Advances in harvesting and pruning of olive trees
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Abstract
In the last 20 years, following globalization of olive oil market, which caused greater competitiveness in terms of oil quality and production cost, all the countries interested to olive growing must introduce efficient planting and techniques to satisfy these requirements. Two main solutions were proposed: intensive orchards (~400 trees/ha) and super-high intensive orchards (~1600 trees/ha); the first is well known, because it was close to the reference model for new plantings in the last decades. On this model trunk shakers and fruit interception frames greatly improved mechanization degree. In order to optimize mechanical harvesting efficiency, plant characteristic, time of harvesting and plant layout were defined, and intensive cultural practices were suggested to obtain high oil production and quality. Super-high intensive orchards were an alternative with the purpose to use over-row harvester derived from the ones used in grape harvesting. This kind of machine, which operates in continuous, has high harvesting efficiency also in cultivars with small fruit size. This solution fascinated growers and started to spread all around the world. However, very soon, cultivars appeared to be the key-factor. Only very productive and compact cultivars resulted suitable for this system of cultivation. Pruning represents an important factor to facilitate mechanical harvesting and to regulate efficient fruit production. The mechanization of pruning increases work safety and reduces hand work, contributing to a more economical olive production. Optimal solutions were tested and recommended.

Keywords: Mechanical harvesting, Pruning, Intensive olive orchards, Super-high intensive, growing practices, mechanization.

Introduction
In the last years there has been a significative expanding use of extra virgin olive oil in new large countries where the general low prices facilitated the introduction. For the future, the challenge is to increase olive oil production, of quality and at low or moderate price, warranting a right profit to the grower.

In the olive culture, the factors that contribute to reduce the production cost is the increase of crop and the mechanisation of cultural techniques. Between these, the most expensive are harvesting and in some way pruning.

In the mechanisation of harvesting two methods became popular: vibration of the tree and canopy shaking. Trunk and branch shakers were implemented to increase the efficiency. The most interesting technologies regarded the choice of the right vibrating frequency and amplitude, the multidirectional and orbital vibrating models, the reduction of the shaker mass, the manoeuvrability of the shaker, the use of durable components, the employment of larger powers. On the other hand, canopy shakers increased the shaken area and introduced means to better explore the canopy surface.
and volume. The fruit collection was mechanised and the fruit removal machines were equipped with collecting frames to make easy and fast the fruit recovery and movement inside the farm.

**The most efficient olive harvesting machine**

1. **Trunk shaker and reverse umbrella**

The trunk shaker has fruit removal efficiency of 70-95% and high operation capacity, because the time to detach fruits is 5-15 seconds. The success of trunk shaker has been enforced by the evolution of fruit interceptors, and the reverse umbrella mounted on a basal box to store the removed olives represents the optimum solution to complete the harvesting operation in short time.

2. **Trunk shaker and side by side interceptor**

The harvester is composed by two vehicles that run side by side along the row; one supports the trunk shaker located beneath the sloping padded frame that overlap the other sloping frame where operate a fruit collector and elevator that store the fruits in a bin. They are flexible machines, able to harvest trees of different size, with high operative capacities and easy to transfer.

3. **Over row canopy shakers derived from grape harvester.**

They represent an interesting alternative, and derive mainly from grape harvesters. They vibrate the fruiting branches by 10-12 shaking bars. The shaking box is wide 0.8 m and high 2.0-2.5 or up to 3.5 m in some models. The fruits are collected by a chain with baskets running at the same speed of the machine. The fruit removal is high, 90-95%, also in varieties with small fruits. The speed of operation is between 0.5 and 1.5 km/h.

4. **Big over row canopy shakers.**

The big over row machines have a large frame of 4x4 m with vibrating heads that, through axis penetrating inside the olive canopy, induce the fruit removal, but the machine is heavy and the size makes difficult the transfer and the fruit collection.

**Optimal harvesting period and oil quality**

Olive fruits should be harvested when the oil quantity and quality are at the highest level and machinery efficiency is satisfying. During the final stage of fruit ripening, which lasts approximately two months, the fresh and dry fruit weight does not change significantly. Instead the fruit oil content increases considerably, because this period still coincides with intense oil formation.
Tab. 1. Harvesting efficiency and cost of different machines

<table>
<thead>
<tr>
<th>Machine price €</th>
<th>Year utilisation h</th>
<th>Hour cost</th>
<th>Trees/h And trees/ha</th>
<th>Average crop/tree Kg</th>
<th>Fruit removal %</th>
<th>Harvested fruit /h Kg</th>
<th>Harvesting cost €/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk shaker + reverse umbrella</td>
<td>70,000</td>
<td>360</td>
<td>80</td>
<td>30-200/400</td>
<td>30</td>
<td>75-90</td>
<td>742</td>
</tr>
<tr>
<td>Syde by side trunk shaker</td>
<td>250,000</td>
<td>1200</td>
<td>320</td>
<td>100-200/400</td>
<td>30</td>
<td>75-90</td>
<td>2475</td>
</tr>
<tr>
<td>Derived from grape harvester</td>
<td>220,000</td>
<td>600</td>
<td>250</td>
<td>700-1600</td>
<td>6</td>
<td>80-90</td>
<td>3570</td>
</tr>
<tr>
<td>Over row Colossus harvester</td>
<td>500,000</td>
<td>1200</td>
<td>320</td>
<td>100-300/500</td>
<td>30</td>
<td>80-90</td>
<td>2550</td>
</tr>
</tbody>
</table>


