Evaluation of the Ground Speed Effect on the Performance of the Row-Side Continuous Canopy Shaking Harvester Prototype in a High-Density Olive Grove

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Abstract:
In 2009 authors begin the development of the Row-Side Continuous Canopy Shaking Harvester (RSCCSH) prototype. The prototype comprises two symmetrical harvesters trailed by a farm tractor. Each harvester has a vibratory rotor with flexible rods, a catching platform with conveyors belts and a temporary storage bag. The detachment efficiency of canopy shakers are influenced by shaking frequency, ground speed and olive canopy characteristics.
Between 2015 and 2017 a trial to evaluate the ground speed effect in the performance of the RSCCSH was carried out. The trial was established in an irrigated olive orchard of Picual variety planted with the array 7m x 3.5m. In a randomly design with three replications, the following treatments were evaluated: V400 - ground speed of 0.4 kmh^{-1}; V600 - ground speed of 0.6 kmh^{-1}; V800 - ground speed of 0.8 kmh^{-1}; V1000 – ground speed of 1.00 kmh^{-1}; V750 - ground speed of 0.75 kmh^{-1}; V910 - ground speed of 0.91 kmh^{-1}.
Olive detachment efficiency tends to decrease with an increase in ground speed.
No significant differences were found between treatments in olive losses to the ground.
The best option in terms of harvesting rate (kgh^{-1}) will correspond to the interval between 600 and 800 mh^{-1}.

Keywords: canopy, shaker, efficiency.

1. Introduction

In Portugal there are about 377 thousand hectares of olive groves [0] of which 33% are high-density groves [1].

Olive harvest in high density olive orchards is usually performed by a tractor mounted trunk shaker and a canvas manually placed on the ground under the tree. Less labour demanding solutions based on inverted umbrellas linked to the trunk shaker have limited use since trees are very closely spaced to allow the umbrella to open.

Only changing from a discrete trunk shaking to a continuous canopy shaking principle will improve working capacity and will reduce the dependency over scarce and expensive labour.

The increase in the area of new olive groves that occurred in the first decade of 21st century in Portugal led to testing alternative harvesting solutions. The use of the Colossus straddle harvester proved to be inappropriate as it is a machine too heavy and expensive, hardly suitable to the difficult wet soil conditions encountered in Portugal.

A row-side, instead of over-the-row, concept imposing fewer limitations on tree growth is a technique bound for high-density olive groves and may even be adequate for the large trees of the traditional non-irrigated orchards [2].

In 2009 the authors started the development of the Row-Side Continuous Canopy Shaking Harvester – RSCCSH prototype [3].

This paper presents and discusses the results of research conducted on a 20-year-old intensive olive grove to evaluate the influence of ground speed in the performance of the RSCCSH prototype.

2. Material and Methods

2.1. Olive grove

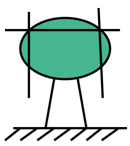
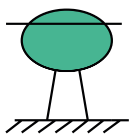
The high-density olive orchard (HD) used in the trial was established in 1996 in Herdade da Torre das Figueiras in the Alentejo region of southern Portugal (lat. 39º 03′ 34.04′′ N; 07º 28′ 22.00′′ W). This drip irrigated HD olive orchard of Picual cultivar was installed in an array of 7m x 3.5m.

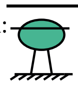
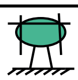
The orchard was planted on Chromic Luvisol soil (FAO). This region is semi-arid with strong continental influence and an annual rain mean of 500 mm concentrated in the winter.

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

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.
Table 1 shows the pruning interventions carried out in this olive grove between 2014 and 2017.

Table 1. Sequence of pruning interventions made in the olive grove between 2014 and 2017.

2014	2015	2016	2017
	No pruning	Manual pruning	

Legend:  

- mechanical pruning ("topping"); - mechanical pruning ("topping" + "hedging").

2.2. Equipment

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 [3].

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 [4]. Table 1 show the operational parameters of RSCCSH in each harvesting season.

Figure 2 – Row-side continuous canopy shaker prototype

In 2015 and 2016 tractors with continuously variable transmission (CVT) were used while in 2017 a tractor with powershift transmission had to be used (Table 2).

