Evaluation of the influence of mechanical pruning in the performance of the row-side continuous canopy shaking harvester prototype

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Abstract

In high density olive orchards, mechanical harvesting is made by trunk shaking requiring a high demand of manual labour. The use of adapted over-the-row grape harvesters is not available in these groves due to large canopies dimension. A prototype based on the side row concept was developed. The prototype comprises two symmetrical harvesters trailed by a farm tractor. Each harvester has a vibratory rotor with flexible rods, a catching platform with conveyor belts delivering fruits to a temporary storage bag. From 2015 to 2018, authors carried out a trial to evaluate the adequacy of olive canopy based on mechanical pruning in the performance of the prototype. The trial was established in an irrigated olive orchard of the 'Picual' cultivar planted with the array 7×3.5 m. In a randomized complete block design with three replications, three treatments are being compared leading to 9 plots with 30 trees plot^{-1}. The treatments under study are: T1 – mechanical pruning: topping the canopy parallel to the ground at 3.5 m high in 2015 and 3.3 m in 2017; hedging the two sides of the canopy in 2015 at 1.4 m from the tree trunk; T2 – mechanical pruning: topping the canopy parallel to the ground at 3.5 m high in 2015 and 3.3 m in 2017; hedging the two sides of the canopy in 2015 at 1.0 m from the tree trunk; T3 – mechanical pruning + manual pruning complement: topping the canopy parallel to the ground at 3.5 m high in 2015 and 3.3 m in 2017; hedging the two sides of the canopy in 2015 at 1.0 m from the tree trunk; manual pruning complement in 2015 to remove wood in the external faces of the canopy and in 2017 to remove wood suckers inside the canopy. Regarding the olive removal efficiency, significant differences were registered between years, but no significant differences were found among treatments in each year.

Keywords: mechanical harvesting, high density olive groves, pruning

INTRODUCTION

In Portugal, there are currently 40,000 ha of high-density olive groves (200 to 500 trees ha^{-1}), mostly irrigated. Despite the recent diffusion of the hedge olive grove, there will still be more than 1.5 million ha of high-density olive groves worldwide (Dias et al., 2020).

Olive harvest in high density olive orchards is usually performed by a tractor mounted trunk shaker to remove fruits from the trees that are caught in canvas manually on the ground under the tree. The use of inverted umbrellas linked to the trunk shaker has limited use since trees are very closely spaced to allow the umbrella to open.

Harvesting made by an equipment based on the continuous canopy shaking principle will be the solution to reduce the dependency over scarce and expensive labour.

Grape and coffee over-the-row canopy harvesters could be used with good results in young intensive olive orchards not higher than 2.5 to 3.5 m or wider than 2 m (Ravetti and Robb, 2010). In a trial performed in Australia with a Colossus straddle harvester, Ravetti and Robb (2010) have obtained harvest efficiencies of 86 to 96%. In Portugal, at the beginning of the century, this harvest solution was used in some new olive orchards, but it was abandoned.

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The machine is too heavy and hardly suitable to the normally wet soil conditions and requires low travel speed in order to obtain high harvest efficiencies.

The row-side canopy harvester principle imposes fewer limitations on tree growth. Ferguson et al. (2002) used a side-by-side canopy prototype to harvest table olives with 90% harvest efficiency in the centre of the canopy, but with significant efficiency losses in the leading and trailing edges of the canopy.

Harvesting efficiency with canopy shakers are affected by the cultivar, tree shape, canopy density and pruning solution applied (Ferguson et al., 2010).

In table olive orchards mechanically pruned, Ferguson and Castro García (2014) have obtained higher harvest efficiency with canopy shaker than with manual harvesting of manually pruned trees.

In a hedgerow olive grove, harvesting efficiency with side-by-side canopy shaker in the mechanically pruned trees did not differ significantly from that of manual harvesting in manually pruned trees (Ferguson and Castro García, 2014).

The development of the Row-Side Continuous Canopy Shaking Harvester - RSCCSH (Peça et al., 2014) was started in 2009.

