area Index (LAI) of the tree canopies on July 26, 2016. Columns represent mean ± standard error of 6 replicates. Different letters indicate significant differences between treatments according to Tukey (HSD) test, $p < 0.05$.

A similar pattern was observed for the percentage of ground light interception (shade level, Fig. 4 left) as WLT gave a higher percentage of shade compared to SLT. Regarding the distribution of the canopy density along the row (Fig. 4, right) there was a significant lower intercepted PAR for SLT compared to WLT, but with a similar pattern of maximum level of light interception close to the trunk (20–40 cm) and a rapid drop further from trunk (60–80 cm). The same pattern was observed for SLWT and WLST pruning treatments that showed intermediate values. Control pruning behaved differently, as the light interception decreased more slowly with distance from the trunk, so that at 60 and 80 cm from the trunk, it had the highest values compared to all other treatments.

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 4

Fig. 4



Light interception by the canopy as percentage of shade on the ground near the trunk and at 30 cm from the trunk (left) and PAR intercepted at different distances from the trunk (right). Columns represent mean ± standard error of 8 replicates. Different letters indicate significant differences between treatments according to Tukey (HSD) test, $p < 0.05$.

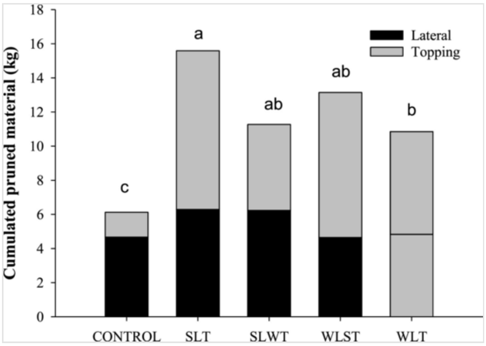
The cumulated weight of the pruned material in the 3 years was significantly higher for summer lateral and topping pruning (SLT) than for winter lateral and topping pruning (WLT). The lowest value was recorded for the Control (Fig. 5). It is interesting to note that these differences were due only to the topping treatments (apical), where the amount of material removed was significantly higher in the summer toppings (SLT and WLST). This was followed by the winter toppings (WLT and SLWT) and lastly by the Control. The amount of material removed with lateral pruning was similar in all the treatments.

Images are optimised for fast web viewing. Click on the image to view the original version.

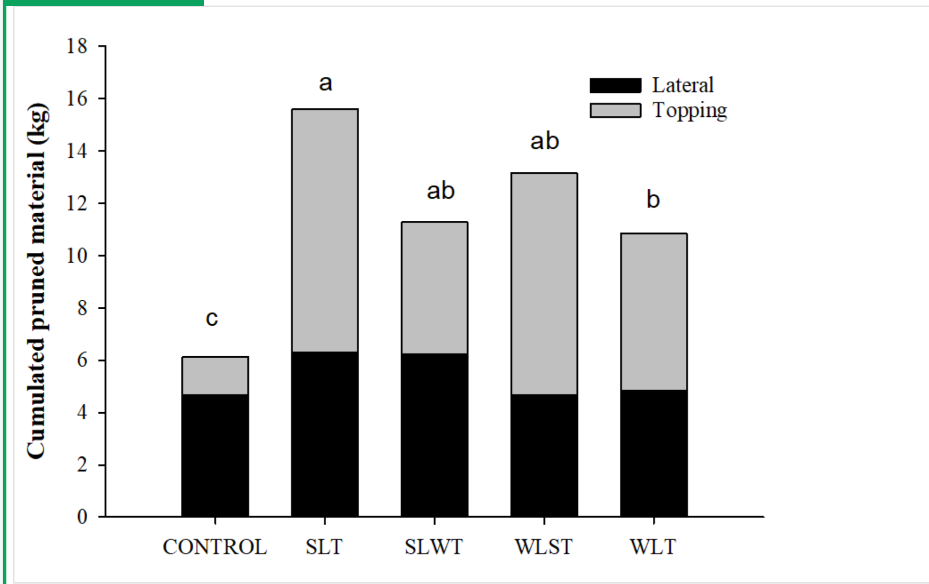
alt-text: Fig 5

Fig. 5

Previous Version



Updated Version



Cumulated weight (kg) of pruned material from lateral and topping in the three years. For the Control, lateral and apical material were weighed. Columns represent mean values of 10 replicates. Different letters indicate significant differences between treatments considering pruning materials from both lateral and topping and according to Tukey (HSD) test, $p < 0.05$.

