Influence of different pruning solutions in kernel production of a super high density almond orchard

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Abstract

The success of the super high density (SHD) system on olive production has been extended to almond orchards, where it is necessary to ensure adequate canopy dimensions for over-the-row harvesting machines. In an almond orchard from Soleta cultivar planted in September 2014 at Herdade da Torre das Figueiras in Monforte, Portalegre, Portugal (39°04'N, 07°29'W), a trial to evaluate different pruning solutions was established. Four treatments (T0, T1, T2, T3) were compared: T0 (farmer pruning) - summer pruning (mechanical pruning in 2018 and 2019, postharvest pruning (mechanical pruning in 2017) and winter pruning (manual pruning in 2018 and mechanical pruning followed by manual pruning in 2017); T1 – no pruning interventions in 2017 and manual pruning in 2018 and 2019; T2 – involving postharvest pruning (mechanical pruning in 2017, 2018 and 2019), and T3 - summer pruning (mechanical pruning in 2018 and 2019) and postharvest pruning (mechanical pruning in 2017). In 2018, manual winter pruning was carried out in the treatments mechanically pruned. Significant differences were registered in harvested kernel almond yield between years (2017-2019). In 2018, there were significant differences between treatments, with T0 recording a significantly lower almond kernel production harvested than those obtained by T2. However, in the average of 3 years, there were no significant differences between treatments.

Keywords: pruning, kernel almond yield, costs

INTRODUCTION

In Portugal, after the expansion of the super high density (SHD) olive orchards, some SHD almond orchards have also been planted. According to Torrents (2015), the main goals of these training system are to reduce the harvesting costs due to the use of the same machinery as in vineyards and olive orchards. The same author refers that the advantages of this system are the reduction of labor cost for planting and pruning and an increasing of almond production, namely in the first years, with a reduction of bearing alternation and the quality improvement of almond kernels.

In the training of SHD almond orchards, farmers are concerned about making sure that the canopy dimensions adequate to the over-the-row harvesting machine. The canopy should be trained as a disorganized hedge with multi axes, canopy width should not overcome 0.70-0.80 and 2.75 m in height (Torrents, 2015). In order to control canopy dimension, Torrents (2015) suggests the use of mechanical pruning with topping and hedging since the first year of plantation. Manual pruning should only be used to eliminate dead shoots or vigorous branches (Torrents, 2015). Due to the lack of references about the management of SHD almond orchards, in a commercial orchard, authors established a trial to evaluate the effect of different pruning solutions on almond yield and harvesting efficiency. This paper shows the results of the first three years of assessment.

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MATERIALS AND METHODS

Almond orchard

The orchard was established in September 2014 at Herdade da Torre das Figueiras-Monforte-Portalegre-Portugal (39°04'N and 07°29'W) on a soil map unit of Colluvic Regosols and Chromic Luvisols. The orchard was ridge planting in a 5×1.5 m array with east-west orientation, with the cultivars 'Soleta', 'Belona', 'Guara' and 'Lauranne' grafted on RootPac 20 or Densipac® (www.rootpac.com) rootstock (*Prunus besseyi* × *Prunus cerasifera*). Plants with 6 months nursery from Agromillora Catallana were used. Trees were trained to ensure central axis formation, seeking to ensure a distance of about 0.5 m from the canopy base to the ground.

The orchard is drip irrigated 3 times per week, from May until October, receiving annually an estimated volume of 2000 m^3 ha. The SHD orchard was sprayed to control almond red leaf blotch (*Polystigma amygdalinum* P.F. Cannon), coryneum blight (*Stigmina carpophila*), false tiger (*Monosteira unicostata*) and spider mites (*Tetranychus urticae* Koch and *Panonychus ulmi* Koch). Weeds were mechanically controlled between rows with a shredder machine and chemically in the rows. Fertigation and foliar fertilization were used.

The trial was established in the orchard plot of 'Soleta' cultivar.

Equipment

In 2015, mechanical pruning was performed using a portable Sthill hedge trimmer. In the following years, 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 were used.

Figure 1. Summer pruning with tractor mounted disc-saw pruning machine.

Harvesting was done by a Gregoire G9.330 self-propelled harvesting machine (Figure 2).

Figure 2. Self-propelled Gregoire G9.330 harvesting machine at 2017 trial harvest.

