CLIMATE CHANGE MITIGATION THROUGH A SUSTAINABLE SUPPLY CHAIN FOR THE OLIVE OIL SECTOR

HANDBOOK FOR A SUSTAINABLE MANAGEMENT OF THE OLIVE GROVES

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1 INTRODUCTION

Olives and olive oil are a key sector for the European Union, in particular those States with Mediterranean coastlines. In Spain, Greece, Italy and Portugal, the main producers of olive oil all over the word, the olive oil production is a major contributor to the country economies. But the economic benefits of olive oil production, and of the production of table olives have also a cost due to the environmental impact of the olive grove management. Olive growing has become more intensive over the last two or three decades and is using an increasing amount of agricultural land. Olive growing and olive oil production use considerable volumes of water in countries and the processes used by the sector lead to significant waste, especially wastewater containing phenols and soluble salts, and solid waste in the form of an olive paste, containing phenols.

During the last 20 years, EU commission has financed several LIFE projects to analyse and reduce the impacts of olive grove management. These projects have been as main themes: soil erosion, water protection, improved irrigation techniques, waste management (wastewater treatment; waste prevention, recycling and re-use; soil protection; and production of biogas), pest control, landscape protection, conservation activities, and co-ordination with the Common Agricultural Policy (CAP) agri-environmental measures.

The LIFE15 project **OLIVE4CLIMATE** confirms the EU commitment towards more environmentally-friendly olive oil production.

This manual takes in consideration the main phases of modern olive growing with particular attention to sustainable management of the crop. The main phases of olive growing, starting from the planting up to the collection and to the treatment of co-products, are treated proposing an approach which allows a reduction of environmental impact. In particular, these sustainable good practices propose reduction of CO2 emissions into the atmosphere and carbon accumulation in the plant biomass. These actions make the olive tree and therefore olive growing an effective tool for the climate change mitigation.

The adoption of these virtuous behaviours in the management of the olive grove can be rewarded with the accounting of carbon credits. These credits (calculated as tons of CO_2) can be bought by companies interested in reducing their environmental impacts on the voluntary market of ecosystem services. The voluntary carbon credit market sells the produced credits to individuals, usually from the industrial world, who wish to reduce their environmental impacts. The last chapter of this manual contains guidelines for collecting the information necessary to account for some of the good practices proposed by the OLIVE4CLIMATE project.

2 PLANTING

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The design of a new olive grove must consider clear objectives:

- obtaining high and constant productions;
- environmental sustainability of the orchard;
- high oil quality standard;
- reducing as much as possible the management costs.

For these reasons, it is necessary to ensure that the olive trees can grow and fruit at optimal levels and make possible to apply a high level of mechanization of all crop operations, with reference to harvesting and pruning, the two most expensive operations for the olive grove.

Figure 1: design of a new olive grove must allow an optimal vegetative-productive activity and a high level of mechanization

Environmental sustainability will be pursued through limiting the inputs and upgrading the agro-ecological services of the plantation: anti-erosion actions, carbon sequestration, landscape value, etc.

The olive tree is a very rustic species and can adapt to unfavourable pedological and climatic conditions, but it cannot withstand extreme events, such as water stagnation, strong thermal lowering and fog.

To the great diversity of pedo-climatic conditions in which the crop can settle corresponds a very high number of cultivars, each of them well adapted to its territory of origin.

To evaluate the environmental suitability of an area for the establishment of an olive grove and to drive the choice of best cultivars and the type of orchard, the following factors must be considered.

2.1 Climate factors

The environmental suitability of an area for the settlement of the olive growing can be assessed based on the historical and precise series (at least 30 years) of local climate data (temperatures, rainfall, wind, fog, etc.), the physical and chemical soil analysis and exposure. A useful indication can be provided by the vegetative and productive state of olive groves eventually present near the plantation site.

For the evaluation of the climatic factors, the following parameters must be taken into consideration.

