BIOSYSTEMS ENGINEERING 158 (2017) 1–9

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Mechanical vibration transmission and harvesting effectiveness is affected by the presence of branch suckers in olive trees

Sergio Tombesi [a,*], *Stefano Poni* [a], *Alberto Palliotti* [b], *Daniela Farinelli* [b]

[a] *Dipartimento di Scienze delle Produzioni Vegetali Sostenibili, Università Cattolica del Sacro Cuore, Via Emilia Parmense 84, 29122, Piacenza, Italy*

[b] *Dipartimento di Scienze Agrarie, Alimentari e Ambientali, Università degli Studi di Perugia, Via Borgo XX Giugno 74, 06121, Perugia, Italy*

ARTICLE INFO

Article history:
Received 14 December 2016
Received in revised form
19 March 2017
Accepted 22 March 2017

Keywords:
Pruning
Trunk shaker
Harvesting effectiveness
'Leccino'
Orbital
multidirectional

Trunk shakers are among the most widespread machines for mechanical harvesting in intensive olive orchards (300–500 trees ha^{-1}). Harvesting effectiveness is an important issue for this sort of machine because, due to the heterogeneity of the tree canopy structure, vibration transmission is uneven and some branches vibrate poorly. The aim of the present work was to determine if the removal of internal suckers before harvesting could improve vibration transmission and harvesting effectiveness. 'Leccino' and 'Frantoio' trees trained to free vase and planted in an intensive olive orchard (400 trees ha^{-1}) were used in experiments carried out in 2012 and 2013 in two different orchards. Triaxial accelerometers, placed on tree trunk and on the main branches, were used to measure vibration transmitted to the canopy by two custom-built orbital and multidirectional trunk shakers. On average, harvesting effectiveness increased significantly from 83.4% to 95.6% as a consequence of sucker removal. Maximum acceleration transmitted to the trunk and branches increased by 33.1% and 46.6% respectively after internal sucker removal. These results suggest that internal suckers reduce vibration transmission through the canopy, affecting harvesting effectiveness. Furthermore, the larger the fruit retention force per fruit mass was, the larger was the effect of sucker removal on harvesting effectiveness. These results suggests that sucker removal prior to harvesting is advisable to improve harvesting effectiveness in open vase trees harvested by trunk shakers, in particular when mechanical harvesting is carried out at an early stage of fruit ripening.

1. Introduction

Olive is one of the most important tree crops in the world with roughly 10.2 billion hectares distributed over 47 countries (FAOSTAT, 2017). Only 4.2% of world's olive orchards have a tree density above 800 trees ha^{-1}, while about 21.8% has between 180 and 800 trees ha^{-1} and the remaining 74% has less than 180 trees ha^{-1} (IOOC, 2015). The largest part of intermediate-low density orchards are trained to free vase

* *Corresponding author.*
E-mail addresses: sergio.tombesi@unicatt.it (S. Tombesi), daniela.farinelli@unipg.it (D. Farinelli).

http://dx.doi.org/10.1016/j.biosystemseng.2017.03.010

with single or multiple trunks. In these planting systems, harvesting is the most expensive cultural operation, accounting for between 25 and 60% (IOOC, 2015) of total cropping cost. In orchards planted at intermediate density, different harvesting machines are available, yet the most widespread are trunk shakers (Zion et al., 2011). Trunk shakers, if coupled with automated fruit intercepting systems, can achieve a work productivity between 30 and 100 trees h^{-1} (Tombesi, 2012; Vieri, 2002). However, harvesting effectiveness largely varies from 50% to 90% (Castro-Garcia, Castillo-Ruiz, Jimenez-Jimenez, Gil-Ribes, & Blanco-Roldan, 2015; Sola-Guirado et al., 2014; Tombesi, Boco, Pilli, & Farinelli, 2002; Zion et al., 2011). In fact, harvesting effectiveness is largely dependent on cultivar, ripening stage, fruit detachment force and tree characteristics (Farinelli, Tombesi, Famiani, & Tombesi, 2012; Tombesi et al., 2002). In particular, canopy volume and density appear to play an important role in trunk shaker harvesting effectiveness (Visco, Molfese, Cipolletti, Corradetti, & Tombesi, 2008).