In a trial to evaluate the effect of different pruning solutions on the RSCCSH prototype efficiency, Dias et al. (2020) have obtained harvest results between 70 and 76% on average, without significant differences between the pruning treatments. However, it was found that in one of the years, mechanically pruned trees achieved significantly higher efficiency than those manually pruned (Dias et al., 2020).

As mechanical pruning allows for lower pruning costs, a trial to evaluate the RSCCSH prototype efficiency in trees submitted only to mechanical pruning was established.

This paper presents and discusses the results of the trial.

MATERIALS AND METHODS

Olive orchard

The high-density olive orchard (HD) used in the trial was established in 1996 in Herdade da Torre das Figueiras in the Alentejo region of southern Portugal (39°03'34.04"N, 07°28'22.00"W). This drip irrigated HD olive orchard of the 'Picual' cultivar was installed in an array of 7×3.5 m.

The orchard was planted on Chromic Luvisol soil (FAO). This region is semi-arid with strong continental influence and an annual rain mean of 500 mm concentrated in the winter.

The orchard is drip irrigated twice a week, from May till October, receiving annually an estimated volume of 1500-2000 m^3 ha^{-1}.

The HD olive orchard was sprayed to control olive leaf spot (*Flusicladium oleaginum* (Castagne) Ritschel & U. Braun), olive moth (*Prays oleae* Bernard), olive fly (*Bactrocera oleae* Gmelin.) and olive anthracnose (*Colletotrichum acutatum* Simmons or *Colletotrichum gloeosporioides* Penz.). Weed control was done by spraying Glyphosate in the rows and with a shredder between rows. About 80 units of nitrogen, 30 units of phosphorus and 50 units of potassium were applied to the soil and by drip irrigation in average by year.

Equipment

Mechanical pruning was performed using an R&O (Reynolds & Oliveira Ltd.) disc-saw pruning machine (Figure 1), with a 3.0 m cutting bar (Peça et al., 2002), mounted on a front loader of a 97 kW (DIN) 4WD agricultural tractor.

The manual pruning complement to the mechanical pruning was executed by telescopic chain saws.

The Row-Side Continuous Canopy Shaking Harvester (RSCCSH) is a prototype (Figure 2) developed to remove fruits from the tree brunches, collect and transport the fruits to temporary storage (Peça et al., 2014).

Figure 1. Disc-saw pruning machine performed “topping”.

Figure 2. Row-side continuous canopy shaker prototype.

The RSCCSH is based on two symmetrical machines, each one trailed by a tractor, moving alongside a same tree row, harvesting both sides of the trees. Fruit removal is made by a vibratory rotor with flexible rods for engaging and shaking the olive bearing branches. Vibration frequency of the vibratory rotor can be altered by adjusting the tractor power-take-off speed. Removed olives are collected on a platform and conveyed to a temporary storage bag (Dias et al., 2020). Table 1 shows the operational parameters of RSCCSH in each harvesting season.

Table 1. Operation parameters of RSCCSH.

Harvesting season	2015	2016	2017	2018
Ground speed (km h^{-1})	0.4	0.6	0.75	0.4
PTO of left unit (rpm)	430	540	610	*
PTO of right unit (rpm)	500	540	540	540

* in 2018 the harvesting was performed only using right unit, because farmer only have one tractor with equipped with variable continuous transmission. It was necessary to pass with the right unit in the two sides of the canopy. Canvas were placed in the ground in the opposite side of the prototype unit in order to collect the removed olives that fallen in the opposite side.

Treatments

Three treatments (T1, T2, T3), shown in Figure 3, are being compared in a randomized complete block design with three replications leading to 9 plots, of one line each, with 30 trees per plot.

- treatment 1 (T1) – mechanical pruning performed in 2015 and 2017; in 2015, a horizontal cut (topping) of the canopy parallel to the ground at 3.5 m high and vertical cut on each side of the tree (hedging) at 1.4 m from the tree trunk; in 2017, topping was done at approximately 3.3 m in height, from the ground;
- treatment 2 (T2) – mechanical pruning performed in 2015 and 2017. In 2015, trees were topped as in T1 followed by a vertical cut on each side of the tree (hedging) at 1.0 m from the tree trunk; in 2017, topping was done at approximately 3.3 m in height, from the ground;
- treatment 3 (T3) – mechanical pruning + manual pruning complement in 2015 and 2017; in 2015, trees were mechanically pruned as in T2, followed by manual pruning complement to remove wood in the external faces of the canopy; in 2017, trees were topped as in T2 followed by manual pruning complement to remove wood suckers inside the canopy.