Replacement Image: fig.5.png

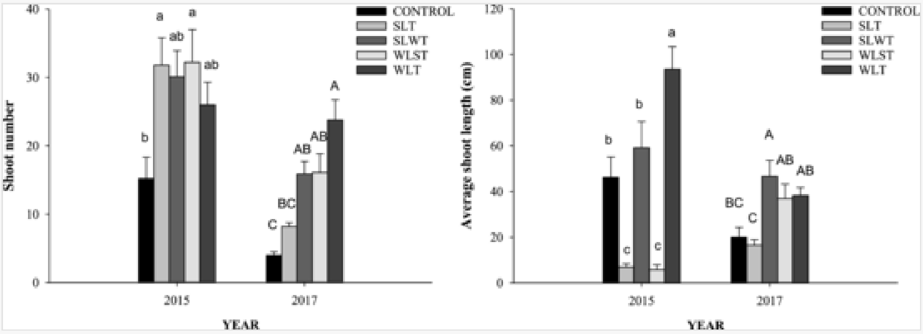
Replacement Instruction: There is a graphical mistake in the last column of the graph. Please replace the figure with this attached.

Pruning technique and timing influenced new water-sprout formation (Fig. 6). The Control was lower in comparison to the other treatments. Summer topping (SLT and WLST) significantly reduced the vegetative growth of the new-emitted water-sprouts with significantly lower values especially in 2015 (Fig. 6, right). On the contrary, winter topping treatments (WLT and SLWT) greatly stimulated the vegetative growth of the water-sprouts.

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 6

Fig. 6



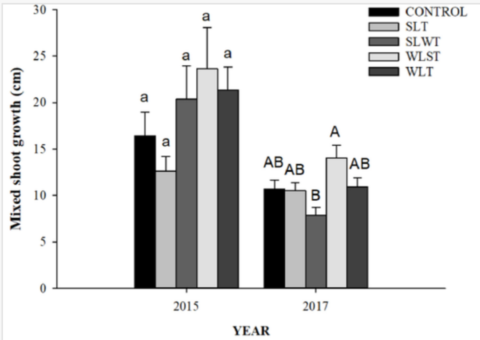
The number of new-emitted water-sprouts (left) and their length (right) with respect to pruning treatments at the end of the growing season in 2015 and 2017. Columns represent mean ± standard error of 10 replicates. Different letters indicate significant differences between treatments according to Tukey (HSD) test, $p < 0.05$.

The growth of the 1-year-old mixed shoots was not influenced by the pruning treatments in 2015 and only slightly in 2017, when WLST induced significantly higher vegetative growth than SLWT (Fig. 7).

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 7

Fig. 7



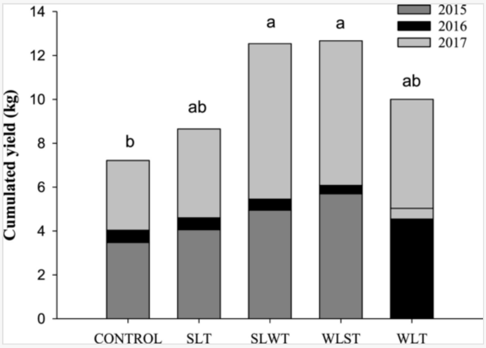
Mixed shoot growth in the 2015 and 2017 seasons. Columns represent mean ± standard error of 10 replicates. Different letters indicate significant differences between treatments according to Tukey (HSD) test, $p < 0.05$.

The cumulated fruit yield over the three years was higher in the SLWT and WLST treatments and lower in the Control (Fig. 8). All treatments showed strong alternant bearing, with 2015 and 2017 being the ON years and 2016 the OFF year.

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 8

Fig. 8



Cumulated yield in the 3-year trial. Different letters indicate significant differences (HSD Tukey's test). Columns represent mean values of 10 replicates. Different letters indicate significant differences between treatments according to Tukey (HSD) test, $p < 0.05$.

