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Strategies to reduce mechanical harvesting costs in traditional olive orchards

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Abstract

Olive harvesting mechanization is adopted in different types of olive orchards: traditional, intensive, in hedgerows.

In Mediterranean basin, traditional olive orchards have an important economic value. In this type of olive orchards planting densities are 100 to 240 trees per hectare, and over 30 years old.

In these olive orchards, the most used mechanical harvesting system is based on a trunk shaker to detach fruits, and an inverted umbrella to collect them.

With this harvesting system it is usual to collect 70% to 90% of the production.

The olives that remain in the tree is a problem. To solve it, farmers adopt manual harvesting as a complementary task.

This procedure increases the cost of harvesting with the addition of labour and reduces the mechanical harvesting system work rate (trees hour⁻¹).

It is important to understand if this complementary manual harvesting is advantageous or not.

In field tests carried out in the Northeast of Portugal on traditional olive orchards with “Cobrançosa” and “Verdeal Transmontana”, cultivars, two different procedures were compared: (I) mechanical harvest performance complemented by manual harvesting; (II) mechanical harvest performance without the addition of manual work.

In both procedures were evaluated: a) work rate (trees hour⁻¹); b) production harvested; b) associated costs; c) harvest efficiency considering it as the percentage of fruits collected in relation to total production.

To evaluate work rate system, a methodology based on measurement of each elementary operation time (in minutes) was adopted.

Costs was computed under international standards for agricultural machinery management.

The reduction in work rate and the increase in harvesting costs with complementary harvesting may be balanced by the increase in production that is harvested in this way. However, this does not seem to be the case, given the results presented.

Complementary manual harvesting may be a solution, but an evaluation of other agronomic and mechanical solutions is recommended.

Keywords: olive orchard; mechanization; trunk shaker; costs; labour.

1. Introduction

The mechanical harvesting system mostly adopted in traditional olive orchards in the Northeast of Portugal consists on a trunk shaker to detach olives and an inverted umbrella to collect fruits, both mounted on the front loader of four-wheel drive tractors of 70 kW to 95 kW.

In these olive orchards planting densities range from 100 to 240 trees per hectare, and are over 30 years old.

With this harvesting system, the entire production is not removed from the olive trees.

It is usual to harvest 70% to 90% of the olives (Sola-Guirado et al, 2018). Harvesting 80% to 85% of production is already a reasonable objective (Castro-Garcia et al, 2012).

It is important to improve the mechanical harvesting efficiency, considering it as the percentage of fruits removed in relation to total production (Ferguson 2006), (Ravetti et al 2014), in order to obtain a better net return for farmers.

Harvest efficiency is one of the most important factors to consider on mechanical harvesting olives for olive oil (Ferguson 2006).

To avoid this loss of production, farmers usually adopt traditional manual harvesting methods to remove the olives that remain on the tree, after the trunk shaker work.

This procedure improves harvesting cost: (I) by the increase in labour and (II) by the reduction of mechanical harvesting system work rate (trees hour⁻¹). This reduction in work rate is a consequence of the time required for manual harvesting.

It is important to assess if olives manual removal remaining on the tree after the trunk shaker work has a compensatory cost.

With this objective field tests were carried in the Northeast of Portugal on traditional olive orchards with “Cobraçosa” and “Verdeal Transmontana” cultivars, to evaluate the work rate (trees ha⁻¹) of this harvesting system, through the measurement of each elementary operation time.

In these field tests harvest system performance was compared: (I) without supplementary manual harvesting; (II) with the addition of manual harvesting and in this case evaluated the increase in production harvested.

In both procedures were evaluated: a) work rate (trees hour⁻¹); b) production harvested; b) associated costs; c) harvest efficiency considering it as the percentage of fruits collected in relation to total production.

The results can contribute to a better decision-making by farmers.

2. Materials and Methods

Field tests took place in Portugal - Trás-os-Montes region from 2018 to 2020 in irrigated olive orchards with the cultivars “Cobraçosa” and “Verdeal Transmontana”, with 200 trees per hectare, spaced 7 m x 7 m (Figure 1).