Winter temperatures - They must be considered considering that, to avoid damages to plants, should not fall below -6 -7°C (temperatures that may damage the leaves), especially if such low temperatures should remain for a few days. Where temperatures fall frequently below -14 -15°C (more than once every 10-15 years), even if for a limited period, the planting of the olive grove is not recommended, because such temperatures could seriously damage the whole aerial part of the tree. The concomitance of snow, fog or wind can aggravate the effects of frost.

Figure 2: damage from low winter temperatures on adult plants and young ones

On the other hand, it should be considered that winter periods with temperature values between 0 and +7°C are necessary for optimal differentiation of flower buds and, therefore, to obtain abundant bloom. In addition, low winter temperatures may help to significantly reduce the populations of some parasites and pathogens of the olive tree (fungi, olive fly, black scale, olive moth, etc.).

The cold requirement necessary for flower differentiation can vary considerably among the different cultivars, going from 50-60 hours at temperatures below +4°C for most varieties, up to over 1,000 hours in specific cases.

An area can be considered suitable for olive production if the risks of late (April-May) and/or early (autumn) frosts are null or very limited (no more than one frost every 10-15 years). In areas where there is a risk for autumn frosts, it is preferable to complete harvesting early, to minimize fruit frost damages, which could cause a serious sensorial defect to the oil ("freezed").

Figure 3: moraiolo olives damaged by an early frost

Spring frosts could damage young vegetation, causing small lesions that may favour the settlement of the olive knot disease (Pseudomonas savastonoi).

In the northern olive-growing areas, the hilly areas between 150-200 and 450-500 m above sea level show lower cold risks compared to those in the plain or in the mountain.

In areas where winter temperatures can reach critical levels for the species, the proximity of large masses of water (lakes and seas) can play a positive role in thermal mitigation.

Summer and autumn temperatures - The content of oleic acid and other unsaturated fatty acids is linked to summer and autumn temperatures, because they can cause the increase of saturated fatty acids (palmitic and stearic), with reduction of mono- and poly-unsaturated fatty acids. Oils produced in cold environments are richer in unsaturated fatty acids, whose biological reason may be related to their greater energy power, which would give greater resistance to low temperatures to cells. In areas with relatively cold climates, the total oil phenol content also tends to be higher. The high content of oleic acid and phenols confers added value to the oil.

Minimum temperatures should not fall below 10°C from flower bud sprouting to flowering, 15°C during flowering, 20°C from fruit setting to fruit veraison, 5°C along fruit ripening and during the period of harvesting.

During the vegetative season, the optimal temperatures to favour plant photosynthesis, at the base of the vegetative and productive activity, are around 25°C.

The olive tree can withstand particularly high temperatures (up to over 40-45°C) but, if they are prolonged over time, the vegetative activity could be strongly limited, especially if they are associated at low water availability, because foliar transpiration can be reduced with a raising of leaf temperature. Where solar radiation and summer temperatures reach very high values, it would be preferable to adopt tree shapes (e.g. globe) that may help avoiding exposure of the branches to direct sunlight, to avoid harmful burns of the wood.

The protection from excessive sunlight by whitening trunk and branches with lime-based products are too expensive and should be avoided.

Rainfall - The following limits could be established for the rainfall (figure 4):

- With rainfall above 700 mm/year, the olive tree generally has an adequate vegetative-productive activity in dry cultivation, however, irrigation can be useful for particularly hot and dry periods during the vegetative season;
- With rainfall between 500 and 700 mm/year, good levels of tree growth and production can still be achieved in dry cultivation, but irrigation can lead to significant improvements for plant development and fruiting;
- With rainfall below 400-500 mm year, irrigation becomes a very important practice, as it determines very high increases in vegetative growth and production. Alternatively, a series of measures can be implemented to reduce plant water stress (careful control of weeds, low plant density, adequate intensity of pruning, etc.).

