International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July

Ref: C0659

Olive harvesting by canopy shaker

Gregorio L. Blanco-Roldán, Francisco J. Castillo-Ruiz, R. Rubén Sola-Guirado, Francisco Jiménez-Jiménez, Sergio Castro-García, Juan Agüera-Vega and Jesús A. Gil-Ribes, Rural Engineering Department, University of Cordoba, Edificio Leonardo da Vinci. Campus de Rabanales, Ctra. Nacional IV, km. 396, 14014 Córdoba, Spain.

Abstract

Oil Olive growing is one of the most relevant crops in the Mediterranean basin, mainly in Spain where the higher olive oil production are located. Harvesting is the most time and cost consuming operation due to its high labour requirements and the low yield obtained by operator, mainly in traditional olive orchards. A one section tractor hitched canopy shaker was developed at Córdoba University based on a eccentric system that drove two circular clusters of rods. It was tried in olive (Olea europaea L,) high density orchard 6 x 7.5 m spacing, located in Córdoba, southern Spain. All possible combinations between three shaking frequencies (3, 4 and 5 s^{-1}) and two speeds (0.21 and 0.35 m s^{-1}) were employed to harvest a fraction of each canopy sides of nine trees. Trees were characterized by measuring Fruit Detachment Force, Ripeness Index and Fruit Weight. Canopy shaker detached fruit was weighted and then, the collected canopy volume was exhausted manually to obtain the fruit detachment percentage. Mean fruit detachment percentages trended to increase while the shaking frequency got higher. It varied from 54.57 % obtained for 3 s^{-1} shaking frequency to 69.39 % provided by 5 s^{-1} shaking frequency. Significant differences were observed between these two values. Speed did not show significant differences in detached fruit, probably due to the narrow gap tried, though, between the two speeds, this parameter should be chosen depending on the maneuverability of the harvester, or the desired work capacity. The trials provided low levels of detached fruit, mainly due to the difficulty to detach fruit when the trials were carried out. Mean ripeness index was 3.92, and mean fruit detachment force/fruit weight ratio was 2 N/g. Besides the canopy shaker has a unique section of 0.5 m width, therefore, shaking energy transmitted to the canopy, were lower than if the tree were harvested shaking the whole canopy face at the same time in one wipe. However, debris values did not showed significant differences depending on the shaking frequency or the speed, due to it had a strong dependence on branches architecture or other factors of operation performance as shaker entry angle in the canopy, or the approximation of the detachment device. Mean debris fluctuated between 9.61 kg/100 kg harvested fruit provided for 3 s^{-1} and 25.03 kg/100 kg harvested fruit produced for 4 s^{-1} shaking frequency.

Keywords: Detached fruit, canopy comb, frequency, speed.

1 Introduction

Olive for oil crops are concentrated in south Europe and north Africa. The IOC foresights for 2013/14 harvesting season are that Mediterranean basin will produce 2,975,000 t of olive oil, while other countries will obtain only 123,000 t. Spain will harvest the highest olive oil quantity, 1,536,600 t, about 50 % of olive oil world production (IOC, 2014). However, Olive oil ob-