Replacement Image: fig.8.PNG

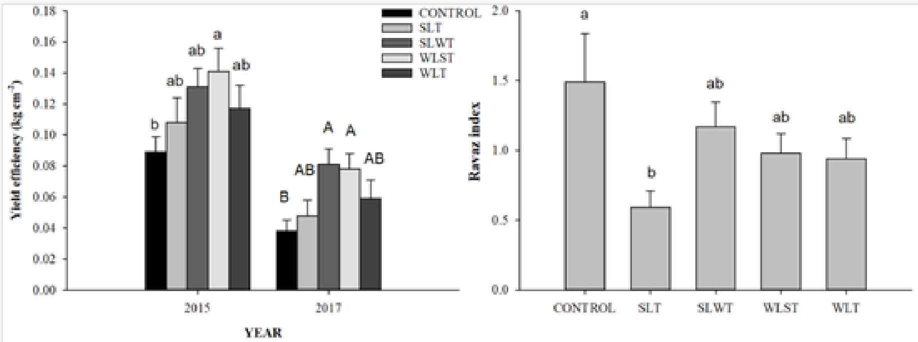
Replacement Instruction: There is a graphical mistake in the last column of the graph. Please replace the figure with this attached. Please check if the figure has been properly relpaced with the correct one.... the system does not allow me to have a confirmation as for figure 5.

Considering yield efficiency (Yield TCSA^{-1}), Control trees were significantly lower compared to WLST and SLWT, which showed the highest efficiency in both 2015 and 2017 (Fig. 9, left).

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 9

Fig. 9



Yield efficiency (Yield TCSA^{-1}) in 2015 and 2017 (left) and Ravaz index for cumulated fruit production and pruned material (right). Columns represent mean + standard error of 10 replicates. Different letters indicate significant differences between treatments according to Tukey (HSD) test, $p < 0.05$.

When the Ravaz index was calculated, dividing the cumulated fruit yield by the cumulated material removed with pruning in the three years, a significant higher and lower ratio was found for the Control trees and SLT, respectively (Fig. 9 right).

4 Discussion

The conical shape (Control pruning) produced a limited amount of pruned material removed with a fewer number of new-emitted water-sprouts. Control pruning also produced a canopy with a uniform density, while lateral/topping approach produced a canopy with decreasing density in the first 80 cm from the trunk. Tree height and canopy dimensions were generally smaller for the lateral/topping treatments. These are essential requirements in a high-density olive orchard, since the canopy must be maintained as a hedgerow within specific dimensions to allow the use of over-the-row harvesters and reduce damage (Lodolini et al., 2018). The lateral/topping treatments were more effective in maintaining the height of the trees around 3 m, 1 m less compared to the conical shape pruning (Control).

Summer pruning (lateral and topping) produced equal (2015) or less (2017) new-emitted water-sprouts than the winter treatments and with lower vigor and smaller canopy volumes. These results confirm what Lodolini et al. (2019) previously reported for three olive cultivars trained to the free polyconic vase system in a low-density orchard and indicate a completely different vegetative response of the tree to pruning according to the phenological stage (vigorous at vegetative restart at the end of winter and weak during summer). Mixed treatments, with summer lateral pruning and winter topping or winter lateral pruning and summer topping, produced intermediate results.

Nevertheless, the amount of pruned material, cumulated in the years of the trial, was unexpectedly higher for the summer pruning (Topping and Lateral pruning combined); summer pruning was hence effective in maintaining the canopy dimensions during the same year of pruning because of the reduced growth within the summer time, but the vegetative resprouting in the apical portion of the canopy in the following years was possibly higher than that of the winter operations. This is probably due to a stronger vegetative growth of the water-sprouts formed in the previous summer topping during the spring of the following year, thus requiring the elimination of a bigger amount of foliage in summer to maintain the predetermined height of the tree. A reiterated application of summer topping could therefore lead to an excess of wood and vigorous water-sprouts accumulation in the upper part of the canopy (Fig. 10, left), requiring an extraordinary selective manual thinning after few years (Fig. 10, right). Our study confirms that even for hedgerow olive systems, mechanical pruning should be considered in an integrated approach which includes manual pruning, as previously reported by other authors (Lodolini et al., 2006; Dias et al., 2012; Albarracin et al., 2017). With a time-differentiated application of pruning combined with a different position on the canopy (i.e. selective lateral pruning in winter and topping in the summer) the amount of material removed was similar to the winter pruning.