Figure 1. Olive orchard example used in field trials

Tests were carried out in four different olive orchards (L1; L2; L3 and L4). L1 and L2 in 2018 (L1A and L2A) and 2019 (L1B and L2B). In 2020, the tests were carried out in olive groves L3 and L4.

Olive orchards L1, L2 and L4 are “Cobraçosa” cultivar. L3 olive orchard is “Verdeal Transmontana” cultivar.

In L1 olive orchard there were 3 replications in randomized blocks in each of the years considered (2018 and 2019). In L2 olive orchard there were 2 replications in randomized blocks in each of the years considered (2018 and 2019). In L3 olive orchard there were 3 replications in randomized blocks (in 2020). In L4 olive orchard there were 2 replications in randomized blocks (in 2020).

The harvesting system is based on a trunk shaker to detach the olives and an inverted umbrella to collect them. The inverted umbrella can temporarily store 200 to 250 kg of olives in a collecting tray. Under the inverted umbrella a door can be hydraulically opened to allow unload the olives.

Four-wheel drive tractors of 70 to 95 kW were used.

To assess harvesting system work rate, the following elementary operation time were measured in

minutes:

T_{vib} – average trunk shaking time;

T_{var} – average additional manual harvesting time;

T_{vibVar} – average trunk shaking time and complementary manual harvesting simultaneously;

T_{desloc} – average time to move the tractor with trunk shaker from one tree to the next;

$T_{limpfolhas}$ – average time for cleaning leaves accumulated on the inverted umbrella;

$T_{desclinha}$ – average tractor travel time, from one headland to the other. Farmer's option due to the slope of the olive orchard greater than 10%. Traveling in reverse from the higher level headland to the lower level headland;

T_{desc} – average time to discharge the inverted umbrella;

N_a – number of trees between inverted umbrella discharges.

Work rate harvesting system (trees hour⁻¹) was computed by the following equation Eq (1):

$$Ct = \frac{3600}{T_{vib} + T_{var} + T_{vibVar} + T_{desloc} + T_{limpfolhas} + T_{desclinha} + \frac{T_{desc}}{N_a}} \quad (1)$$

In each field test not all of the elementary operation referred in the equation were used. In cases where any of the elementary operation was not recorded, it was not considered in the equation.

In each of the olive orchard, per replication, the quantity of olives harvested was evaluated.

In order to evaluate harvest efficiency, in olive orchards L1, L2 and L4, the amount of olives that remained in the tree after shaking was evaluated. This assessment was carried out by randomly choosing 1 tree in every 10. In cases where additional manual harvesting was used, this procedure was interrupted in the trees selected for this assessment.

In order to estimate the cost kg⁻¹ of mechanical harvesting without manual complementary harvesting and with manual complementary harvesting after and during mechanical shaking, the following assumptions were adopted:

Cost hour⁻¹ of trunk shaker, inverted umbrella and operator = € 75.

Labour cost for additional harvesting (1 operator) = € 6.25 hour⁻¹.

Figure 2 shows the complementary manual harvesting procedure.



Figure 2. Complementary manual harvesting procedure

In 2018, replications of three of the olive orchards, L1 (L1AR1; L1AR2; L1AR3), L2 (L2AR1; L2AR2) and in 2020 in L3 (L3R1; L3R2) the harvest was carried out with complementary manual harvesting. In 2019, replications of four of the olive orchards, L1 (L1BR1; L1BR2; L1BR3), L2 (L2BR1; L2BR2) and in 2020 in L3 (L3BR3) and L4 (L4R1; L4R2) the harvest was carried out without additional manual harvesting.

3. Results

Tables 1 and 2 show the results obtained in olive orchards where harvest was carried out using complementary manual harvesting.

Table 3 shows results obtained in olive orchards where harvest was carried out without additional manual harvesting.