Table 2 – Tractors used to tow the RSCCSH prototype in each season

Harvesting season	2015	2016	2017
Tractor used in left unit	Fendt 714 Vario	Fendt 313 Vario	Fendt 313 Vario
Tractor used in right unit	Fendt 313 Vario	Fendt 714 Vario	Kubota 135 GXIII
PTO of left unit (*rpm*)	500	540	540

PTO of right unit (*rpm*)	500	540	540

2.3. Treatments

In the period from 2015 to 2017, the effect of ground speed on the performance of the RSCCSH prototype in olive harvesting was evaluated, and the following treatments were defined:

- V400 – a ground speed of the RSCCSH prototype of 0.4 kmh^{-1}
- V600 - a ground speed of the RSCCSH prototype of 0.6 kmh^{-1}
- V800 - a ground speed of the RSCCSH prototype of 0.8 kmh^{-1}
- V1000 – a ground speed of the RSCCSH prototype of 1.08 kmh^{-1}
- V750 - a ground speed of the RSCCSH prototype of 0.75 kmh^{-1}
- V910 - a ground speed of the RSCCSH prototype of 0.91 kmh^{-1}

Table 3 show the different ground speed of the RSCCSH prototype tested in the period between 2015 and 2017.

Table 3. Treatments evaluated in each year.

2015	2016	201
V400	V600	V750
V600	V800	V910
V800	V100	

In 2017, the need to use the Kubota 135GX III (Table 1) led to defined the treatments being defined according to the ground speed obtained in this tractor:

- V750 - 1st speed in the slow range with engine rotation that guarantees 540 rpm in the PTO. In the Fendt tractor was selected equal working speed for an engine rotation that ensures 540rpm in the PTO;

- V910 - 2nd speed in the slow range with engine rotation that guarantees 540 rpm in the PTO. In the Fendt tractor was selected equal working speed for an engine rotation that ensures 540rpm in the PTO;

In 2015, 12 olive grove rows were selected and randomly distributed for each treatment (table 4).

Table 4. Distribution of the olive rows by treatment

Olive row	Number of trees	2015	2016	2017
1	37	V600	V600	V750
2	41	V800	V800	V910
3	41	V400	V1000	V910
4	42	V800	V800	-
5	39	V600	V1000	V910
6	34	V400	V600	V750
7	31	V400	V1000	V910
8	33	V800	V800	V750

9	31	V600	V600	V750
10	29	V600	V600	V750
11	29	V400	V1000	V910
12	27	V800	V800	V750

2.4 Assessments

The time spend to harvest each plot was recorded. 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 per tree 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:

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

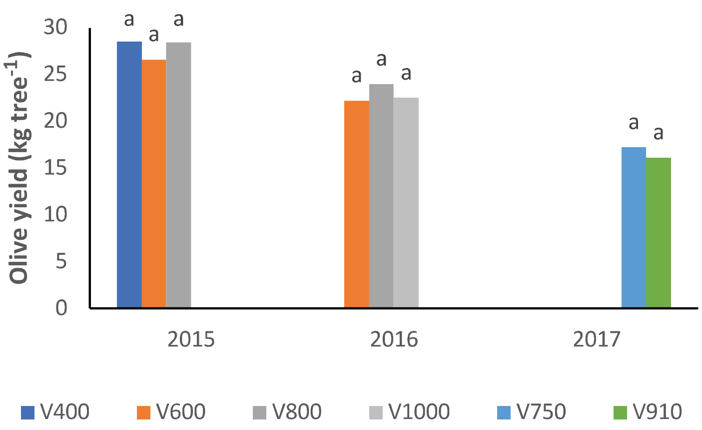
One-Way Analysis of Variance was performed to annual data and GLM Univariate Analysis for average data, using IBM SPSS version 24 software. Mean separation was performed by Multiple Range Duncan test at 5% significance level.

3. Results and Discussion

3.1. Olive yield

Figure 2 shows the average yield of olives per tree by treatment in each year. As the same pruning intervention were made all the treatments, in each year, no significant differences (P>0.05) were registered between treatments in each year.

The pruning interventions applied by the farmer may have contributed to the variation in olive yield between years.



