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Economic and Technical Features of Different Levels of Mechanization in Olive Harvesting

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The olive tree (*Olea europaea* L.) is one of the most important crops in Italy, both in terms of economic relevance and environmental role. However, its cultivation entails high production costs, especially for harvesting. Harvesting methods range from manual, to simple hand-held equipment, up to fully mechanized grove, depending on numerous economic, technical and social factors. Facing this wide range of crop conditions, we individuated three main different scenarios of olive oil production, in terms of mechanization intensity and cropping system. The paper reports the costs and the technical features of these three levels of mechanization intensity for olive oil harvesting. The economic evaluation of harvesting operation shows that manual harvesting costs attained around 3300 € ha^{-1}; thanks to mechanization, it is possible to obtain the following cost reductions: 40-48% using hand-held equipment; 59-72% with trunk-shakers and ground nets; 68-80% with trunk-shakers equipped with collecting umbrellas; 85-90% with straddle harvesters. Consequently, the cost of olive oil ranges from 4.7-2.7 € kg^{-1} (manual harvesting) up to 0.3-0.5 € kg^{-1} (straddle harvester).

1. Introduction

The Italian olive and olive oil sector is a key part of the whole Italian agriculture, with a cultivated area of about 1.1 million of hectares, about 900,000 producing farms, and an average year production of 475,000,000 kg of olive oil (ISTAT, 2015). Moreover, in Italy 42 PDO (Protected Designation of Origin) and 1 PGI (Protected Geographical Indication) are registered. However, the average farm area is only about 1.25 ha, with the most part of farms located in slope and marginal soils (more than 70% farms are in mountainous and hilly areas). Therefore, the mechanization of olive oil producing farms is not an easy task, also because other factors (low availability of capital, farm fragmentation, different cropping systems, etc.) are negatively acting (Sarri and Vieri, 2011).
Nowadays, a wide offer of equipment and tools is available on the market to enhance and ameliorate the level of mechanization (Tombesi et al., 2004; Biocca et al., 2005) and several solutions with different level of mechanization intensity and investment request, can be achieved (Toscano and Scazziotta, 1998; Zimbalatti and Bernardi, 2013). These machineries allow to make possible the requalification of olive orchards that are endangered to be abandoned.
The harvesting is the most important cost in olive oil production and its mechanization should be carefully chosen and evaluated (Vannucci and Biocca, 2004). The aim of this paper is to describe the common harvesting methods and equipment, and to evaluate harvesting costs and economic sustainability of different harvesting methods. The study entails three different scenarios: (1) low level of mechanization – using hand-held equipment; (2) intermediate level – using trunk shakers; (3) fully mechanized - using straddle harvesters.

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2. Description of mechanization scenarios

2.1 Low level of mechanization: hand-held equipment

Olive harvesting by hand-held equipment is common solution where a low capital investment is demanded. It represents a minimum level of mechanization because the equipment is carried by the operator (Pannelli et al., 1993; Ianniccelli and Ragni, 1994).
This harvesting method replaces the manual harvesting, without any drastic changes in tree training system and cultivar choice. In essence, there is an adaptation of the machine to the crop and not vice versa, that is the reason for the high number of solutions on the market (Biocca and Sperandio, 2000).
Hand-held equipment is widespread in areas where it is not economically viable to invest in the purchase of large machines (small farms) or where environmental conditions are not suited to the use of complex machines (sloping ground, traditional training system) or where farms are not specialized (i.e. with part time labor) (Famiani et al., 2010).
The equipment is \furnished with simple devices, such as vibrating or oscillating combs hooks, which should be positioned inside the canopy and which, when actuated, cause the detachment of drupes. The collector tool is generally mounted on a pole by metal, or fiberglass or carbon fibre, with fixed or variable (telescopic) length. The tools are operated with compressed air or directly from small internal combustion engines or electric engines, and the requested powers are very low. In accordance with the principle of fruit detachment we can have: (1) beaters; (2) grazers; (3) shakers. The beaters have teeth mounted on counter-vibrating combs, which beat the olives and the twigs causing the detachment of the drupes directly or by the induced vibrations. There are numerous models, differentiated for the material of teeth (generally plastic materials), the type of movement and the frequency of vibration. The grazers (less common), which mimic the manual collection, have teeth that penetrate the olive vegetation causing the detachment by traction of drupes trapped between the teeth spiral shaped. The shakers transmit the vibrations induced by an eccentric gear to the main branches or secondary branches and the drupe is detached for the vibration transmitted to the petioles.
Depending on the type of actuation we can have:
1. electrical machines, which have the advantage of being light and little noisy; modern batteries (lithium-ion or lithium-polymer) are worn by the operator (backpack or "fanny pack") and ensure excellent performance;
2. equipment operated by compressed air; they require a compressor (autonomous or operated by a tractor, with power and air tanks of varying sizes, but able to serve at least 2 operators); the harvesting tool is light, from 3 to 5 kg;
3. equipment operated by internal combustion engines, typically derived from brush cutters, with displacements from 30 to 60 cm^3, and powers from 1.5 to 2.2 kW. The weight of these machines is around 10 kg.