tained data from oil mills showed that until March 2014 Spain have produced 1,752,000 t (AICA, 2014).
Most of the olive orchard area in Spain is currently planted according to the traditional model two or several trunks per tree and wide spacing between trees. However, 24% of the area total olive growing area presents a major challenge to mechanized operations due to steep slopes. The majority of traditional olive tree orchards, 52% is considered suitable for mechanisation under traditional orchards. Only 22 % of the total olive area in Spain are high density groves (AEMO, 2012). Traditional olive orchards are usually established in dry-farmed areas and characterised by wide planting spacing (30 - 180 tree ha^{-1}) one or several trunks tree trained, wide irregularly shaped canopy and having many operations performed manually, resulting from that, low olive production by unit of ground area are obtained (1.1 - 4.5 t ha^{-1}), (Rallo *et al*., 2013). This production system has showed low levels of adaptation, conversion and mechanisation. As a consequence, production costs have been very high, reducing or eliminating the profitability of this crop (AEMO, 2012)
Traditional olive orchards has a lack of mechanized solutions for its integral harvesting, because since the trunk shaker, no new harvesting systems have been developed for olives (Gil-Ribes et al, 2009). Thus far, trunk shakers are the widest mechanized harvesting solution for traditional and high density olive orchards. The development and improvement of trunk shakers have made these machines more efficient (Barranco, Fernandez-Escobar, & Rallo, 2010) providing high harvesting efficiency values, as from 72 to 90 % in a Portuguese traditional olive orchard of 100 trees ha^{-1} (Dias et al., 2012) and 75.9 % provided by an Australian high density orchard of 357 trees ha^{-1} (Ravetti & Robb, 2010). A citrus canopy shaker provided 78.8 % harvesting efficiency in a Spanish traditional olive orchard, being similar to that obtained with manual harvesting in the areas where the rods are in contact with the tree canopy (Sola-Guirado *et al*., 2014).
The harvesting of traditional olive trees is difficult due to their complex structure and geometry and relies on several compatible technical solutions (Gil-Ribes et al., 2011), although there are no commercial solutions for an traditional olive groves integral harvesting. Operation performance could be improved by developing an integral canopy shaker combine, for instance canopy shaker harvesting system has been developed for citrus trees, increasing the harvesting yield 2 or 3 times with respect to the observed with trunk shakers and 15 times higher in relation to manual picking harvesting rate (Sanders, 2005), furthermore, canopy shaker harvesting systems improve the field capacity of traditional harvesting systems in traditional olive orchard to 0.25 - 0.30 ha h^{-1}, as reported for self-propelled trunk shaker, or 0.36 ha h^{-1} for a canopy shaker with a catch frame, both working in a traditional olive orchard (Agüera-Vega et al., 2013).
Canopy damages, known as debris, must be avoided during harvesting operation. The detachment of leaves, stems and branches has implications for the productive capacity of the trees (Wiesman, 2009). It also facilitates the transmission of disease and increases the cost of transport and processing of the product (Spann & Danyluk, 2010).
The main objective in this research is to characterize olive canopy shaking, determining the optimal shaking parameters to obtain a efficient labor performance.

2 Materials and methods

An experimental canopy shaker was designed at Cordoba University, adapted to harvest traditional and high density olive orchards (Figure 1). This machine provided an eccentric movement of 140 mm amplitude on their beating drums. It was mounted on a tractor rear fork lift by mean of a structure. This implement was coupled to the tractor 3 point hitch due to its lightness. The canopy shaker was powered by a T7.185, New Holland (CNH Global, Belgium) 103 kW power. Power requirements were composed by 3 point hitch lifting capacity, pulling force, and hydraulic power to operate de shaker. The main restriction was the tractor hydraulic flow, which was the reason to choose a high powered tractor, although the canopy shaker consumed much less power than the tractor provides.

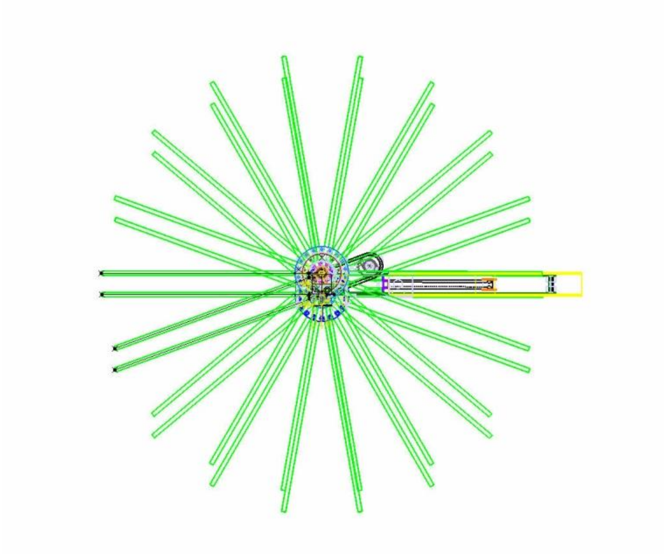

Figure 1: Schematic design of the one section canopy shaker.