Table 1. Olive orchards with manual complementary harvesting: total production and per tree; measured and estimated work rate without manual harvesting and harvest time per tree. In the “work rate” and “minutes per tree” columns, the maximum and minimum values are marked in bold.

Orchard	Total production (kg)	kg tree ⁻¹	Work rate (tree hour ⁻¹)	Minutes tree ⁻¹	Estimated work rate without manual harvesting (trees hour ⁻¹)
L1AR1	1511	30.2	33.10	1.81	52.41
L1AR2	1215	21.7	37.94	1.58	50.68
L1AR3	2143	33.5	34.36	1.75	46.34
L2AR1	905	18.1	15.22	3.94	20.70
L2AR2	638	10.6	22.72	2.64	29.22
L3R1	920	17.4	14.27	4.20	17.55
L3R2	750	14.2	10.96	5.47	13.63
Average		20.81	24.08	3.06	32.93

Table 2. Olive orchards with manual complementary harvesting: production by manual harvesting, harvesting efficiency, costs kg⁻¹ of total harvested production, estimated costs kg⁻¹ without complementary manual harvesting and costs kg⁻¹ of production harvested by complementary manual harvesting. In columns 2, 3 and 6, the maximum and minimum values are marked in bold.

Orchard	Production by manual harvesting (kg)	Harvesting efficiency (%)	Costs kg ⁻¹ of total harvested production, (€)	Estimated costs kg ⁻¹ without manual harvesting (€)	Costs kg ⁻¹ of production harvested by manual harvesting (€)
L1AR1	82.5	94.5	0.07	0.05	0.52
L1AR2	58.24	95.2	0.07	0.07	0.07
L1AR3	65.92	96.9	0.06	0.05	0.45
L2AR1	130	85.6	0.17	0.14	0.66
L2AR2	100.8	84.2	0.23	0.22	0.76
Average		91.28	0.12	0.11	0.49

Table 3. Olive orchards without complementary harvesting: total production and production per tree, harvesting efficiency, work rate, harvesting time per tree and costs kg⁻¹ of harvested production. In columns 4, 5 and 6, the maximum and minimum values are marked in bold.

Orchard	Production harvested (kg)	kg tree ⁻¹	Harvesting efficiency (%)	Work rate (tree hour ⁻¹)	Minutes tree ⁻¹	Cost kg ⁻¹ harvested production (€)
L1BR1	910	19	94.0	47.38	1.27	0.08
L1BR2	720	13	96.9	49.76	1.21	0.12
L1BR3	890	15	100	68.34	0.88	0.07
L2BR1	1184	24	100	42.39	1.42	0.07
L2BR2	2994	49	100	32.84	1.83	0.05
L3R3	584	17.7	100	24.57	2.44	0.08
L4R1	703	20.7	91.1	63.46	0.95	0.05
L4R2	725	17.7	95.0	67.12	0.89	0.06
Average		2.01	97.13	49.48	1.36	0.07

As it is not possible to present for all the olive orchards in which field tests were carried out the values of the elementary working times that allowed to compute working rate and its relative importance, was taken the

option to present these results for two representative olive orchards, one in which additional manual harvesting was used (Figure 3) and another in which this option was not taken (Figure 4).

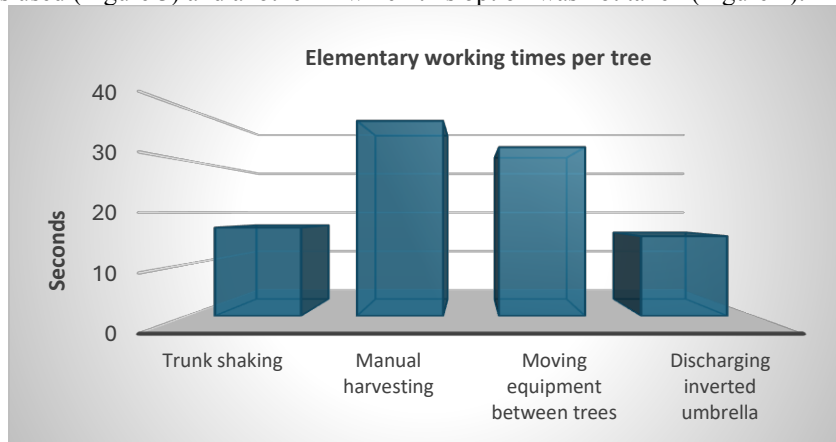


Figure 3. Olive orchard L1AR1 with additional manual harvesting - elementary working time per tree.

