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Mechanical Thinning of Apricot Fruitlets

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Apricot trees usually bear more fruits than they can adequately support. Crop load adjustment through fruit thinning is a routine practice adopted by fruit growers to obtain a marketable product. Manual thinning, although effective, is a labor-intense and expensive operation, accounting for over 30% of the production costs; chemical thinning, on the other hand, provides inconsistent results and, though relatively inexpensive, is an unreliable practice.The aim of this study is to test a new thinner machine on apricots fruitlets, identifying the most suitable working speed combining thinning with the lack of visible damage on branches and on the remaining fruits.
The machine is composed by a rotor equipped with radial rods on a central axe mounted in a rear tree point linkage of a tractor. Trials were carried out in April 2016 in an apricot orchard sited in Cesena (FC). The experiment aimed to compare mechanical thinning at different working speeds (1.11 and 0.83 m s^{-1}) and hand thinning on green fruits (2 ≤ Ø ≤ 2.5 cm). The thinning effect was evaluated by counting the remaining fruits from 40 randomly chosen branches in the upper and down part of four plants replicates. After the mechanical thinning, a manual thinning of finishing was performed, aimed to eliminate the fruits too close together on the branch and, in general, to ensure a uniform fruit set on the tree. The time required for thinning was measured in the mechanically thinned trees and compared with the ones thinned only by hand (control).
The two different working speeds gave two different thinning intensities: at 0.83 m s^{-1} fallen fruits counted for 44 % of the total while 47 % at 1.11 m s^{-1}. The thinning effects depended on the branch length: the highest fruit reduction was recorded (50.3 %) in more-than-35-cm long branches at 1.11 m s^{-1} while the lowest one (44.4 %) was recorded in less-than-15-cm long branches. The results obtained in the thesis at 0.83 m s^{-1} were different. The percentage of fruit reduction varied, indeed, from 47.5 % recorded in more-than-35-cm long branches and 41.3 % recorded in less-than-15-cm long branches.
Mechanical thinning can produce a net economic impact on apricot cultivation and, in some cases, can replace manual thinning and reduce the labor costs considerably.

1. Introduction

Apricot trees (*Prunus armeniaca*) usually bear more fruits than what they can adequately support until fruit harvest. Crop load adjustment through fruit thinning is a commercial practice to obtain a marketable product (Costa and Vizzotto, 2010; Rettke and Dahlenburg, 1999). Most apricot growers worldwide remove manually the excess fruit around 40-60 days after the full blooming (DAFB) (Webster and Spencer, 2000; Son, 2004). Fruit hand thinning is very expensive as well as complex in terms of labour management. The time required to manual thinning can reach up to 12-15% of the total. Indeed, according to the planting density, the training system and the crop load, fruit hand thinning can require 60÷340 h ha^{-1} (Glozer and Hasey, 2006; Neri et al., 2010). The numerous trials to cost-effectively reduce the crop load by spraying chemicals with caustic effect produced inconsistent results on stone fruits, the thinning effect varying from excessive to minimal according to factors such as air temperature, humidity, stage of flower or fruit development, training system or other

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factors (Ambroziv Turck B. et al., 2014; Baugher et al., 2010; Byers, 1999; Coneva and Cline, 2006; Greene et al., 2001; Fallahi et al., 2006; Klein and Cohen, 2000; Southwick, 1997). In the recent years, the interest towards the mechanization of thinning has increased. For peach orchards, several studies demonstrated that mechanical thinning is a viable method for initial crop load reduction, provided that a follow-up hand thinning is contemplated to reach optimal crop load and distribution of fruit in the canopy (Myers et al., 2002; Schupp and Baugher, 2011). Mechanical thinning can reduce the manual thinning requirement from 40 % to 100 % (Schupp et al., 2008). A new machine has been recently developed by the French manufacturer La Canne Vale ltd, consisting in a 3.05 m large rotor equipped with rods radially inserted on a vertical axe, whose rotation is triggered by the contact with the branches. According to the manufacturer, the device can be used to thin both flowers and fruits, on hedgerow as well as on volume training systems.

The present study was carried out to test this new thinner machine (Figure 1) on a commercial apricot orchard, to identify the working speed best combining fruit thinning with the minimum damages to the canopy, and to assess the time saving compared with the only hand thinning operation.

2. Materials and Methods

2.1 Thinning device characteristics

The machine, to be mounted at the three-point linkage of a tractor, is composed by a vertical rotor on which 2,808 flexible working tools (rods) are radially inserted with nut spring system. Rods are made of flexible glass fiber with soft plastic end cap (Figure 1). Two hydraulic connections with 10 L min-1 flow and at least 190 bar pressure are required to set the machine. The rotor device rotates freely when rods come into contact with the tree branches, with simultaneous input and output of a high number of rods that, when contacting the flowers or fruits cause their detachment. The relevant characteristics of the thinner are summarized in Table 1. For road transport, the machine is mounted on a hydraulic transport frame where the rotor width is reduced from 3.05 to 2.0 m. In the test, we used a tractor Landini, model Advantage 95 GT (66 kW engine power).