Trials were conducted in a high density olive orchard (*Olea europaea* L.) cv. 'Picual' located in southern Spain (37º 48' 38'' N, 5º 6' 36'' W). Trees were one-trunk trained, with 5 mean scaffolds per tree. Trunk height was too short, complicating trunk shaker grabbing, for this reason, canopy shaking can be a good choice in this plantation, and even more in several trunk trained traditional olive orchards, where trunk shaker grabbing generates high time losses. Trees were 6 x 7.5 m spacing, with a canopy volume oscillating between 25 and 35 m^3. In the Table 1, other fruit parameters are showed.

Table 1: Fruit parameters in the harvested plot.

	FDF* (cN)	Fruit weight (g)	FDF/Peso (cN/g)	RI**	FDF < 300 cN*** (%)
Mean	424	2,61	168	3,85	14,8
Standard deviation	82	1,24	68	0,33	15,1

* FDF: Fruit detachment force.

** RI: Jaén ripeness index.

*** FDF < 300 cN: Fruit percentage under 300 cN fruit detachment force.

18 trees were chosen, nine of them were harvested using steel rods, and the rest of them were shook using glass fiber rods. Two sides of the canopy were considered separately to harvest a tree, the harvesting performance consist on the shaker made a round one side linearly, brought the detaching device as close as it were possible. Three shaking frequencies were tested, 3, 4 and 5 s^{-1} applying the same frequency to the both sides of a canopy in each tree. In addition, two different tractor speeds were employed (0.21 and 0.35 m s^{-1}), one in each tree side.

Detached fruit were harvested and weighted. Also thrown fruit were collected with a plastic net extended on the soil in the opposite side that the one was being harvested in each wipe, and weighted. Generated debris was weighted for each round in each tree after harvest. Finally, fruits remained on shook canopy volume were exhausted and weighted to determine canopy shaker harvesting efficiency.

Tree structure was also considered. It was characterized by two methods: The first one consists on separate tree main branches in three groups depending on their growing habit, vertical limbs (VL), horizontal limbs (HL) and hanging limbs (HL), which were those ones that fad a crotch angle over 180 º. These groups were assigned a value to calculate a mean verticality value for each round (Equation 1). The second method was based on horizontal and vertical measurements between the first limb crotch along the main limbs, and the next crotch in the inserted branch. These measurements allowed calculating the angle between the branch and the horizontal line (Figure 2). To characterize trees, using the second method, mean value of all shook branches in one round along a canopy side, was calculated.

$Verticality = (VL * 2 + HL)/(VL + HL + HL)$ Equation 1

SPSS (IBM, Armonk, NY, USA) were used for the statistical analyses.

Figure 2: Measuring inclination method to calculate horizontal branch angle.

3 Results

Steel rods have provided significant differences between the three tested frequencies, while glass fiber rods only have showed significant differences between 3 and 5 s^{-1} shaking frequency (Figure 3). Tested rod materials only provided significant differences for 5 s^{-1} shaking frequency (Figure 4). At low frequencies, harvesting efficiency was very similar for both materials. Certain combination of frequency and amplitude are needed to reach adequate harvesting efficiency rates (Torregrosa, Cuenca, & Ortiz, 2012), however, there are many vibration patterns that can obtain high amount of detached fruits by means of very different vibration patterns (Sola-Guirado et al., 2014). Highest tested frequency was four times under tree structure natural frequencies according to Castro-García, Blanco-Roldán, Gil-Ribes, & Agüera-Vega (2008).

Reported harvesting efficiency values ranging from 54 to 82 %, slightly lower values than 89 to 86 % described by Ravetty, & Robb (2010) in an intensive olive orchard cv. 'Frantoio' using a commercial straddle canopy shaker. Other authors have achieved high harvesting efficiency values using a whole canopy shaker prototype, Vieri & Sarri (2010) obtain 80 – 85 % harvesting rate in cultivars that usually have high FRF values, as cv. 'Moraiolo'.