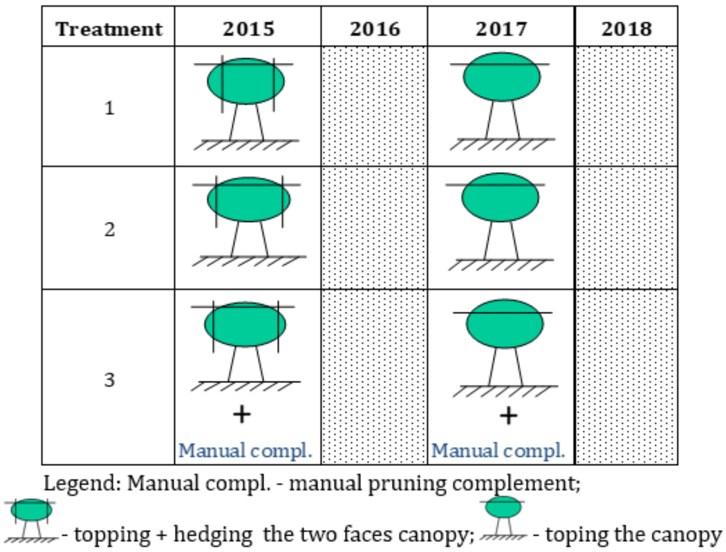

Figure 3. Sequence of pruning interventions by treatment.

Assessments

Pruning operations were timed to calculate the work rates. In 2015, tree measurements of the height of the tree from the ground and width of the canopy were recorded in 5 trees randomly selected in each plot. In the other years (2016-2018), all the trees were measured. Measurements were taken after pruning interventions (2015 and 2017) in early spring (2016) and before harvesting (2017 and 2018).

The mass of olives caught by the RSCCSH was measured by weighing the bags from each plot. The evaluation of the mass of olive removed but not caught by the harvester was done weighing the fruits collected on canvas placed under a group of 3 olive trees at 3 locations randomly selected in each plot. To quantify the mass of olives not removed by the harvester, all trees in each plot were vibrated by a trunk shaker complemented by manual harvest with poles. Total yield tree^{-1} was obtained by adding the mass of olives caught by the harvester to the mass of olives dropped to the ground plus the mass left on the tree.

Harvest efficiency was calculated as follows:

$$Harvest\ efficiency\ (\%) = \frac{\text{Mass of olives caught per tree}}{\text{Total yield per tree}}$$

One-way analysis of variance was performed to annual data and GLM Univariate Analysis for average data, using IBM SPSS version 24 software. Mean separation was performed by multiple range Duncan test at 5 and 10% significance level.

RESULTS AND DISCUSSION

Pruning rate

Table 2 shows the pruning work rates obtained in 2015 and 2017. "Topping" and "hedging" on both faces (2015) requires 4 passes of the pruning machine by tree line while in 2017, only two passes was needed ("topping").

Table 2. Average pruning rates (trees h^{-1} man^{-1}).

Pruning intervention	2015	2017
Mechanical pruning	184	327
Manual pruning complement	40	23

The pruning rate of the manual complement obtained in 2015 was higher than in 2017. The removal of exposed wood stumps on the sides of the canopy, due to the hedging, requires less time than the elimination of wood suckers inside the canopy (2017).

Tree height

Figure 4 shows the result of the assessment of the height of the trees, per year and treatment.