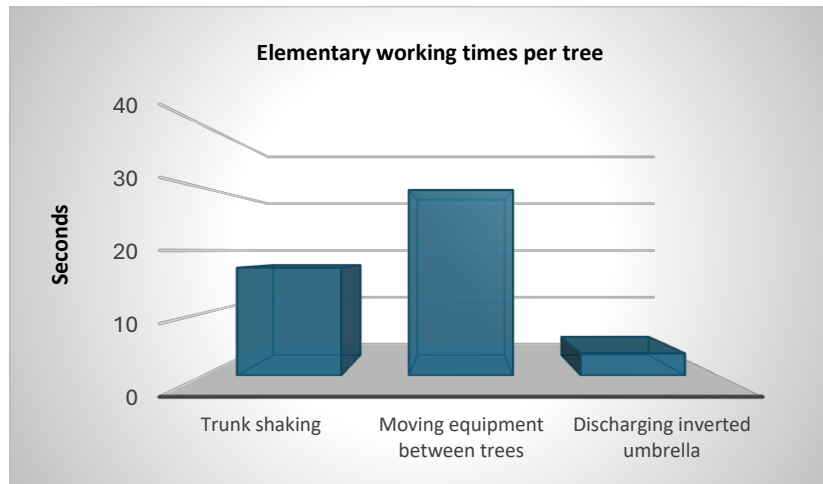


Figure 4. Olive orchard L4R2 without additional manual harvesting - harvesting elementary working time per tree.

4. Discussion

Results presented in tables 1 to 3 show important differences between the performance of the harvesting system when there is use of complementary manual harvesting and when there is no use of complementary manual harvesting.

Work rate with complementary harvesting (Table 1) varies from 10.96 trees h⁻¹ to 37.94 trees h⁻¹. Without additional harvesting (Table 3), work rate varies from 24.57 trees h⁻¹ to 68.34 trees h⁻¹.

These results show a work rate reduction when supplementary harvesting is used. The same can be seen in the time spent per tree (Table 1), which ranges from 1.58 minutes tree⁻¹ to 5.47 minutes tree⁻¹ using complementary harvesting and from 0.88 minutes tree⁻¹ to 2.44 minutes tree⁻¹ without complementary harvesting (Table 3).

Based on values presented in the fifth column of Table 2, it is assumed that a reduction in the cost kg⁻¹ of harvest would be possible if there were no use of additional manual harvesting.

The cost of production harvested mechanically with complementary manual harvesting (Table 2) is on average €0.12 kg⁻¹. The cost of production harvested mechanically without manual harvesting is on average €0.07 kg⁻¹ (Table 3).

The reduction in work rate and the increase in harvesting costs with complementary harvesting can be balanced by the increase in production harvested in this way. However, this does not seem to be the case,

given the results presented in the second and sixth columns of Table 2. It can be seen that the increase in harvested production varies from 130 kg in an olive grove with a total production of 905 kg, to an increase in harvested production from 58.24 kg in an olive grove with a total production of 1,215 kg. Labour costs to obtain this increase in harvest range from €0.07 kg⁻¹ to €0.76 kg⁻¹ with an average value of €0.49 kg⁻¹ (Table 2).

It will be worth reflecting on these costs for additional manual harvesting. The results obtained show that the increase in harvest is reduced and the price per kg of this increase in harvested production is much higher than the commercial value of the olives.

Harvest efficiency results show that in the olive orchards where complementary manual harvesting was used (Table 2), the values varied from 84.2% to 96.9%, with an average of 91.28%. In olive orchards where no additional manual harvesting was used (Table 3), values ranged from 91.1% to 100%, with an average of 97.13%.