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Fig 10

Fig. 10

Strong emission of vigorous vegetative shoots (water-sprouts) in the trees subjected to topping during the three years of experimentation (left). This condition leads in a few years to an excess of wood and vegetative activity in the upper portion of the canopy and to a weakening of the productive branches in the lateral one (right).

Concerning fruit production, both pruning techniques (topping and lateral) and timing (winter and summer) influenced yield, with better results recorded when lateral pruning and topping were done at different times of the year. Higher yield efficiency was obtained with WLST (Winter Lateral pruning and Summer Topping), even though a better vegetative-reproductive balance was obtained with the Control when a conical shape of the canopy was maintained (higher fruit yield per unit of material removed). This is in agreement with Paoletti et al. (2008) who reported less emission of water-sprouts and suckers, quicker canopy recovery and higher fruit production when the leaders of the primary branches were maintained rather than eliminated.

For olive hedgerow systems, the choice of the position of the pruning on the canopy and the phenological stage to perform it depends mainly on the vigor of the cultivar, as also confirmed by Vivaldi et al. (2015). In our study where the high-vigor cultivar ‘Ascolana tenera’ was used, a summer intervention (especially in the upper portion of the tree) was able to contain the canopy volume and reduce the emission of new water-sprouts, ensuring an acceptable fruit yield. On the contrary, selective winter pruning of the lateral portion of the canopy can reduce the inter-row enlargement and stimulate the emission of new laterals.

5 Conclusion

Two different pruning approaches were considered in this study, one aimed at maintaining a central leader with a conical shape of the canopy with selective manual pruning (Control) and the other with unselective topping 2 m from the ground surface (simulating mechanical pruning) and selective lateral pruning for restraining the vegetation close to the trunk (SLT, SLWT, WLST, WLT). In high density olive groves, pruning at two different times of the year compared to the traditional one time at the beginning of spring was more efficient in controlling the shape and volume of the trees and in improving fruit yield. Summer pruning limits the vigor of the trees and winter pruning is more suitable for maintaining the shape. It is worth noting that it is beneficial to prune in winter and summer, to maintain a better equilibrium between yield and vegetative growth, while pruning only in summer or only in winter was less efficient.

Maintaining a conical shape of the tree by applying selective and simplified pruning during the first years after planting can force the vegetative growth of the canopy to close the empty space within the row and speed up the onset of fruit production. Contrarily, when the height and width of the hedgerow are approaching the maximum dimensions allowed for the use of over-the-row harvesters, as in the case of our experimental conditions, traditional winter pruning to maintain the conical shape of the trees resulted always less efficient than topping with apex head back combined with selective lateral pruning, but only when lateral pruning and topping were split in the two periods (winter and summer, respectively). Selective lateral pruning by manually removing 1–2 branches per side helps to contain the lateral expansion of the hedgerow. Moreover, topping was effective in controlling tree height to enable harvesting with over-the-row machines, even though there was a higher amount of pruning material with the summer topping throughout the three years of experimentation.

Further studies are necessary to assess the effect of these pruning combinations on the water balance of the tress during the summer, on the allocation of dry matter and on the quality parameters of the fruit.

Funding

The study was funded by 'Ricerca scientifica di Ateneo' Marche Polytechnic University, Ancona, Italy.

CRediT authorship contribution statement

E.M. Lodolini : Conceptualization, Methodology, Data curation, Writing – original draft, Writing – review & editing, Supervision. **S. Polverigiani :** Investigation, Data curation. **V. Giorgi :** Data curation, Writing – original draft, Writing – review & editing. **F. Famiani :** Writing – review & editing. **D. Neri :** Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are grateful to Luciano and Luca Gobbi of the private farm 'Maggiorana Cinzia' for the assistance provided during the in-field trial.