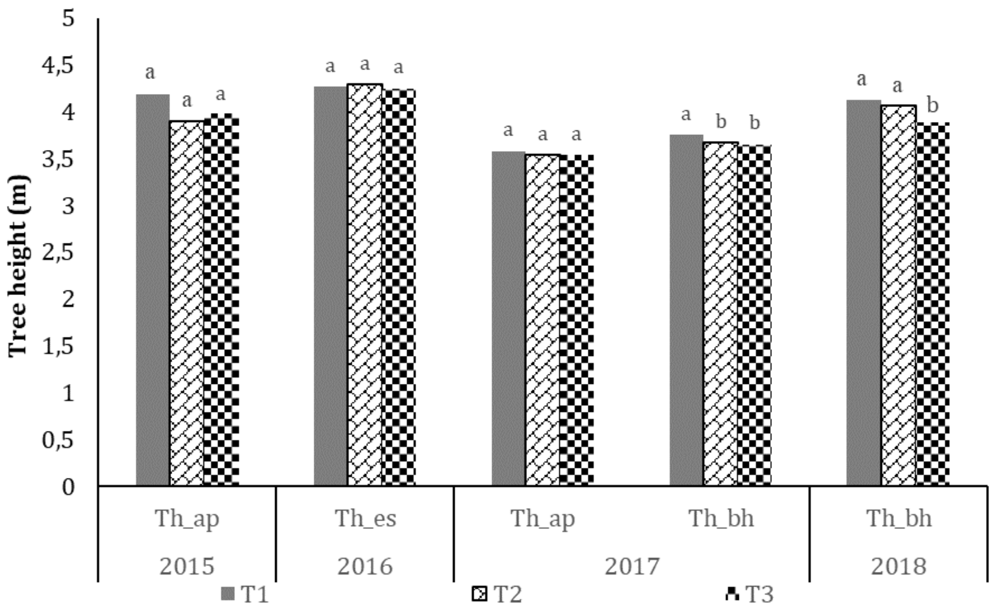

Figure 4. Average tree height by treatment. Th_ap – tree height after pruning; Th_es – tree height in early spring; Th_bh – tree height before harvest. In each date, columns followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

Since the positioning of the cutter bar of the pruning machine was the same in all the treatments, there were no significant differences (P>0.05) between treatments in tree height, in 2015 and 2017.

At the beginning of the spring of 2016, no significant differences (P>0.05) in tree height were registered between treatments. This reveals a similar regrowth between treatments after the winter topping made in 2015

In the harvest campaign of 2017, there were significant differences (P<0.05) between treatments in tree height. Treatment 1 registered the tallest trees which were significantly higher (P≤0.05) than those of the other treatments.

In the harvest campaign of 2018, there were also significant differences (P<0.05) between treatments in tree height: Treatment 3 has the lowest trees, which are significantly (P≤0.05) smaller than the other treatments.

These differences did not have any relevance in terms of adequacy of the trees to the vibratory rotor of the RSCCSH prototype, since the branches at the top of the canopy do not bear fruit. As these branches are located at a higher level than the upper limit of the vibratory rotor, their predictable evolution to bearing branches would recommend a new topping in the following year. The cutter bar should be positioned below the upper limit of the vibratory rotor (3.6 m) to avoid carrying out this intervention every year.

Canopy width

Figure 5 shows the result of the assessment of the canopy width of the trees, per year and treatment. Significant differences (P<0.05) were registered between treatments in all the assessments. Treatment 1 registered the larger canopy width, which is significantly (P≤0.05) different from the other treatments in most of the years, as a result of the highest distance of the hedging cut to the tree trunk. In the harvest campaign of 2018, no significant differences were registered between treatments 1 and 2.