2.2 Intermediate mechanization: trunk-shakers with ground nets or collecting umbrellas

Shaking machines transmit vibrations to the trunk that, through the appropriate frequency and amplitude of vibrations, cause the detachment of the drupes and their subsequent collection on nets lying on the ground or in specific devices mounted on the machine (umbrellas) (Toscano, 2007).
The shakers include models with different length of the shaker arm, different mass of the vibrating head, different size of the head jaws to bind trunks and / or branches of different diameters (up to 400-600 max 800 mm). Due to actual olive production per plant and site conditions, the harvesting performance can largely vary (Briccoli-Bati et al., 2006; Tombesi et al., 2011).
The main parts are the support frame and the connection to the tractor (mounted shakers) or to the motorized frame (self-propelled shakers), the pivoting carrier arm (different in length and / or adjustable), the head rotating shaker, with its jaws; the mechanical box containing or bearing the eccentric masses, the hydraulic actuating motor, the motion transmission system. The integral shaker is constituted by the shaker arm and by a system of olive fruits harvesting, entailing a reverse umbrella, mounted on an adjustable frame that can turn around the trunk to intercept the olive fruits subject to shaking; the umbrella deliver the olives to a collection point to facilitate the automatic unloading of the containers. The average power required need tractors of 40-60 kW, while for the self-propelled the power requirement is higher (around 80-100 kW), depending on the weight of the shakers (200-400 kg for light shakers; 600-800 kg for heavy shakers) (Toscano, 2010).

2.3 Advanced mechanization: straddle harvester

Straddle harvester are specific machines for the integrally mechanized harvesting in super-intensive olive groves (Camposeo and Godini, 2010). They can perform, in a single step, the picking up of the olives from the tree, the interception, the collection, the cleaning and the unloading of the olives on a special trailer. These machines are derived, with minor modifications related to the increase in the number of shaking elements, from grape harvesting (Bellomo and D’Antonio, 2008). They are characterized by a harvesting system proportional to forward speed of the machine. The harvesting system consists of shakers formed by oscillating rods, made by highly flexible plastic material. The olives are cleaned using a suction system actioned by fans.

3. Materials and methods

3.1 Economic analysis

The economic analysis was developed by examining the cost of harvesting in relation to the use of different level of mechanization, with reference to manual harvesting operation. To make possible the comparisons, we referred to a specialized olive grove with a planting layout of 6 x 6 m, with 277 plants ha^{-1}. For the analysis of the harvesting with straddle harvesters we necessarily referred to a super-intensive olive grove with a planting density of 1,670 plants ha^{-1} (layout of 4,0 x 1,5 m). Then we hypothesized two production levels (without any harvesting losses), representative of the national average productions: 4,500 and 8,000 kg ha^{-1} (equal to 16.2 and 28.9 kg plant^{-1}, respectively) (ISMEA, 2012). For super-intensive olive groves, we hypothesized a production of 2.7 and 4.8 kg plant^{-1}. To calculate the cost of produced oil, we considered an average yield of oil equal to 16% (weight/weight) (Table 1).