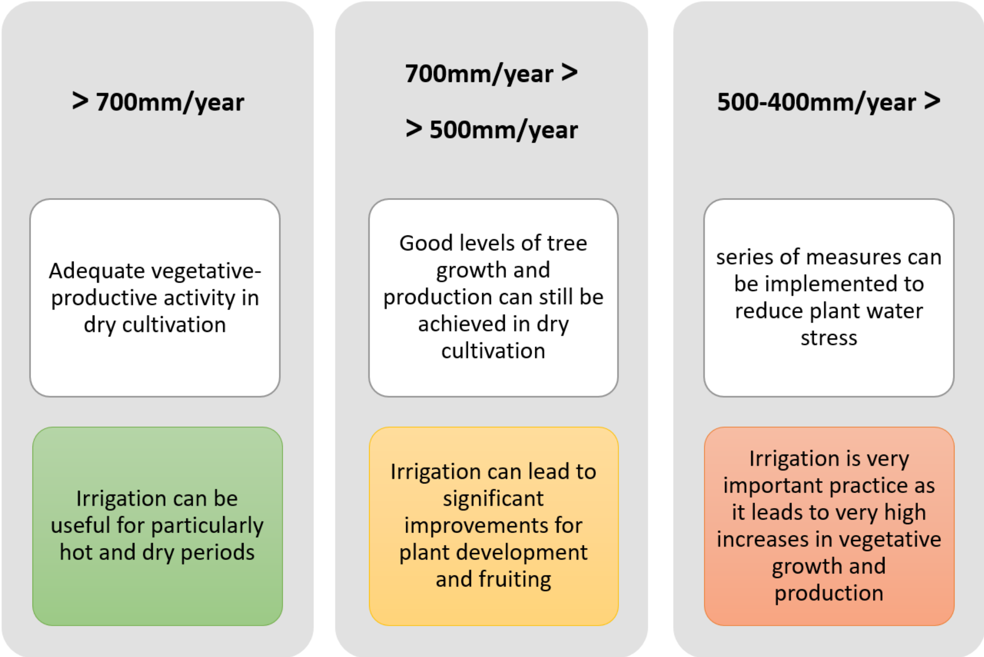

Figure 4: managing irrigation

Distribution of precipitations - In dry farming, the distribution of rainfall during the vegetative-productive season should allow to avoid periods without rains of more than 40-45 days. Fruits, in fact, have lower force than leaves in attracting the water available in the plant and therefore, in conditions of water shortage, they can easily shrivel. The wilting is reversible and, when the water availability returns to increase, fruits can recover their turgidity.

Figure 5: water stress effect

But prolonged and/or repeated water stress may bring to considerable negative effects, as it slows fruit growth and reduces oil accumulation. The prolonged water stress during fruit ripening and oil synthesis can induce the onset of a sensorial defect in the oil ("dry-wood").

Relative humidity - The high air humidity, more frequent in the valley bottoms (as fog), near lakes and in coastal areas, favouring the pest attacks, may determine unfavourable conditions to the olive tree. In sites characterized by high humidity, it is necessary to choose cultivars with good tolerance to potential pests.

Figure 6: avoid areas with recurrent mists

Windiness - Another factor that must be taken into account is the windiness:

- impetuous winds can break shoots and branches and drop flowers and fruits;
- marine winds, transporting salt, can exert a caustic action on leaves and young shoots;
- northern winds can cause sudden temperature drops, while hot winds can cause burns in apical leaves and damage flowers and fruits;
- wind can also interfere with plant disease and herbicides treatments (drift effect).

Wind damages can be avoided in windy areas using living windbreaks (with cypresses, eucalyptus, etc.), or by mechanical barriers constituted by robust nets anchored to iron, wood or concrete piles.

Figure 7: Eucalyptus windbreak

They should be planted at a distance from each other not higher than 5 m, depending on the height of the curtain and the expected intensity of the winds. They provide protection for a distance corresponding to 8-10 times the height of the windbreak. The density of the windbreak net should be 50-60%, to avoid creating turbulence downstream of the shelter. Nets with greater density (60-70%) can protect trees also from saltiness.