Methods

In the plot orchard of 'Soleta' cultivar, four treatments (T0, T1, T2, T3) shown in Figure 3 are being compared in a randomized complete block design with three replications leading to 12 plots, of one line each, with 95 trees per plot. The treatments were as follow:

- treatment 0 (T0 – farmer pruning) – summer pruning: mechanical pruning performed in 2018 and 2019 In June 2018 and 2019, summer topping at 2.6 m height followed by hedging both sides of the canopy at a distance of 0.4 m from the tree trunk were done. In 2019, a manual pruning complement was done to remove the branches from the base of the canopy that the pruning machine had not cut. Postharvest pruning: in September 2017, trees were topped at 2.6 m height, followed by hedging both sides of the canopy at a distance of 0.4 m from the tree trunk. Winter pruning: in 2017, the trees were topped at 2.7m height followed by a manual pruning to remove some branches in order to increase sun light exposure inside the canopy;
  Before the beginning of the trial the following interventions were made: in July of 2015, trees were hedged in each side of the canopy at a distance of 0.3 m from the tree trunk and topping was performed in July (1.1 m height) and September (1.40 m height). Manual pruning to remove shoots developed lengthwise were made in 2016 in the winter and also in July.
- treatment 1 (T1) – winter manual pruning in 2018 and 2019 to remove wood branches with excessive growth lengthwise and to reduce tree height.
- treatment 2 (T2) – postharvest pruning: mechanical pruning in 2017, 2018 and 2019. Trees were hedged in each side of the canopy at a distance of 0.3 m from the tree trunk and topping was performed at 2.7 m height.
  Before the beginning of the trial the following interventions were made: in July of 2015, trees were hedged in each side of the canopy at a distance of 0.3 m from the tree trunk.
- treatment 3 (T3) – summer pruning: mechanical pruning performed in 2018 and 2019. In July 2018 and 2019, summer topping at 2.6 m height followed by hedging both sides of the canopy at a distance of 0.4 m from the tree trunk were done. Postharvest pruning: mechanical pruning in 2017. Trees were hedged in each side of the canopy at a distance of 0.3m from the tree trunk and topping were performed at 2.7 m height.
  Before the beginning of the trial the following interventions were made: in July of

2015, trees were hedged in each side of the canopy at a distance of 0.3 m from the tree trunk and topping was performed in July (1.1m height) and September (1.40 m height).

Before trial		Pruning season	Treatments	Trial		
2015	**2016**			**2017**	**2018**	**2019**
	Manual P.	**Winter pruning**	**T0**	Topping + Manual p.	Manual P.	
Topping + Hedging	Manual P.	**Summer pruning**	**T0**		Topping + Hedging	Topping + Hedging Manual P.Comp.
		Post harvest pruning	**T0**	Topping + Hedging		
		Winter pruning	**T1**		Manual P.	Manual P.
		Winter pruning	**T2**		Manual P.	
Hedging		**Summer pruning**	**T2**			
		Post harvest pruning	**T2**	Topping + Hedging	Topping + Hedging	Topping + Hedging
		Winter pruning	**T3**		Manual P.	
Topping + Hedging		**Summer pruning**	**T3**		Topping + Hedging	Topping + Hedging
		Post harvest pruning	**T3**	Topping + Hedging		

Legend: Manual P. - manual pruning; Manual P. comp. - manual pruning complement; - mechanical pruning (topping + hedging two sides canopy); - mechanical pruning (hedging two sides canopy); - mechanical pruning (topping).

Figure 3. Pruning interventions sequence of different treatments.

In 2018, a manual winter pruning was done in the treatments pruned mechanically, to remove branches with excessive growth lengthwise.

Pruning operations were timed in order to calculate the work rates. Tree measurements of the height of the tree from the ground, width of the canopy and losses of almonds to the ground at harvest were recorded in 3 sub-plots of 10 trees randomly selected in each tree line. Measurements were done in the same trees in the entire period of tests (2017, 2018 and 2019) and taken before harvesting, before and after winter pruning interventions and before summer pruning interventions.

In 2017, 2018 and 2019, each row was harvested, weighing the mass of almonds caught by the harvester and monitoring the losses of almonds to the ground by sampling

One-Way Analysis of Variance was performed to annual data using IBM SPSS version 24 software. Mean separation was done by Multiple Range Duncan test at 5% significance level.

RESULTS AND DISCUSSION

Tree height

In the harvesting campaign of 2017, significant differences (P<0.05) were found between treatments in tree height (Table 1). Treatment 2 had significantly higher (P≤0.05) trees, which could be due to the hedging made in 2015, that led to these trees always being taller (Dias et al., 2018). In treatment 3, the lower height may be a consequence of the "topping" performed at the early stage of tree development, resulting in always being lower than the other ones (Dias et al., 2018).

Table 1. Average tree height by treatment, in each year (m).