The trials provided low levels of detached fruit, mainly due to the difficulty to detach fruit when the trials were carried out. Mean ripeness index was 3.92, and mean fruit detachment force/fruit weight ratio was 2 N/g. As the canopy shaker has only 0.5 m height, therefore, shaking energy transmitted to the canopy, were lower than if the tree were harvested shaking the whole canopy face at the same time in one round.

Rod material slightly influenced harvesting efficiency, and did not affect debris production. Steel was stiffer than glass fiber, though the first one has lower elastic limit than steel. This stiffness increase the harvesting efficiency achieved using steel rods related to glass fiber rods. However previous research showed that there are no significant differences between steel rods and glass fiber rods in terms of acceleration and time that the acceleration values are over a threshold (Blanco-Roldán *et al*., 2013)

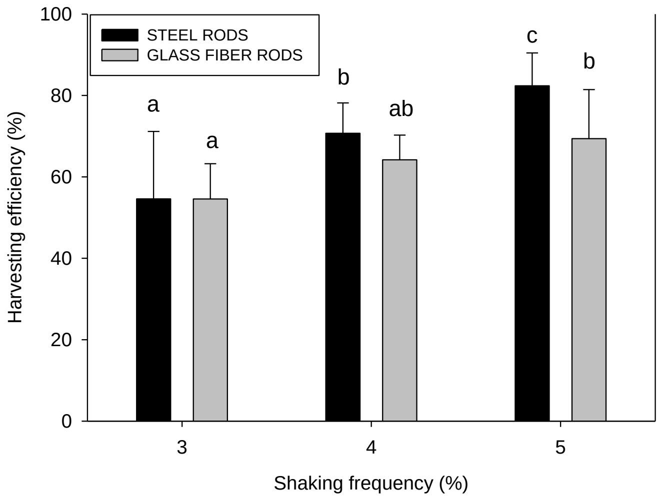

Figure 3: Harvesting efficiency depending on the rod material and the shaking frequency. Different letters show significant differences (ρ<0.05) between shaking frequencies according to Kruskal-Wallis non parametric test.

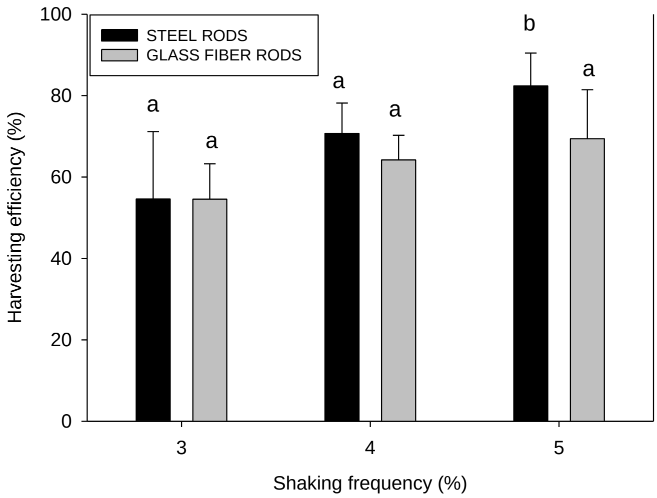

Figure 4: Harvesting efficiency depending on the rod material and the shaking frequency. Different letters show significant differences (ρ<0.05) between rod materials according to Kruskal-Wallis non parametric test.

Debris was a rather random performance, showing high deviation values. It did not provide significant differences for any considered variable, either shaking frequency, rod material or speed (Table 2). In other crops such as vines, canopy shaker harvesting influenced debris production depending on shaking frequency (Pezzi & Caprara, 2009), however in this research these differences cannot be found. It was probably due to olive tree structure variability, and maneuverability difficulties, since tractor + 3 m long hanging machine make difficult to move along the plantation alleys. Above of all, The canopy shaker produced more debris quantity than trunk shaker employed without complementary beating (1 – 5 kg/100 kg harvested fruit), but it is lower than the debris produced when complementary beating was used along trunk shaker (15 - 30 kg/100 kg harvested fruit).

For the tested canopy shaker mechanism, speed did not show significant differences either for detached fruit or debris production, probably due to the narrow gap tried, therefore, between the two speeds, this parameter should be chosen depending on the maneuverability of the harvester, or the desired work capacity. Authors spected that speed strongly influence harvesting efficiency and labour performance. Further researchs are needed, testing wide ranges of this parameters to ensure its influence on canopy shaking.