Legend: V400 – ground speed of 400 mh^{-1}; V600 - ground speed of 600 mh^{-1};

V800 - ground speed of 800 mh^{-1}; V1000 - ground speed of 1000 mh^{-1};

V750 - ground speed of 750 mh^{-1}; V910 - ground speed of 910 mh^{-1}

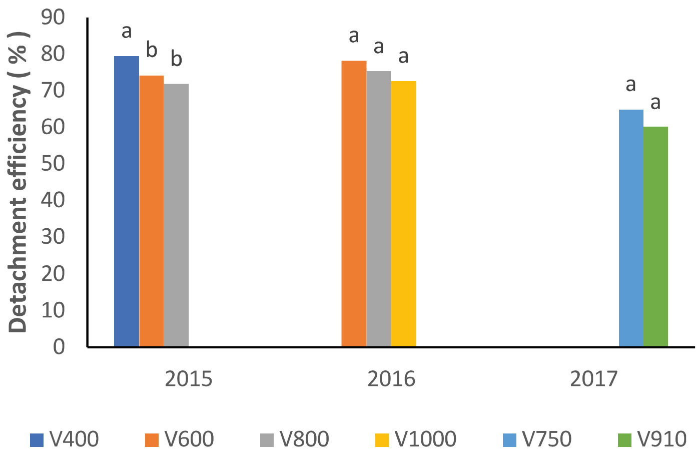
In each year, columns followed by the same letter are not significantly

different by Duncan multiple range test at the 5% level

Figure 2. Average olive yield by treatment in each year.

3.2. Olive detachment efficiency

Figure 3 shows the olive detachment efficiency obtained by treatment in ach year. The results shows that there is a tendency to reduce the detachment efficiency as the ground speed increase, although in 2015 there were significant differences ($P<0.05$) between treatments .



Legend: V400 - ground speed of 400 mh^{-1}; V600 - ground speed of 600 mh^{-1};

V800 - ground speed of 800 mh^{-1}; V1000 - ground speed of 1000 mh^{-1};

V750 - ground speed of 750 mh^{-1}; V910 - ground speed of 910 mh^{-1}

In each year, columns followed by the same letter are not significantly

different by Duncan multiple range test at the 5% level

Figure 3. Average olive detachment efficiency by treatment in each year.

The decrease in detachment efficiency with the increase of the ground speed could be due to the reduction of the vibration time, as mentioned by conforme referem Aragon e catro cit Castro.
This is due to the fact that a higher foward speed corresponds to a shorter period of contact between the flexible rods of the vibratory rotor and the olive canopy.
In canopy shakers, the interaction between rods and canopy is essential to ensure good fruit detachment. According to [4, 5] the zones of the canopy with less penetration of the rods receive lees aceleration, leading to less fruit detachment.

3.3. Olive losses

Figure 4 shows the losses of olives to the ground by treatment in each year. Although there was a slight decrease in the losses to the ground between 2015 and the other years, there were no significant differences ($P>0.05$) between treatments.

Olive losses to the soil can be caused by:

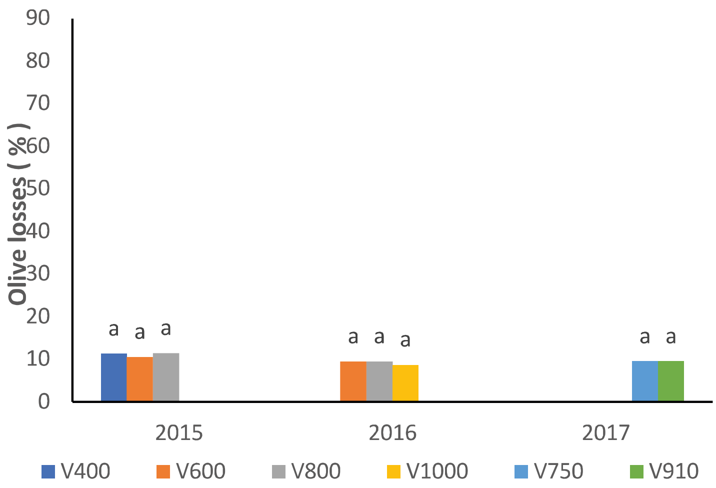
- an inadequate positioning of the machine-olive trunk interface, which is controled by an auxiliary operator;
- in the transition between conveyor belts.

Since it is the auxiliary operator who adjust the position of the machine to the tree row, when occur an increase in the forward speed, greater control of the deviations of the prototype to the tree row is required.

In 2016 and 2017, the decrease in the olive losses to the ground could be due to the higher experience of the auxiliar operators.

The losses of olives to the ground obtained was higher than those registered by straddle harvesters in hedge olive groves. To obtain lower straddle harvesters losses requires an adequate control of canopy distance to the soil.

In the RSCCSH it is necessary to improve the catching and transport system since a considerable part of the losses occurs in tne transition between conveyor belts.