Table 1: Hypothesis of olive production and work productivity of the different harvesting methods

Harvest method	Planting density (plant ha^{-1})	Unitary production (kg plant^{-1})	Productivity per operator (kg h^{-1})	Yard productivity (kg h^{-1})	Operators (N.)
Manual	277	16.2 - 28.9	15 - 25	60 - 100	4
Pneumatic or electrical combs	277	16.2 - 28.9	35 - 50	140 - 200	4
Trunk-shakers with ground nets	277	16.2 - 28.9	90 - 110	450 - 550	5
Trunk-shakers equipped with collecting umbrella	277	16.2 - 28.9	230 - 280	460 - 560	2
Straddle harvesters	1,670	2.7 - 4.8	900-1,200	1,800-2,400	2

The evaluation was focused on the determination of both harvesting costs for the surface unit (€ / ha) and the product unit (€ kg^{-1} of olives and olive oil).

The harvesting yards were composed as follows:
a) manual harvesting, which entails the picking up the olives by hand or with small auxiliary tools (rakes, combs or tools with rotary combs);
b) low level of mechanized harvesting, which involves the use of facilitators machines, vibrating combs (beaters) or hand held shakers;
c) mechanized harvesting with shakers and manually operated nets, which entails machinery mounted or self-propelled with shakers or beaters; the collection of olive fruits occurs on nets placed on the ground.
d) fully mechanized harvesting with shakers equipped with a mounted reverse umbrella;
e) advanced mechanized harvesting, which entails the use of a self-propelled straddle harvester for super-intensive groves.

The calculation of the operating costs of the used machines and equipment, was carried out by means of an analytical method (Biondi, 1999), considering the fixed costs (reintegration of the invested capital, the cost of using the capital, and the various expenses as insurance, storage and taxes) and the variable costs related to the use of the agricultural machinery (repairs and maintenance, fuel, lubricants and labor). The costs for the labor force, was calculated according to the salary, as determined by the National Collective Agreement in force (2015-2017), inclusive of all and social security contributions, namely: € 10.73 h^{-1} for ordinary workers, € 11.97 h^{-1} for qualified workers, € 13.19 h^{-1} for specialized workers and 13,85 h^{-1} for super-specialized workers. We considered the costs for ordinary workers for manual harvesting and the others costs progressively up to fully mechanized harvesting.
The main technical and economic elements used in the analytical calculation of the hourly cost of the machines are reported in Table 2. The calculation of machine costs was carried out with reference to an annual use equal to the average time required for the harvesting season, which is a variable period ranging from 45 to 60 days per year, approximately 360 and 480 h year^{-1}. Since we have used an analytical method to determine the cost of machinery, the costs of hiring out of machinery and equipment were not considered.

Table 2: Main elements considered in the analytical calculation of the operating cost of the machines for the different harvesting methods

Description	Pneumatic or electrical combs	Trunk-shakers with ground nets	Trunk-shaker with collecting umbrella	Straddle harvesters
Purchase price (€)	1,700	58,000	80,000	235,000
Salvage value (€)	285	6,228	8,590	52,006
Service life (y)	8	10	10	10
Annual usage (h y^{-1})	480	480	480	480
Power (kW)	3	60	60	129
Interest rate (%)	3	3	3	3
Fuel consumption (L h^{-1})	0.57	5.25	5.25	15.48
Lubricant consumption (L h^{-1})	0.02	0.21	0.21	0.62
Labor cost (€ h^{-1})	11.97	13.19	13.19	13.85

4. Results

Figure 1 shows the results of the analytical calculation in terms of hourly costs for the different harvesting systems, for the two periods of machine utilization and for the yard compositions.