These harvest efficiency values are above 85%, a value that is referred to by (Castro-Garcia et al, 2012) as an objective for harvesting systems based on trunk shakers. For (Farinelli et al 2012), harvesting efficiency of 85% is considered the breakeven point for mechanical harvesting of olives with a trunk shaker, meaning that 15% or less of the total production remaining on the tree, losing it, is worthwhile compared to the cost reduction that the harvesting system provides.

Figure 3 show the substantial value that the elementary time for manual harvesting has in the set of elementary working times, followed by the elementary time for moving equipment between trees.

Figures 3 and 4 show the importance that time for moving equipment between trees has for work rate. All measures that reduce this value, such as good trafficability conditions of the equipment within the olive orchard and the use of mechanical devices that allow easy and quick coupling of the shaker to the tree, contribute to improving the work rate of this harvesting system.

5. Conclusions

Mechanical olive harvesting systems based on trunk shakers do not detach all production.

The majority of farmers who use this type of harvesting equipment, to harvest the entire production opt for complementary manual harvesting with the consequent increase in labour.

Before making the most appropriate decision, it is worth checking the cost/benefit ratio of this solution.

Mechanization brings considerable benefits, such as significantly reducing the time required for the operation, which allows harvesting a larger area of olive orchards in the time period considered optimal. With effective operation management, this increase in work rate reduces the time required and harvesting costs, despite not harvesting the entire production. The references cited in previous points indicate that with a harvesting efficiency of 85% the breakeven point is reached, that is, it is economically worthwhile to lose some production that remains on the tree.

With these harvest efficiency values (>85%), the use of complementary manual harvesting results in an unnecessary increase in costs, without obtaining a compensatory increase in harvested production.

This is what the results obtained in this work show. In the field tests carried out, (Table 2) for an average harvesting efficiency of 91.28%, the olives harvested by complementary harvesting had an average cost of €0.49 kg⁻¹, much higher than their value.

Being harvesting efficiency less than 85%, it is necessary to adopt solutions that can include complementary harvesting, or others such as agronomic solutions, or such as better mechanical solutions, which increase harvest efficiency.

A set of agronomic factors are known that affect harvest efficiency, such as canopy shape and density, pruning, orchard density and cultivar (Ferguson et al, 2010).

The shape and density of the canopy can affect the efficiency of mechanical harvesting, impairing the performance of the trunk shaker, by reducing the capacity to transmit vibration energy to the fruiting zone (Martin, 1994).

The density of the canopy can affect mechanical harvesting (Tombesi et al, 2002), as it makes difficult the visibility for the operator and jeopardize the equipment performance by limiting access for the shaker clamp to the most convenient area of the trunk.

Proper pruning should provide enough space under the canopy to facilitate shaker access to the trunk and efficiently transmit vibration to the fruiting zone. Suitable olive orchard density for trunk shakers is between 150 to 400 trees per hectare (Ferguson et al, 2010).

Among the factors linked to the cultivar, fruit removal force (FRF), fruit weight (P) and the relationship between them are important for harvest efficiency (Tombesi 1990; Ferguson 2006, Farinelli et al 2012). To know FRF/P ratio that can be used as an indicator of good harvesting efficiency is an important objective that remains to be carried out. In addition to the cultivar, it depends on the agro-ecological region in which the olive grove is located.

The choice of mechanical equipment is another factor that affects harvesting efficiency. For Ferguson (2006), the vibration pattern must be characterized by a short amplitude, less than 2.5 cm and a high frequency, above 2500 cycles minute⁻¹.

Before making the decision to use complementary harvesting, it is important to assess if it is really need, for instance, what harvesting efficiency is expected. With the values obtained in the field tests presented, it may have led to an increase in harvesting costs, without the corresponding return.

Being expected a harvesting efficiency lower than the reference values, complementary manual harvesting can be a solution, but an evaluation of the other agronomic and mechanical solutions mentioned is recommended.

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