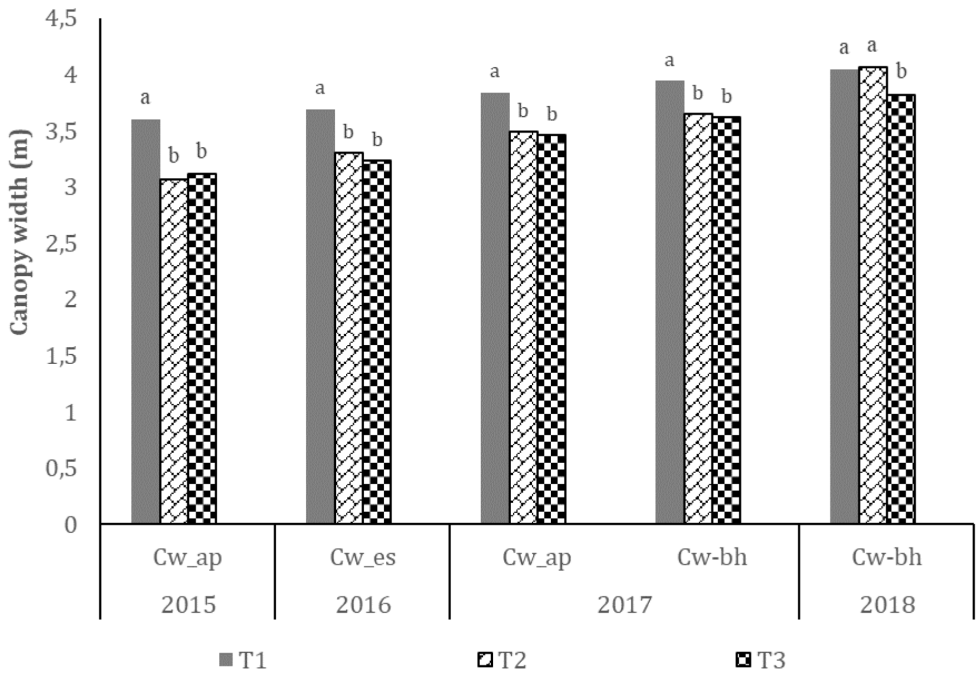

Figure 5. Average canopy width by treatment. Cw_ap – canopy width after pruning; Cw_es – canopy width early spring; Cw_bh – canopy width before harvest. In each date, columns followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

The canopy width limits should be between 1.5 and 3.6 m (Dias et al., 2020), in order to leave the steel guiding tubes of the rods of the vibratory mast outside of the canopy. More protruding woody branches on the side faces of the canopy tend to break because their limited flexibility does not allow them to mould to the steel guide tubes of the mast.

Hedging on the sides of the canopy tends to eliminate a considerable amount of fruiting branches. The adequacy of the canopy width to the RSCCSH should consist of more severe hedging (T2 or T3) performed less frequently (each 3-4 years).

Olive yield

Table 3 shows olive yield obtained by tree from 2015 until 2018. There were significant differences ($P<0.05$) between the years, with the highest production achieved in 2018, which was significantly higher ($P\leq0.05$) than in the other years, which differed from each other.

Table 3. Olive yield tree^{-1} from 2015 until 2018 (kg tree^{-1}).

Treatment	2015	2016	2017	2018	Average by treatment
T1	25.4 a	24.7 a	14.7 a	27.8 a	23.5 A
T2	20.2 b	26.1 a	15.5 a	30.5 a	23.1 A
T3	23.4 ab	28.1 a	14.9 a	29.9 a	23.7 A
Average by year	22.9 C	26.3 B	15.1 D	29.4 A	23.4

In each year, in average by year and in average by treatment, values followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

These results confirm the alternate bearing typical of this specie, which can be changed with pruning interventions. After the increase in production verified from 2015 to 2016, the pruning interventions executed in 2017, with a reduction in the canopy volume (Figures 3 and 4) and the elimination of potentially productive branches, the result was a decrease in production in comparison to those obtained in 2016. The higher canopy volume reach in 2018 resulted in an increase in the yield obtained.

No significant differences ($P>0.05$) were found between treatments in the most of the years (Table 3). In 2015, significant differences ($P<0.05$) were registered in olive yield tree^{-1} between treatments. Treatment 1 has revealed a significantly ($P\leq0.05$) higher yield than treatment 2, which could have resulted from the larger canopy of treatment 1 (Figure 4).

Although T1 and T3 were submitted to different pruning intensities, there were no significant differences ($P\leq0.05$) between these treatments.

On average, no significant differences ($P>0.05$) between treatments were found.

The comparison of the results with those obtained by Dias et al. (2020) in another pruning test, shows a greater stabilization of olive yield over the years and a better adaptation of the canopy size to the RSCCSH.

Harvest efficiency

Table 4 shows harvester efficiency obtained from 2015 until 2018. There were significant differences ($P<0.05$) between the years, with significantly higher efficiencies ($P\leq0.05$) in 2015 and 2016 than in 2017 and 2018. Differences in the RSCCSH working parameters and differences in the canopy dimension between years have contributed to that result.

No significant differences ($P>0.05$) were found in harvester efficiency between treatments, in any years of the trial.