References

Albarracín, V., Hall, A.J., Searles, P.S., Rousseaux, M.C., 2017. Responses of vegetative growth and fruit yield to winter and summer mechanical pruning in olive trees. Sci. Hortic. 225, 185–194.

Albarracín, V., Hall, A.J., Searles, P.S., Rousseaux, M.C., 2018. Impact of simulated mechanical hedge pruning and wood age on new shoot demography and return flowering in olive trees. Trees 32 (6), 1767–1777.

Camposeo, S., Ferrara, G., Palasciano, M., Godini, A., 2008. Varietal behaviour according to the superintensive olive culture training system. Acta Hortic. 791, 171–274.

Caruso, T., Campisi, G., Marra, F.P., Camposeo, S., Vivaldi, G.A., Proietti, P., Nasini, L., 2014. Growth and yields of the cultivar arbequina in high density planting systems in three different olive growing areas in Italy. Acta Hortic. 1057, 341–348.

Cherbiy-Hoffmann, S.U., Searles, P.S., Hall, A.J., Rousseaux, M.C., 2012. Influence of light environment on yield determinants and components in large olive hedgerows following mechanical pruning in the subtropics of the Southern Hemisphere. Sci. Hortic. 137, 36–42.

Connor, D.J., Gómez-del-Campo, M., Rousseaux, M.C., Searles, P.S., 2014. Structure, management and productivity of hedgerow olive orchards: a review. Sci. Hortic. 169, 71–93. doi:10.1016/j.scienta.2014.02.010.

Dias, A.B., Peca, J.O., Pinheiro, A., 2012. Long-term evaluation of the influence of mechanical pruning on olive growing. Agron. J. 104, 22–25.

Díez, C.M., Moral, J., Cabello, D., Morello, P., Rallo, L., Barranco, D., 2016. Cultivar and tree density as key factors in the long-term performance of super high-density olive orchards. Front. Plant Sci. 7, 1226.

Famiani, F., Gucci, R., 2011. Moderni modelli olivicoli. ~~Collana Dell'accademia~~Collana dell'Accademia. Accademia Nazionale dell'Olivo e dell'Olio, Spoleto, Italy, p. 32~~-VII~~.

Q4

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

Génard, M., Pagès, L., Kervella, J., 1998. A carbon balance model of peach tree growth and development for studying the pruning response. Tree Physiol. 18, 351–362.

Godini, A., Vivaldi, G.A., Camposeo, S., 2011. Olive cultivars field-tested in super high-density system in southern Italy. Calif. Agric. 65, 39–40. doi:10.1016/j.scienta.2011.04.034.

Gucci, R., Lodolini, E.M., Rapoport, H.F., 2007. Productivity of olive trees with different water status and crop load. J. Hortic. Sci. & Biotech. 82 (4), 648–656.

Lodolini, E.M., Neri, D., Cpogrossi, F., Capogrossi, C., 2006. Preliminary results on olive (*Olea europaea* L.) mechanical hedging. In: Proceedings of the Olivebioteq. Marsala (Italy), II. pp. 165–168 Novbember 5th-10th Mazara del Vallo.

Lodolini, E.M., Polverigiani, S., Grossetti, D., Neri, D., 2018a. Pruning management in a high-density olive orchard. Acta Hortic. 1199, 385–390.

Lodolini, E.M., Polverigiani, S., Sirugo, M., Neri, D., 2018b. Damage to several olive cultivars by two over-the-row harvesters in high-density orchards. Acta Hortic. 1199, 415–419.

doi:10.17660/ActaHortic.2018.1199.66.

Lodolini, E.M., Polverigiani, S., Cioccolanti, T., Santinelli, A., Neri, D., 2019. Preliminary results about the influence of pruning time and intensity on vegetative growth and fruit yield of a semi-intensive olive orchard. J. Agric. Sci. Tech. Vol. 21 (4), 969–980.

Mercacei. 2022. The hedgerow olive grove generates 36% of the EVOO produced in the world. https://www.mercacei.com/noticia/57305/actualidad/el-olivar-en-seto-genera-el-36-del-aove-elaborado-en-el-mundo.htmlMercacei, October. 5, 2022. The hedgerow olive grove generates 36% of the EVOO produced in the world (online article). Grupo Editorial Mercacei, Madrid.