Legend: V400 - ground speed of 400 mh^{-1}; V600 - ground speed of 600 mh^{-1};

V800 - ground speed of 800 mh^{-1}; V1000 - ground speed of 1000 mh^{-1};

V750 - ground speed of 750 mh^{-1}; V910 - ground speed of 910 mh^{-1}

In each year, columns followed by the same letter are not significantly

different by Duncan multiple range test at the 5% level

Figure 4. Average olive losses to the ground by treatment in each year**.**

3.4. Harvesting rate of RSCCSH

To calculate the harvesting rate of the RSCCSH the following assumptions were used:

- olive grove of Picual variety planted in the array of 7m × 3.5m;

- olive row with 64 trees (average number of trees by row in the olive grove);

- headland time spend by RSCCSH in average = 4 minutes;

- RSCCSH temporary storage capacity in *"big bags"* = 400*kg*;

- time required for changing *"big bags"* = 1 minute.

Table 5 shows the estimation of the harvesting rate by treatment in 2015.

Although the higher harvest yield by tree in treatment V400, a greater harvesting rate is obtained in the V800 treatment, due to the higher ground speed.

Table 5. Estimation of harvesting rate per treatment in 2015

Treatments	**Olive by tree** (kg)	**Trees by *"big-bag"***	**Stops**	**Harvest time** (min)	**Total time** (min)	**Harvesting rate** (tree hour^{-1})	**Harvesting rate** (kg hour^{-1})
V400	19.4	20	3	32.4	39.4	97.5	1891.5
V600	16.9	23	3	21.5	28.5	134.7	2276.4
V800	17.2	23	3	17.5	24.5	156.7	2695.2

Legend: Olive by tree - average olive yield harvested by tree; Trees by *"big-bag"* - number of trees required for changing "big-bag"; Stops – number of stops for changing "big-bag" by olive row; Harvest time – harvesting time spend by olive row; Total time – harvest time + time required for stops + headland time spend by RSCCSH

Table 6 shows the estimation of the harvesting rate by treatment in 2016.

The olive harvested per tree was lower in treatment V1000, while the V600 and V800 treatments obtained similar values. As a consequence, the harvesting rate of treatment V800, in kg of olives harvested per hour, was higher that that recorded in treatment V600 and with values nearest of those registered in the treatment V1000.

Table 6. Estimation of harvesting rate per treatment in 2016

Treatments	**Olive by tree** (kg)	**Trees by *"big-bag"***	**Stops**	**Harvest time** (min)	**Total time** (min)	**Harvesting rate** (tree hour^{-1})	**Harvesting rate** (kg hour^{-1})
V600	15.3	26	2	23.7	29.7	129.3	1978.3
V800	15.8	25	2	18.5	24.5	156.7	2475.9
V1000	13.6	29	2	14.7	20.7	185.5	2522.8

Legend: Olive by tree - average olive yield harvested by tree; Trees by *"big-bag"* - number of trees required for changing "big-bag"; Stops – number of stops for changing "big-bag" by olive row; Harvest time – harvesting time spend by olive row; Total time – harvest time + time required for stops + headland time spend by RSCCSH

Table 7 shows the estimation of the harvesting rate by treatment in 2017.

The mass of olives harvested per tree was slightly higher in treatment V750, contributing to obtain a higher harvesting rate (kg of olives by hour) in this treatment.

Table 7. Estimation of harvesting rate per treatment in 2017

Treatments	Olive by tree (kg)	Trees by *"big-bag"*	Stops	Harvest time (min)	Total time (min)	Harvesting rate (tree hour^{-1})	Harvesting rate (kg hour^{-1})
V750	9.5	42	1.5	18.3	23.8	161.3	1532.4
V910	8.1	49	1.3	15.3	20.6	186.4	1509.8

Legend: Olive by tree - average olive yield harvested by tree; Trees by *"big-bag"* - number of trees required for changing "big-bag"; Stops – number of stops for changing "big-bag" by olive row; Harvest time – harvesting time spend by olive row; Total time – harvest time + time required for stops + headland time spend by RSCCSH

4. Conclusions

An increase in the ground speed of the RSCCSH results in a decrease in the olive detachment efficiency. An increase of the forward speed beyond 750-800 mh^{-1} reduces considerably the harvesting rate due to the lower olive detachment efficiency.

The decision between 600 mh^{-1} and 800 mh^{-1} will depend on the choice between greater olive detachment and faster harvesting. At the beginning of the campaign the first option could be privileged progressively increasing the forward speed towards the end of the campaign.

5. Thanks

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