	2017	2018			2019		
	At harvest	After winter pruning	Before summer pruning	At harvest	After winter pruning	Before summer pruning	At harvest
T0 (farmer pruning)	2.79 b	2.19 c	2.81 b	3.19 a	3.10 a	3.25 a	2.94 a
T1	2.80 b	2.88 a		3.16 a	2.79 b		3.11 a
T2	2.89 a	2.37 b		3.07 b	2.50 d		2.86 c
T3	2.55 c	2.19 c	2.91 a	2.72 c	2.72 c	3.16 b	2.60 d

In each assessment, values followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

In treatment 0, as a result of the topping performed by the farmer, new shoots issue from the branches cut by the pruning machine, which grew during the spring. The growth of these branches led to the height of the trees at harvest being similar to that recorded in T1. Trees higher than the structure of the harvesting machine (2.70 m), was not prevent the harvest from taking place, since the branches at the top of the trees were flexible. However, there was loss of production due to the fall of fruits to the ground. Significant differences (P<0.05) were registered between treatments after 2018 winter pruning (Table 1). Treatment 1 had significantly higher (P≤0.05) trees than the other treatments (T0, T2 and T3), which show trees lower than the maximum height of the harvesting unit of the self-propelled machine.

Before 2018 summer pruning (Table 1), significant differences (P<0.05) were found between treatments, with higher values in treatment 3. Trees submitted to T3 are allowed to grow about two months more (July cut) than those of T1 (June cut), which contributes to this result.

In 2018 at harvest, treatment 3 had significantly lower (P≤0.05) trees than the other treatments, as a result of the topping performed at 2.60 m. The competition for the assimilates between fruits and vegetative growth in July after summer pruning, can explain the absence of new shoots at the top of the tree as intended. In treatment 0, the summer cut was executed at the same height, but there was an increase in tree height from summer pruning to almond harvest. At harvest, although there were no significant differences (P≤0.05) between T0 and T1, there was a difference in the type of branches in the upper part of the trees. At T0, the shoots located above the summer cut zone were flexible shoots without fruit, while in T1, the shoots, despite being flexible, had fruit because the height of the trees was not reduced efficiently in the winter pruning.

The shoots emerged after the 2017 postharvest pruning (treatment 2) are suckers, flexible branches fruitless, which may be a good indicator of the added value of this solution to control tree height.

Significant differences (P<0.05) were registered between treatments after 2019 winter pruning (Table 1), as a result of the pruning interventions performed. One year without any pruning intervention linked with two periods of vegetative growth (regrowth after 2018 summer pruning and spring 2019) contribute to the higher trees recorded in T0 before the 2019 summer pruning.

In 2019 at harvest, significant differences (P<0.05) were found between treatments in tree height (Table 1). Treatment 3 had the lower trees, showing that summer pruning performed in July is the best option to adequate tree height to the harvesting machine.

Treatment 2 registered trees significantly ($P \leq 0.05$) lower than treatment 0, which reinforces the advantage of this solution to control tree height.

Canopy width

Before 2017 harvesting, significant differences ($P<0.05$) were found between treatments (Table 2). Treatment 1 revealed a significantly ($P \leq 0.05$) larger canopy width as a result of the absence of pruning interventions since planting, while in T0 the removal of developed branches sidewise explain the lower width.

Table 2. Average canopy width by treatment, in each year (m).

	2017	2018			2019		
	At harvest	After winter pruning	Before summer pruning	At harvest	After winter pruning	Before summer pruning	At harvest
T0 (farmer pruning)	1.71 d	1.05 c	1.52 b	1.39 c	1.39 b	1.82 a	1.13 d
T1	2.55 a	1.75 a		1.97 a	1.67 a		2.00 a
T2	2.06 c	1.07 bc		1.68 b	1.15 d		1.45 b
T3	2.20 b	1.11 b	1.93 a	1.30 d	1.30 c	1.70 b	1.30 c

In each assessment, values followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

The manual pruning to eliminate vigorous branches sidewise in T1 is not enough to get a canopy width similar to the other treatments, after the winter pruning of 2018.

Significant differences ($P<0.05$) were found between treatments before 2018 summer pruning, as a consequence of a higher period of vegetative growth in T3.

In 2018, at harvest, as expected treatment 1 had the highest canopy width, followed by treatment T2. The summer hedging in July (T3) allows the trees at harvesting to be significantly ($P \leq 0.05$) narrow in comparison to those pruned in June (T0), due to the vegetative re-growth of the later.

After the winter pruning of 2019 is similar to the registered in winter of 2018, with significant higher ($P \leq 0.05$) values in T1 than in the other treatments.

In 2019 at harvest, as registered in the other years, T1 had a significantly higher ($P \leq 0.05$) canopy width, than in the other treatments. The manual complement to the summer hedging in June (T0) allows the trees at harvesting to be significantly ($P \leq 0.05$) narrow in comparison to those pruned in July (T3). T2 confirm the tendency to have a canopy width significantly ($P \leq 0.05$) higher than the treatments submitted to summer pruning (T0 and T3).

Pruning work rates

Table 3 shows the pruning work rate of manual pruning by treatment obtained in each year.