The fuel consumption of the tractor was calculated using the full to full method. The fuel tank was filled at the beginning of the trial and refilled at the end of it. The hourly consumption was obtained from the total working time.

Figure 1 – Eclairvale: the new thinner machine

Table 1: Main characteristics of the thinner machine.

Parameters	Unit	Value
Linkage		rear mounted
Tree point category		2°
Height	m	3.23
Length	m	3.50
Width	m	3.05
Machine mass	kg	682
Total mass (machine + transport frame)	kg	993
Working tools	n°	2,808
Working tools length	m	1.30
Road transport width	m	2.10

To perform the thinning operation adequately, the total mass and the front ballast of the tractor must guarantee the stability of a longer-than-3-meter working line. In the test carried out in the apricot orchard to assess the performance and efficiency of the thinning device, the engine power of the tractors used was ≥ 50 kW.

The machine performance was calculated by measuring the working time according to ASABE standard methods (ASAE, 2007; ASAE, 2011). Other references include the “Commission Internationale pour organization scientifique du travail en agriculture” (CIOSTA) and the Italian Society of Agricultural Engineering (AIIA) 3A R1(Bodria at al., 2006). The acronyms of times derive from Latin (i.e., TAC = tempus adiuvandi curando). An equation can be formalized as follows:

$$TA = TAS + TAV + TAC \quad (1)$$

Where:
TA = accessory time
TAS = maintenance
TAV = turning
TAC = adjustment
Everyone expressed in s/% of operating time.

As the machine operates in field condition, and the tree orchards are organized in rows where the trees are aligned, its effective field capacity was also determined and expressed as area capacity (C_a):

$$C_a = (S * W * E_f)/10 \quad (2)$$

Where:
C_a = area capacity (ha h^{-1})
S = field speed (km h^{-1})
W = implement working width (m)
E_f = field efficiency (decimal)

The slippage percentage of the tractor was calculated from relationship between real and theoretical speed by:

$$S\ (\%) = 100 * (1 - V * V_t^{-1}) \quad (3)$$

Where:
S= slippage
V= real speed (km h^{-1})
V_t= theoretical speed (km h^{-1})

2.2 Orchard and trial description

The trial was carried out in April 11th 2016, on an apricot commercial orchard, located in Cesena (44°10′ N; 12°14′ E), North-East of Italy. The relevant features of the orchard are summarized in Table 2.

Table 2: Relevant characteristics of apricot commercial orchard, where thinning tests were carried out

Parameters	Unit	Values
Orchard	ha	7.06
Cultivar		Orange Rubis
Tree age	years	8
Training system		palmette
Canopy height	m	4.0÷4.5
Tree spacing	m	4.0 x 3.5
Planting Density	n ha^{-1}	714

Before the thinning experiment, preliminary tests were carried out on additional rows of the orchard in order to establish the tractor speeds to apply in the thinning trials, and to exclude those resulting in insufficient thinning (<5% of fruit removed) and those causing over thinning (>80%) or damages. The evaluated speeds were 0.83 m s^{-1}, 1.11 m s^{-1} and 1.39 m s^{-1}. Based on these preliminary results, the thinning tests were performed at two travel speeds: 1.11 and 0.83 m s^{-1}. A complete randomized block with three 3-trees plots per speed treatment (0.83 m s^{-1}, 1.11 m s^{-1}, and control plot with hand thinning) were chosen randomly. On the central tree of each plot, 40 bearing shoots, distributed in the canopy, were tagged and their shoot length (cm) was measured. The number of green fruits on each shoot was counted before and after the thinning. According to their length, shoots were ranked into the following length classes: ≤ 15 cm; ≤ 15 to 25 cm; ≤ 25 to 35 cm; ≥ 35 cm. The fruit density (number of flowers/fruits per unit length of shoot) was calculated before and after the thinning, as well the fruit removal percentage was calculated for each shoot.

The control treatments (i.e. the standard practice consisting in only manual thinning) were performed at the same dates of follow-ups by the same laborers. Recorded data were analyzed using a randomized block design with 3 replicates. The treatments were the tractor speed and the classes of shoot length (one way ANOVA) using the free software IBM SPSS statistics 23.

3. Results

The new France-designed thinning machine is suitable to thin peach orchards (Cacchi et al., 2016) and, according to the manufacturer, also apricot and plum orchards in any phase of the fruit growing cycle, from the balloon stage of flowers onwards. In order to ascertain the performance of this machine, we carried out our thinning trials on a commercial apricot tree when fruits were in their green stage.

The preliminary trials carried out to set up the speeds to test in the experiments allowed us to exclude the speed that would have caused excessive thinning and damages to vegetation (≥1.11 m s^{-1}) or, on the contrary, would have obtained an insufficient thinning effect.

Although preliminary, the test showed that the thinning effect of the machine varied depending on the shoot length, the thinning time and the tractor speed.