Fruit detachment is mainly caused by three oscillation modes; the pendulum, the tilting, and the rotational (or twisting) and longitudinal (or beam-column) (Fridley & Yung, 1975; Tsatsarelis, 1987; Zhou, Long, Manoj, and Zhang, 2016). However, according to Newton's second law of motion (i.e. $F = m \times a$, where F is the force, m is the mass and a is the acceleration), the transmission of high acceleration to fruits can provide the tensile force necessary to cause fruit detachment (Fridley & Adrian, 1960). On the other hand, branches of a tree act as tuned mass dampers, preventing the tree from developing large dynamic responses to excitation from forced vibration. The total damping is complex and has components of aerodynamic damping, mass damping and internal or viscoelastic damping due to internal damping and energy dissipation in the root structure (Castro-Garcia, Blanco-Roldan, Gil-Ribes, & Agüera-Vega, 2008; James, Haritos, & Ades, 2006; Lang, 2006). Previous papers have reported negative correlation between large canopy volume and density vs. harvesting effectiveness (Tombesi et al., 2002; Visco et al., 2008). The hypothesis tested in this work was that the suckers (vegetative, unproductive shoots borne on the main branches in the internal part of tree canopies trained to free vase) cause a consistent vibration damping decreasing branch vibration magnitude and, as a consequence, harvesting effectiveness. Thus, the hypothesis is that removal of vegetative suckers before mechanical harvesting might reduce canopy damping by reducing canopy mass. Consequently, sucker removal before mechanical harvesting should improve vibration transmission through the canopy. Pruning operations in olive could be roughly divided into two categories: removal of unproductive vegetative shoots borne in the centre of the canopy, and mid and external canopy thinning, in which part of fruiting branches are removed to adjust optimal canopy density (mainly to optimise light availability) and size to obtain an equilibrium between annual fruiting shoot growth and fruit bearing. Currently, sucker removal is a common pruning practice that is carried out during winter–spring pruning. In our experiment, we anticipated sucker removal, which does not imply the removal of fruiting shoots, before harvest that, in the northern hemisphere, is carried out between November and January.

The aims of the present work were to determine the effect of sucker removal on 1) primary branch vibration during mechanical harvesting by trunk shakers and 2) harvesting effectiveness.

2. Materials and methods

Experiments were carried out in 2012 and 2013 in two olive orchards near Perugia, Italy (Table 1). In 2012 in an olive orchard located in Prepo (43°11′ N, 12°29′ E, elevation 425 m a.s.l.), Italy, planted at 5 m × 5 m in 1987 and trained to free vase, a trunk shaker prototype mounted on a 60 kW caterpillar (Agrifull 80 S-C, Italy) was used. The shaking head had a total mass of 250 kg and had a single rotating mass of 15 kg with an eccentricity of 20 cm. Rotating mass was moved by an hydraulic motor of 50 cm^3, directly coupled with the shaft of the rotating mass. The engine mounted on the shaking head was

Table 1 – Layout of the experiments described in the paper.

Year	Place	Cultivar	Tree age	Crop management	Treatment	Vibration sequences and duration (s)
2012	Prepo	‘Leccino’	25	Manual Pruned	SR + A[a]	35 + SR + 35
2012	Prepo	‘Leccino’	25	Manual Pruned	SR[b]	35 + SR + 35
2012	Prepo	‘Leccino’	25	Manual Pruned	Control	35 + 35
2013	Prepo	‘Leccino’	26	Manual Pruned	SR	SR + 35
2013	Prepo	‘Leccino’	26	Manual Pruned	Control	35
2013	Prepo	‘Frantoio’	26	Manual Pruned	SR + A	35 + SR + 35
2013	Prepo	‘Frantoio’	26	Manual Pruned	SR	35 + SR + 35
2013	Prepo	‘Frantoio’	26	Manual Pruned	Control	35 + 35
2013	Deruta	‘Leccino’	18	Mech. Pruned	SR	SR + 35
2013	Deruta	‘Leccino’	18	Mech. Pruned	Control	35
2013	Deruta	‘Leccino’	18	Manual Pruned	SR	SR + 35
2013	Deruta	‘Leccino’	18	Manual Pruned	Control	35

[a] SR + A: sucker removal and trunk and branch acceleration measurement.
[b] SR: sucker removal.