Moutier, N, Ricard, J.M., Le Verge, S., 2011. Vigour control of the olive tree in a high density planting system: Two experimentale approaches. Acta Hortic 924, 185–194.

Neri, D., Cioccolanti, T., Zuccherelli, G., Navacchi, O., Giorgi, V., Lodolini, E.M., 2020. Micropropagation effects on juvenile traits, flower differentiation, and tree architecture in young olive trees. Agronomy 10, 1742. doi:10.3390/agronomy10111742.

Ottanelli, A., Marone, E., Fiorino, P., 2019. A new device to improve the mechanical winter pruning in olive trees hedgerows. Adv. Hortic. Sci. 33 (1), 113–122. doi:10.13128/ahs-24787.

Paoletti, A., Padula, G., Rosati, A., Pannelli, G., 2008. Effetti della “funzione di cima” nella riforma degli alberi di olivo. Atti Del Convegno COM.SI.OL – Competitività del Sistema Olivo in Italia. Accademia Nazionale dell’Olivo e dell’Olio, Spoleto, Italy, pp. 111–118 March the 7th 2008.

Peça, J.O., Dias, A.B., Pinheiro, A.C., Santos, L., Morais, N., Pereira, A.G., De Souza, D.R., 2002. Mechanical pruning of olive trees as an alternative to manual pruning. Acta Hortic 586, 295–299.

(Chapter 7) Rallo, L., Barranco, D., Castro-Garcia, S., Connor, D.J., del Campo, M.G., Rallo, P., Janick, J., 2013. High-density olive plantations. Hortic. Rev. 41, 303–384. doi:10.1002/9781118707418.ch07.

Rius, X., Lacarte, J., 2015. La Revolución del Olivar. El Cultivo en Seto. Agromillora, Barcelona.

Silvestroni, O., Lanari, V., Lattanzi, T., Palliotti, A., 2018. Delaying winter pruning, after pre-pruning, alters budburst, leaf area, photosynthesis, yield and berry composition in Sangiovese (Vitis vinifera L.). Aust. J. Grape Wine Res. 24 (4), 478–486.

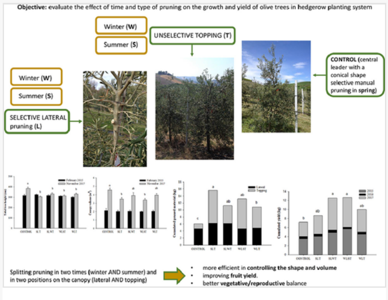
Tous, J., Romero, A., Hermoso, J.F., 2010. New trends in olive orchard design for continuous mechanical harvesting. Adv. Hortic. Sci. 24, 43–52.

Vivaldi, G.A., Strippoli, G., Pascuzzi, S., Stellacci, A.M., Camposeo, S., 2015. Olive genotypes cultivated in an adult high-density orchard respond differently to canopy restraining by mechanical and manual pruning. Sci. Hortic. 192, 391–399.

Graphical abstract

Images are optimised for fast web viewing. Click on the image to view the original version.

alt-text: Image, graphical abstract



Highlights

- Different pruning times and types were studied in a high-density olive orchard.
- Summer topping contained the tree height in the limit of the over-the-row machine.
- Summer topping and hedging reduced the canopy volume.
- 1-year-old mixed shoots growth was the same for the tested pruning strategies.
- Fruit yield per tree resulted higher for winter hedging and summer topping combination.

Queries and Answers

Q1

Query: Please confirm that given names and surnames have been identified correctly.

Answer: Yes

Q2

Query: Please check and validate author byline.

Answer: Checked. Please see revisions and comments

Q3

Query: Gucci et al. (2007), Moutier et al. (2011), Silvestroni et al. (2018) are not cited in the text and missing in the reference list, please make the list complete or delete the reference from the text.

Answer: Requested citations are cited in the last four lines of the paragraph 2.4 in M&M.

The citations have been added to the reference list.

Q4

Query: Please provide complete details in Ref. Mercacei (2022).

Answer: Additional details have been provided.