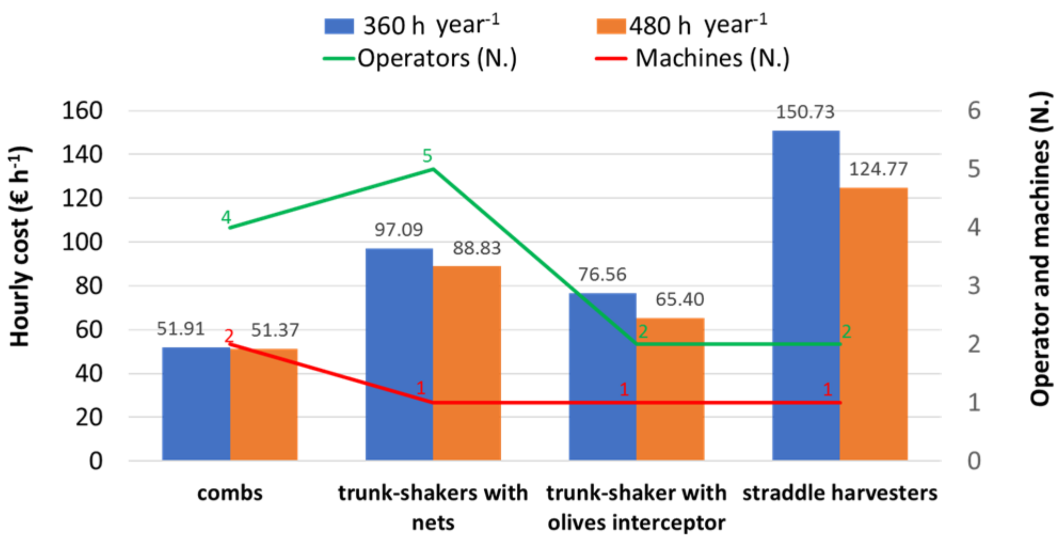

Figure 1: Operating costs of olive harvesting for the different levels of mechanization and labor employed.

Since manual harvesting costs about 3200-3400 € ha^{-1}, there is a progressive cost reduction with increasing mechanization level, up to reach the cost of about 300-500 € ha^{-1} in the case of maximum technological effort, represented from the continuous harvesting adopted in super-intensive orchards (Fig. 2).
The estimation of olive harvesting costs per unit of olive oil (€ kg^{-1}) for the different mechanization levels in relation to the different olive productions and harvesting period is shown in Fig. 3.
The cost of harvesting per kg of oil varies: (1) from € 4.7 to 2.7 for the manual harvesting; (2) from € 2.3 to 1.6 for the harvesting with hand-held tools; (3) from € 1.3 to 1.0 for the shakers; (4) from € 1.0 to 0.7 for the shaker with umbrella; (5) from € 0.3-0.5 for the self-propelled straddle harvester. Observing the different scenarios, harvesting costs are greatly affected by the different labor needs. The labor requirements range as follows: (1) 300-320 h ha^{-1} per worker in the manual harvesting; (2) 129-160 h ha^{-1} with hand held machines; (3) 50-75 and 20-29 h ha^{-1} for harvesting with shakers with and without umbrella, respectively; (4) 5-7 h ha^{-1} for worker with self-propelled straddle harvester. Consequently, with reference to manual harvesting, a progressive reduction of labor request was observed, varying from 50-57% (hand-held equipment), up to 97-98% in the full mechanized yards (self-propelled straddle harvester).