Table 3. Average work rate of manual pruning by treatment and year (trees h^{-1} $person^{-1}$).

	2017	2018	2019
T0 (farmer pruning)	68 c	191 b	622 a
T1		56 c	38 c
T2		75 c	
T3		59 c	

Values followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

Manual pruning performed in 2017 in treatment T0 contributed for the significant ($P<0.05$) increase in pruning rate registered in the following year (2018). The significantly ($P<0.05$) higher pruning rate obtained in 2019, was due to the removal of just one or two branches from the base of the tree canopy made after the summer hedging.

No significant differences ($P<0.05$) were registered in the time spent in manual pruning of treatments T1, T2 and T3, due to the fact that these treatments did not have been manual pruning interventions until 2018.

In 2019, manual cuts executed in the top of the canopy in treatment T1, in order to reduce tree height, resulted in a decrease of the pruning rate in comparison to the obtained in 2018.Table 4 shows the disc-saw pruning machine work rates by treatment in each pruning season. In 2017, the significantly (P<0.05) higher pruning machine work rate in treatment T0 was justified by the fact that only "topping" was carried out, for which just one machine pass was necessary for each row of trees. In the case of the other interventions, 3 machine passes were always carried out per tree row, as well as their end of turn maneuvers. This explains the inexistence of significant differences (P<0.05) in the pruning machine work rate between summer pruning and postharvest pruning.

Table 4. Average work rate of the disc-saw pruning machine in each pruning season (trees h^{-1} $person^{-1}$).

	2017	2017	2018	2018	2019
	Winter pruning	Postharvest pruning	Summer pruning	Postharvest pruning	Summer pruning
T0 (farmer pruning)	2815 a	625 b	628 b		659 b
T1					
T2		655 b		758 b	
T3		631 b	691 b		658 b

Values followed by the same letter are not significantly different by Duncan multiple range test at the 5% level.

Harvest almond yield

Table 5 shows the average kernel yield harvested by tree in each year, with significant differences (P<0.05) between years. The first kernel almond was harvested in 2017 and was followed by a significantly lower (P<0.05) value in 2018. In a trial carried out in Badajoz-Spain with the same variety-rootstocks combination, Puebla (2016) obtained the first production in the second year after planting, although with a kernel yield per tree about 3 times lower.

Table 5. Average harvested kernel yield by tree (kg $tree^{-1}$).

Year	Harvested kernel yield
2017	0.47 b
2018	0.30 c
2019	1.17 a

Values followed by the same letter are not significantly different by Duncan multiple range test at the 5% level

In our trial, there was an increase in the kernel yield harvested in the third year (2019) as verified by Maldera et al. (2021) in Bari-Italy between the 1st to the 2nd year of production of a hedge almond orchard with the varieties 'Tuono' and 'Lauranne'. However, the productive level of this varieties from the 2nd to the 3rd year was different. While 'Tuono' variety had a 9% increase in yield, Lauranne variety show a 27% decrease in production (Maldera et al., 2021). Yield variations can also occur in older plantations, as recorded by Casanova-Gascón et al. (2019) between the 8th and 9th year, in a Soleta orchard trained as an anarchic hedge with an irrigation level of 6700 m^3 ha^{-1}. In the same orchard, trees trained as open centre produced 30 to 80% more than those trained in hedge system (Casanova-Gascón et al., 2019).

No significant differences (P>0.05) were registered in harvested kernel almond yield between treatments in 2017 and 2019 (Table 6).

In 2018 significant differences were found between treatments (P<0.05) with a significantly (P≤0.05) higher yield harvested in treatment T2 than in treatments T0 and T3.

However, in the average of 3 years, there were no significant differences (P>0.05) between treatments.

Table 6. Harvested kernel yield by treatment in each year and in average between 2017 and 2019 (kg $tree^{-1}$).

Treatment	2017	2018	2019	Average by treatment
T0 (farmer pruning)	0.52 a	0.22 b	1.11 a	0.62 A
T1	0.42 a	0.32 ab	1.06 a	0.60 A
T2	0.44 a	0.41 a	1.36 a	0.74 A
T3	0.47 a	0.26 b	1.14 a	0.62 A

In each 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.

According to Iglésias et al. (2021), in the new hedgerow plantation in Portugal and Spain, there are an annual increase in yield until the 5th-6th year, followed by the stabilization of the production level in the next years, which shows the need to maintain this trial.

CONCLUSIONS

This trial shows the necessity to adequate tree dimensions to the harvesting machine in order to minimize almond losses at harvest to the ground.

The use of the pruning machine allows a quick alteration of tree dimension to the harvesting machine.

Summer pruning made in July or postharvest pruning appears to be solutions to control tree height.

It will be necessary to continue the trial over a longer period of time in order to evaluate the effect of pruning on kernel yield as well as harvesting efficiency and pruning costs.

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