The Fruit Detachment Force (FDF) differs according to variety, it is approximately 6 N before the start of processes leading to the formation of the fruit separation layer. At the intermediate stage it is around 4-4.5 N and then it drops below 3 N at the advanced stage of ripening. Natural fruit drop begins when fruit detachment force values are medium or low; it occurs when abscission of olives with a limited FDF is encouraged by strong winds or gales. FDF values below 3 N are a sign of imminent fruit drop. When more than 5-10% of olives has dropped off the tree, it has significant impact on the amount of obtainable oil. If the olive fruits are healthy, the level of free acidity and the peroxide value of oil does not change during ripening. In contrast the polyphenol content, organoleptic characteristics and colour can vary. Polyphenol content is cultivar characteristic, changes in content tend to be bell-shaped, rising in the initial stage of maturation and later declining. Polyphenol content is generally at the highest value when the FDF starts to decrease. Oil characteristics are basically defined by sensations of fruitiness, bitterness and pungency. Fruitiness is more pronounced during the period of intense oil accumulation and starts to lessen when FDF tends towards intermediate values. Bitterness and pungency are characteristics of oils obtained from early harvested olives. As a rule, balanced, prime quality oils are very fruity and display equilibrium between bitter and pungent attributes which are noted at medium intensity. The optimal time to harvest each variety can be determined by combining the parameters related to the quantity and quality of obtainable oil. For each variety the optimal harvesting period lasts about 20 days.
Mechanical harvesting cost.
In relation to a general high fruit production for tree and to the percentage of fruit removal, the final harvesting cost is very low for all the machines, but there are differences and some considerations between them (Tab.1). The side by side and the Colossus show the values of 0.125 €/kg obtained with a very high year utilisation, operating the harvest in about 60 days, and for 20 daily hours. The trunk shaker with reverse umbrella can operate 40 days with a daily use of 9 hours, inside the optimum harvesting period, and the harvesting cost is at medium level. The cheapest harvesting cost corresponds to the straddle grape derived harvesters. They can operate in 50 days for 12 hours each day. They can enlarge the use, operating after grape harvesting to reduce the amortization cost.

Tree exigency and possible damages of different machines.
For each kind of machine were find out the best operating conditions:
For trunk shakers:
1. Planting production. Larger is the yield, higher is the work productivity. The use of high productive varieties in vocational areas and optimal application of cultural techniques will assure good production. We consider optimal a production of 30kg/tree on planting of 300 trees/ha.
2. Canopy volume. The trunk shakers show good performance with canopy volumes until 40-50 m³, obtainable with almost all the varieties for a long planting life.
3. Application point. The easiest method is the application on the trunk, that must be regular, straight and free of branching for about 1 m. When the application differs from perpendicular and the trees are recently irrigated some bark damages can be observed.
4. Planting distances. The distance of 6x6 m is a good reference, or if the catching frames are side by side the best combinations can be realised by distances of 7x5m or similar values.
5. Optimal harvesting period is when fruit detachment force starts to decrease, when oil content and quality are optimal.
6. Adapted varieties have fruit size more than 1.5-2 g, with upright habit. Many traditional varieties are respondent.
7. Tree age. The trunk shakers can be applied early, at 6-8 years old trees, when the trunk diameter is 8-10 cm, up to 60-70 years old ones, until the trunk is healthy and the shape is regular.
8. Soil sloping. The plain soils are the most respondent, however it is possible to operate until 20-25% of sloping, using chain tractor and light shakers.

Over row harvesters
The over row harvesters showing best results are those derived from grape harvesters, because they are built in large number and are reliable. They have the exigency to operate on trees which size is compatible with the shaking box. Then the trees must be lower than 2.5-3.5 m and not wider than 2.0-2.5 m with elastic branches that can enter inside the shaking box. This tree model must be efficient in terms of yield and life time. When the size of tree is larger some damages can occur regarding lateral branches breaking, bending or extirpation of the tree.
The big over row machine can operate with larger trees, not more than 25m² canopy volume. Some damages regard leaf dropping and branch breaking.