Table 2: Weighted debris for each value of tested variables. Values are mean ± Standard deviation.

Frequency test		Rod material test		Speed test	
Frequency (s^{-1})	Debris (kg/ 100 fruit kg)	Rod material	Debris (kg/ 100 fruit kg)	Speed ($m\ s^{-1}$)	Debris (kg/ 100 fruit kg)
3	10.48 ± 6.04	Steel	8.85 ± 6.73	0.21	13.66 ± 11.82
4	16.32 ± 14.69	Glass fiber	18.37 ± 15.19	0.35	13.56 ± 13.57
5	14.13 ± 15.15				

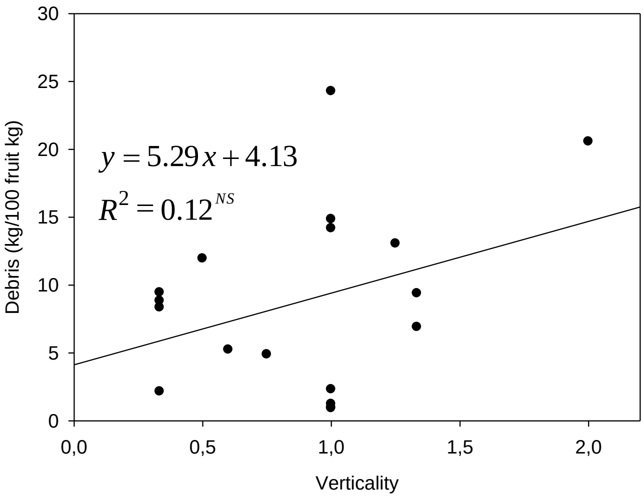

Figure 5: Lineal regression between produced debris and tree structure verticality.

Thrown fruit was indiscernible, its mean value was 0.15 kg per tree side, representing around 3 % of total harvested fruit. Avoid fruit losses after fruit detaching is highly important, because it has to be caught by an structure designed to that purpose, and to facilitate machine maneuverability, detaching and catching devices grouped has to be as small as possible.

Tree structure had not significant influence either on harvesting efficiency or debris. Debris showed a slightly trend related to tree verticality. The more vertical was tree structure more debris has collected from harvested fruit (

Figure ***5***), however these results did not provide significant results. However, it could be perceived that a non significant slightly trend existed between debris production and tree structure. The less vertical was the tree structure, the less debris produced the canopy shaker, although further research and more replications are needed to demonstrate this relationship.

In many crops, mechanical harvesting increase debris production related to manual harvesting, for instance, in hand harvested citrus, canopy shaker harvesting multiplies by 2.5 times debris production (Spann, & Danyluk, 2010). In oil olives, that argument lacks foundations, because manual harvesting usually is performed using long poles that strike the tree canopy, therefore if the operator is not properly trained, debris production will be higher than mechanized harvesting methods.

4 Conclusions

An eccentric canopy shaker system is feasible to detached oil olives in order to catch fruits during their falling. In this way, it is possible to develop lateral integral harvester which do not need coverage to avoid fruit projection far from the catch frame.
According the results, high density olive orchards can be harvested using a canopy shaker by means on a eccentric group of rods device. It must perform with a 5 s^{-1} shaking frequency and steel rods to reach the maximum harvesting efficiency rate, however it was desirable to improve glass fiber rods harvesting efficiency in order to introduce a flexible material to beat the tree canopy.
Further research are needed to determine the optimal harvesting speed and adequate tree structure to make integral harvesting by canopy shaker feasible in traditional and high density olive orchards.

5 Acknowledgements

The authors thank the Ministry of Economy and competitiveness of the Spanish government for economic support by the pre-commercial procurement Mecaolivar project. The second author thank for the support of the Spanish Ministry of Education, Culture and Sport for its financial support through the National Training Program of University Lecturers (FPU). Also, we appreciate Spanish olive oil inter-trade support.