The experiment was carried out maintaining the rotor position parallel to the hedgerow. In case of uneven distribution of fruits in the canopy, deviation from parallelism, eg. higher inclination towards the parts of the canopy with higher fruit density, might modulate the degree of penetration of the rods into the canopy and differentiate the thinning effect as wished. The thinning was performed when fruits weighted, on average, 5.6 g and were 18.7 mm large, BBCH69 stage (Maier et al., 1994). Average fruit density before thinning was 0.44 n° cm^{-1}, highest in the shortest (0.37 n°cm^{-1}) and most represented class of bearing shoots and lowest in the longest shoots (0.14 cm^{-1}; Table 3). Average fruit removal was 43.7 % at 0.83 m s^{-1} vs. 46.7 % at 1.11 m s^{-1}, rather uniform across the shoot length classes (Table 3), regardless the working speed. In the week following the treatments, an additional 20% of natural fruit drop was noticed in the plots thinned mechanically, so that the final fruit drop resulted 63% and 65% at the lowest and the highest speed, respectively. This ‘delayed’ fruit

drop phenomenon, absent in the control plots, is probably due to damages to the fruits that, although contacted by the rods, did not detach immediately.
Fruit removal was unselective, the size and weight of fruits detached being statistically not different from those sampled before thinning (data not shown).

Table 3: Effect of the working speed and the shoot length on fruit removal percentage in the palmette-trained cv. Orange Rubis trees. Values sharing the same letters are statistically not different following post-hoc Tukey test (p-value<0.05)

Speed	Shoot length		Fruit density		Fruit drop
	Classes of length	Representativeness in the canopy	Before thinning	After thinning	
$m\ s^{-1}$	cm	%	$n°\ cm^{-1}$	$n°\ cm^{-1}$	%
0.83	< 15	45.3 *a*	0.63 *a*	0.37 *a*	41.3 *b*
	15 ≤ x < 25	26.3 *b*	0.45 *b*	0.24 *b*	45.2 *a*
	25 ≤ x < 35	12.4 *c*	0.31 *c*	0.18 *c*	40.8 *b*
	≥ 35	16 *c*	0.27 *d*	0.14 *c*	47.5 *a*
1.11	< 15	39 *a*	0.67 *a*	0.37 *a*	44.4 *b*
	15 ≤ x < 25	23 *b*	0.48 *b*	0.25 *b*	47.3 *ab*
	25 ≤ x < 35	11 *c*	0.4 *b*	0.22 *b*	44.8 *b*
	≥ 35	27 *b*	0.29 *c*	0.14 *c*	50.3 *a*

In apricot, the reproductive organs are most concentrate on the very short (≤ 15 cm) branches aged ≥ 2 years and the thinning effects depends on branch length. At 1.11 $m\ s^{-1}$, the highest fruit reduction (50.3 %) was recorded in more-than-35-centimeter long branches while the lowest (44.4 %) one was recorded in less-than 15-centimeter long branches. This latest value is not significantly different to the one for branches with a length between 15 and 25 centimeters. The results obtained in the thesis at 0.83 $m\ s^{-1}$ were different. The percentage of fruit reduction was indeed between 47.5 % of more-than-35-centimenter long branches and 41.3 % of less-than-15-centimeter long branches.
As the thinning effect varied according to the length of the branches, the pruning management - aiming at improving branch length uniformity - would probably improve the uniformity of thinning results.
In the context in which the experiment was carried out, the machine led to a significant reduction in the working time requested to finish the thinning: 26 % with a 0.83 $m\ s^{-1}$ working speed and 36% with a 1.11 $m\ s^{-1}$ working speed.
The fuel consumption measured in the test is 6.4 $L\ h^{-1}$ with a wery low percentage of tractor slippage (<5%).
The 'delayed thinning' phenomenon that was experienced on apricot fruit in the week following the thinning treatment deserve further investigation, because it does not allow to have the immediate perception of the amount of fruit drop caused by the machine and, if not under control, it exposes the grower to the risk of excessive thinning. In terms of the results, the recorded performances are rather positive since the relationship between the manual and mechanical work needs is very favorable for the second one also justifying more interventions on the same orchard. Proper intervention strategy must still be specifically developed.

4. Conclusions

Crop load adjustment through thinning is necessary in stone fruit to obtain yields of high market quality. On the other hand, the high labor and cost required to perform this operation, the increasing difficulty of finding specialized labor, and the low profitability to the grower in the recent years are making less and less sustainable the traditional manual intervention. The development of a mechanical thinning practice, combined with a manual finishing, could represent the solution to these problems.
These first tests showed the good efficiency and performance of the machine, especially operating at maximum sensibility of the fruits and on limited thicknesses canopy. As the thinning effect varied according to

the length of the branches, the pruning management aiming at improving branch length uniformity would probably improve the uniformity of thinning results. Thinner performances could be better if tree pruning was more tailored to the functionalities of the thinner machine.

In order to obtain a complete picture of the advantages obtainable with the machine, also the production parameters and the quality characteristics of peach fruits are under evaluation. The trial is continuing on flowers and fruits of other species and varieties of stone fruits, but these initial positive results lay good foundations for a future appreciation of the system.

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