On average, the higher harvester efficiency was registered in treatment 1, without significant differences ($P>0.5$) to the other treatments.

The differences registered in the canopy width between treatments were not enough to significantly influence the performance of the harvester.

Although Dias et al. (2020) found a significant increase in the RSCCSH efficiency when there was a decrease in production (10 kg tree^{-1}), this did not occur in 2015, since the differences in production between T1 and T2 were smaller (Table 3).

Table 4. Harvester efficiency from 2015 until 2018 (%).

Treatment	2015	2016	2017	2018	Average by treatment
T1	84.9 a	86.9 a	77.2 a	77.2 a	81.6 A
T2	81.0 a	84.1 a	75.5 a	76.6 a	79.3 A
T3	79.1 a	82.4 a	78.4 a	76.1 a	79.0 A
Average by year	81.7 A	84.5 A	77.0 B	76.6 B	80.0

In each year, in average by year and in average by treatment, values followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

CONCLUSIONS

In this 4-year period, there were no significant differences between the pruning options, either in terms of olive yield or in terms of harvester efficiency. It was found that:

- the pruning cycle should begin with topping, followed by an intense hedging in the two faces of the canopy in order to maintain the canopy width adequate to the RSCCSH for 4 years;
- a new topping should be performed two years later to control tree height;
- manual complement to the mechanical pruning was not relevant since it did not lead to increase neither the olive production or the harvesting efficiency of the RSCCSH and led to an increase in pruning costs.

The use of manual pruning complement to remove exposed wood stumps on the sides of the canopy could be useful to reduce the rupture of the rods of the vibratory mast.

ACKNOWLEDGEMENTS

The authors acknowledge Torre das Figueiras Sociedade Agrícola Lda. for the permission and availability of technical and human resources for the implementation of this study.

We also acknowledge the financial support from the National Funds through the project PRODER entitled "Evaluation of the performance of the row-side continuous canopy harvesting machine", and the project PDR2020 entitled "Mechanized pruning and continuous harvesting of olive groves of Portuguese varieties", both from the Ministry of Agriculture.

Literature cited

Dias, A.B., Falcão, J.M., Pinheiro, A., and Peça, J.O. (2020). Evaluation of olive pruning effect on the performance of the row-side continuous canopy shaking harvester in a high density olive orchard. Front Plant Sci *10*, 1631 https://doi.org/10.3389/fpls.2019.01631. PubMed

Ferguson, L., and Castro-García, S. (2014). Transformation of an ancient crop: preparing California 'Manzanillo' table olives for mechanical harvesting. Horttechnology *24* (*3*), 274–280 https://doi.org/10.21273/HORTTECH.24.3.274.

Ferguson, L., Krueger, W.H., Reyes, H., and Metheney, P. (2002). Effect of mechanical pruning on California black ripe (*Olea europea* L.) cv. 'Manzanillo' table olive yield. Acta Hortic. *586*, 281–284 https://doi.org/10.17660/ActaHortic.2002.586.54.

Ferguson, L., Rosa, U.A., Castro-Garcia, S., Lee, S.M., Guinard, J.X., Burns, J., Krueger, W.H., O'Connell, N.V., and Glozer, K. (2010). Mechanical harvesting of California table and oil olives. Adv. Hortic. Sci. *24* (*1*), 53–63.

Peça, J.O., Dias, A.B., Pinheiro, A.C., Santos, L., Morais, N., Pereira, A.G., and Reynolds de Souza, D. (2002). Mechanical pruning of olive trees as an alternative to manual pruning. Acta Hortic. *586*, 295–299 https://doi.org/10.17660/ActaHortic.2002.586.57.

Peça, J.O., Dias, A.B., Pinheiro, A., Cardoso, V., Reynolds de Souza, D., and Falcão, J.M. (2014). Side-row continuous canopy shaking harvester for intensive olive orchards. Acta Hortic. *1057*, 391–397 https://doi.org/10.17660/ActaHortic.2014.1057.48.

Ravetti, L., and Robb, S. (2010). Continuous mechanical harvesting in modern Australian olive growing systems. Adv. Hortic. Sci. *24* (*1*), 71–77.