Choice of cultural olive models adapted to harvesting machine
All the models of intense olive culture must adopt a canopy volume more or close to 10.000 m³/ha
that need to be efficient, maximizing leaf area well exposed to light and reducing structural parts as trunk and main branches. The tree must produce each year shoots of medium size that are more able to promote inflorescences in conditions of reduced competition for assimilate compounds carried out by fruits and vegetative growth points. The inflorescence formation is influenced also by variety, that can express different tendency to form flowers. It is fundamental that the tree have at disposal large amounts of assimilates and a limited vegetative activity. While the assimilate amount depends on leaves and their light exposure, the vegetative activity can be influenced by pruning intensity and by cultural techniques: fertilisation, irrigation, soil management and, first all, by the variety. In fact each variety in relation to its genetic vigour and environmental conditions needs of planting distances able to allow equilibrium conditions that can be maintained for a long period by standard cultural techniques.

The intensive olive culture consists in applying intense cultural practices optimizing assimilation and in adopting a size of tree correspondent to the exigencies of harvesting machines. The trunk shakers with reverse umbrella or with side by side catching frame operate on canopy volumes until 30-40 m³, the over row derived by grape harvesters ask for a canopy volume up to 7-10 m³ and the big ones up to 25-30 m³. Following these harvester requirements the number of trees for hectare can be of 250-400 in intensive orchard and 1000-1800 in high intensive orchards.

Pruning
The plants that show a good production level have a LAI around 6, the factors that determine their high efficiency are a radiant energy interception around 90% and the consequent transmitted light intensity, at maximum sun height, of 140 - 150 mmol photons m⁻² s⁻¹. An improvement in the canopy efficiency can also come from a more uniform distribution of leaf density. Optimal canopy density seems to be 2 m² of leaves for m³ of canopy.

7.1. Intensive system
On intensive planting the training pruning must be as much as possible light, taking care of definition of a trunk, free up to 1 m, then light thinning of canopy to promote the formation of 3-4 main branches on the free vase system.

During the mature stage, fruit production pruning should be carried out regularly to remove suckers and the whole or parts of exhausted branches to control tree height by lowering the top and to keep vegetative cover as close as possible to the scaffold branches. This kind of pruning must be carried out in the following sequence:

1. Check if the tree has the right shape, cutting the main and secondary branches if something has to be corrected.
2. Remove water sprout, possibly retaining a few to replace debilitated branches.
3. Thin the tips of the branches to keep them within the maximum training height.
4. Thin the secondary and tertiary branches to remove any that are misshapen, exhausted or decayed, and head overlong branches to points where there are replacement shoots. Remove dichotomous branches and thin overcrowded shoots and branches.
5. Cut suckers at their point of insertion in the tree base.

As regard to the intensity and the periodicity, the biannual cycle applied with medium intensity pruning showed higher yields, with reduction cost on respect to annual cycle. Leccino and Maurino varieties well respond to biannual and triannual cycle, for Frantoio instead it is recommendable cycles not longer than 2 years because it shows a large production of suckers and a sensibility to olive leaf spot.

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For pruning it is necessary to use fuel chain saw, pneumatic or electrical chain saw, pneumatic or electrical shears with extension arms of 1 or 2 m in length to operate from ground level to increase worker safety.

Also the pruning using bars with 4-5 cutting discs that rotate at 2,000-3,500 rpm and powered by hydraulic motors are effective strongly reducing the hand work. The more efficient applications resulted using mechanical topping and elimination of suckers with electrical shears, applied each 4 years and spaced by mechanical hedging to control the lateral size of canopy.

7.2. Super high intensive systems
On the Super high intensive systems it is necessary to apply the following indications
• Minimum pruning to maintain a regular production of 0.6 kg of olives /canopy m3.
• It is necessary to remove branches below 0.6 m
• Avoid severe pruning because of the increase of vegetative growth
• Removing some lateral branch from insertion
• After planting tie upright the tree to the stake
• At second year remove basal branches below 60 cm and tie upright
• At 3°, 4°, apply light pruning, removing some lateral vigorous branch.
• At 5°-6° year apply a topping to reduce the height and to assure enough light exposure to the basal part of the tree, use every 3 years
• Then, apply a continuous branch thinning cutting them at the base to reduce shading and lateral growth
• Remove any branch below 60 cm to facilitate harvester fruit collection

Avoid strong pruning that reduces flower formation and that can alter the auspicate equilibrium based on medium- high yields to maintain the moderate tree size. There is some interest for a late selective pruning.

Cultural techniques that influence growth and perspectives to maintain equilibrium between vegetative and productive growth.
Besides the fundamental genetic characteristics that are expressed by easy flower formation, high branching capacity facilitating fruiting shoot formation and a limited annual vegetative growth, these parameters can be influenced by cultural practices and environment conditions.
About environment the locations with mild clime offer longer vegetative growth period, North and South areas show different annual growth that influences the early production and the final tree size. The water level, nitrogen availability and light soil increase growth, and their appropriate management can optimise vegetative growth and production.
The pruning will considerably affect the first tree growth and, on full expanse tree, the equilibrium between vegetative and productive activity and the restoring of regular tree size. Also some techniques influencing the assimilate partitioning can be useful to regulate fruiting, growth and size. They can be used properly in intensive and super intensive cultivation.

References

Ruffolo M., 2011, Personal communication