6 References

AEMO. Asociación Española de Municipios del Olivo. (2012). Aproximación a los costes del cultivo del olivo. Available at www.aemo.es, last accessed 08.05.2014.

Agüera-Vega, J., Blanco-Roldán, G. L., Castillo, F. J., Castro-Garcia, S., Gil-Ribes, J. A., & Perez-Ruiz, M. (2013). Determination of field capacity and yield mapping in olive harvesting using remote data acquisition. In J. Stafford (Ed.), Precision agriculture '13 (pp. 691-696). Wageningen: Wageningen Academic Publishers.

AICA. Agencia de información y control agroalimentario. (2014). Información de mercados. Producción. Available at www.magrama.gob.es, last accessed 08.05.2014.

Barranco, D., Fernandez-Escobar, R., & Rallo, L. (2010). Olive growing (1st ed.). Madrid: Mundi-Prensa - Junta de Andalucía - Australian Olive Association Ltd.

Blanco-Roldán, G. L., Castillo-Ruiz, F. J., Sola-Guirado, R. R., Jiménez-Jiménez, F., Agüera-Vega, J., Castro-García, S., & Gil-Ribes, J. A. (2013). Análisis de la interacción de las varas del sacudidor de copa en el árbol para la recolección mecanizada del olivar de almazara. In Proceedings of the sixteenth scientific-technical symposium EXPOLIVA 2013. Jaen, Spain.

Castro-García, S., Blanco-Roldán, G. L., Gil-Ribes, J. A., & Agüera-Vega, J. (2008). Dynamic analysis of olive trees in intensive orchards under forced vibration. Trees, 22, 795-802.

Gil-Ribes, J. A., Blanco Roldán, G. L., & Castro García, S. (2009). Mecanización del cultivo y de la recolección en el olivar (Olive growing and harvesting mechanization). Andalusian regional goverment. Ministry of agriculture and fisheries.

Gil-Ribes, J. A., Blanco-Roldán, G. L., Castro-García, S., Agüera-Vega, J., Muñoz Tejada, R., Jiménez-Jiménez, F., et al. (2011). Introducción de un sistema sacudidor de copa para la recolección mecanizada del olivar tradicional de almazara. In Proceedings of the fifteenth scientific-technical symposium EXPOLIVA 2011. Jaen, Spain.

IOC. (2014). Areas of activity. Economic. World olive oil figures. Available at www.internationaloliveoil.org, last accessed 08/05/2014.

Pezzi, F., & Caprara, C. (2009). Mechanical grape harvesting: investigation of the transmission of vibrations. Biosystems Engineering, 103(3), 281-286.

Rallo, L., Barranco, D., Castro-Garcia, S., Connor, D. J., Gómez del Campo, M., & Rallo, P. (2013). High-density olive plantations. In J. Janick (Ed.), Horticultural Reviews (Vol. 41) (pp. 303-384). New York: Wiley-Blackwell.

Ravetti, L., & Robb, S. (2010). Continuous mechanical harvesting in modern Australian olive growing systems. Advances in Horticultural Science, 24(1), 71-77.

Sola-Guirado, R. R., Castro-García S., Blanco-Roldán, G. L., Jiménez-Jiménez, F., Castillo-Ruiz, F. J., & Gil-Ribes, J. A. (2014). Traditional olive tree response to oil olive harvesting technologies. Biosystems engineering, 118, 186–193.

Spann, T. M., & Danyluk, M. D. (2010). Mechanical harvesting increases leaf and stem debris in loads of mechanically harvested citrus fruit. HortScience, 45(8), 1297-1300.

Torregrosa, A., Cuenca, A., & Ortiz, C. (2012). Detachment of orange fruits with a low frequency and high amplitude shaker. In AgEng2012, international conference of agricultural engineering. Valencia, Spain.

Vieri, M., & Sarri, D. (2010). Criteria for introducing mechanical harvesting of oil olives: results of a five-year project in Central Italy. Advances in Horticultural Sciences, 24(1), 78-90.

Wiesman, Z. (2009). Desert olive oil cultivation. Advanced biotechnologies (1st ed.). Oxford: Academic Press.