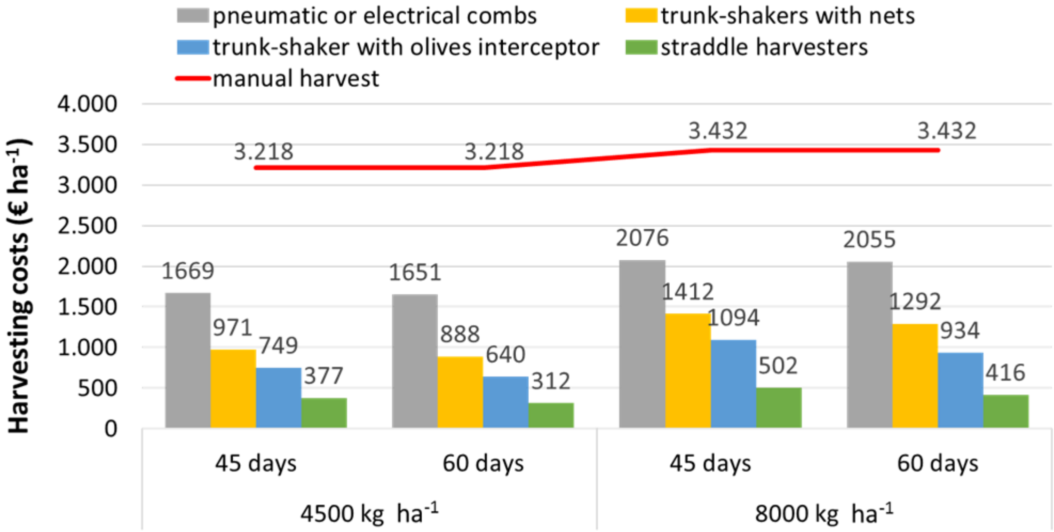

Figure 2: Estimation of olive harvesting costs per hectare for the different mechanization levels for different olive production and harvest period.

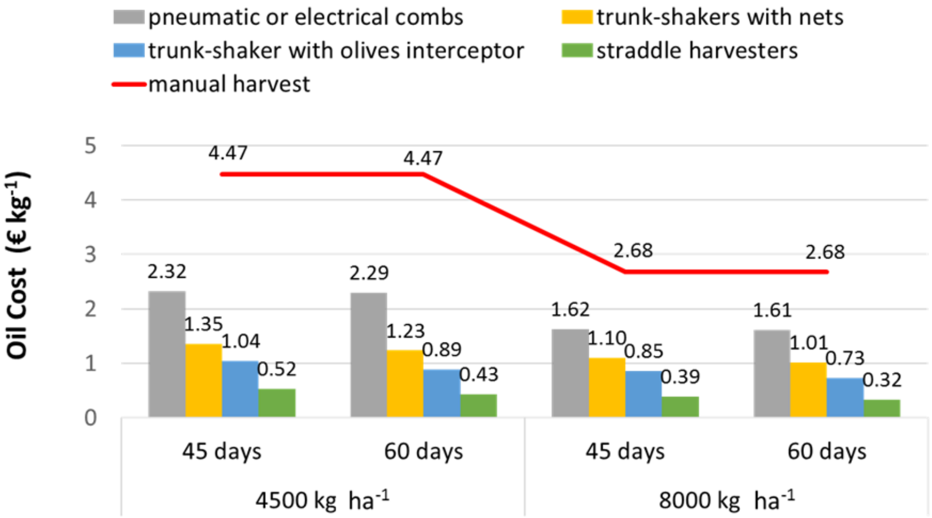

Figure 3: Estimation of olive harvesting costs per unit of oil (€ kg^{-1}) for the different mechanization levels in relation to the different olive productions and harvesting period.

The economic analysis, focused on the harvesting cost per hectare in relation to the mechanization level, showed a clear improvement in the income, compared to manual harvesting, as the level of mechanization and specialization increased. In relation to the assumptions made in terms of production and or productivity, it is noted, compared to manual harvesting, a reduction in harvesting costs per hectare of 40-48% with hand held machines, of 59-72% with shakers, of 68-80% with shaker with collection device, and 85-90% with straddle-harvesters.

5. Conclusions

The analysis of Italian olive oil sector shows an heterogenous panorama in terms of different cultivar, plant density, training system, age of trees, location and so on. Moreover, there is a wide-ranging situation in terms of socio-economical figures of the farms, which include both high specialized and marginal and obsolete farms. In such a condition, one faces to a similar varied level of mechanization. The paper has showed as the different choices in term of harvest mechanization can greatly influence the total harvest cost, contributing to a more general ameliorated management of the entire cycle of olive production.

However, it is important to note that the farmer should take in consideration, beside the costs, many other factors that influence the choice of the harvest method or machinery. In fact, the olive groves represent a unique value in terms of environmental and cultural importance. Therefore, it is desirable that other, more powerful stakeholder can participate and encourage the recovery of a sector that, despite the undeniable potential, often fails to guarantee a sufficient yield and economic return.
This paper has reviewed only one phase of the productive cycle, the harvesting, but a complete economic evaluation about the profitability of different methods requires the analysis of the whole cycle of life of the olive grove (Rosselli and De Gennaro, 2011) Therefore, we consider the paper a starting point of future works.

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