Hail - Hail is always harmful, but it can cause the greatest damages during the phases of flowering and fruit growing and ripening. Hail does not only produce direct damages, breaking the inflorescences and the shoots, injuring the branches and the fruits, but also indirect damages because, through the wood wounds, it favours the penetration of bacterial infections, such as the olive knot disease. Moreover, through the lesions of the fruit peel, the microflora present on the drupe waxy layer can initiate chemical reactions responsible for various alterations, such as increasing the oil acidity or the formation of unpleasant substances, etc. Immediately after a hailstorm, it is therefore advisable to carry out pathogen treatments, especially with conditions favourable to the development of the olive knot disease.

Figure 8: knot attack in Moraiolo as a result of hail

Snow - The snow itself does not represent a serious problem to the olive tree, but if it is too abundant, it can cause the break of branches, especially if the foliage is quite thick and the main branches have a wide insertion angle on the trunk.

Figure 9: generally, snow does not cause damage

2.2 Pedological Factors

To evaluate the soil characteristics of the land for the olive planting, it is necessary to examine its profile and perform chemical-physical analyses.
For the soil profile examination, it is necessary to dig a trench (or more than one if the ground is not uniform or the surface is very wide) of at least 1 m depth, in order to evaluate the useful soil, the texture variations, the presence of stones, rocky or salty or calcareous layers, groundwater level, etc.
Soil samples should be collected after 2-3 days of dry weather from the excavation. For the evaluation, it must be considered that plants will need a volume of soil not limiting root growth, that will guarantee the anchoring of plants and that will provide adequate availability of water and nutrients. Generally, in the soil it is possible to distinguish:

- an active layer, represented by the most superficial part, characterized by softness, porosity and containing nutritive elements, organic substance and aerobic microorganisms,
- an inert layer, represented by the subsoil, characterized by a greater compactness and lower porosity, permeability, etc.

Cultivation layer - It represents the distance between the surface of the soil and the layer of soil representing an obstacle to root growth; the layer can also be limited by a superficial groundwater layer, which can rise due to heavy rains.

Physico-chemical characteristics of the soil - Through the physical-chemical analysis of the soil it is possible to obtain useful indications on texture or granulometry, pH, organic matter content, cation exchange capacity (CEC), total and active limestone, content in nutrient elements, salinity, sodium, etc.
The olive tree prefers:

- medium mixture (35-50% of sand, 25-45% of silt, 20-25% of clay), frank-clay, frank-loamy and frank-silt-clay soils;
- deep, fertile, fresh, well drained cultivation layer, with a pH between 6.8 and 7.5.

However, the olive tree has a wide adaptability to different soils, being able to grow and produce even in soils rich in skeleton or limestone (up to 50-60% of total limestone), rocky, poor and dry, with extreme pH up to 5.5 or 8.5, relatively saline and/or sodic.
Even on loose (sandy) soils, the olive tree can grow and produce well, but only with a good availability of water and an adequate supply of nutrients. Problems could occur on very clay soils (clay > 40-45%), in plain soil, due to problems of water stagnation, to which the olive tree is very sensitive.

Figure 10: olive tree is very sensitive to water stagnation

The modification/correction of the soil texture, in general, is not economically sustainable. Where other optimal cultivation conditions exist, it could be the case to remove or grind the coarser stones or to mix layers of soil with different textures to obtain a better final composition suitable for the cultivation of the olive tree.

Figure 11: soil rich in skeleton

Soil depth - The useful depth should not be lower than 80 cm, considering that most of the roots of the olive tree develop in the first 70 cm of soil thickness. Adjustments of soil depth are only viable when a deep tillage can remove compact layers or when, with the creation of a drainage system, it will be possible to lower the water level in the soil.

Soil acidity - The first symptoms of toxicity due to excess soil acidity occur around pH 5.5, due to a high release in the soil solution of ions such as aluminium and manganese and for the immobilization of other nutrients (calcium, magnesium, potassium, phosphorus, molybdenum, boron, copper). Conversely, when the pH rises to values higher than 8.5, in the presence of a high content in active limestone, there may be problems with ferric chlorosis. As far as the pH is concerned, corrective measures can be implemented but their application must be evaluated very carefully. The pH of acid soils can be increased by adding lime or slaked lime or carbonates, such as dolomite and calcium and magnesium carbonate. In general, corrective interventions must be repeated every 2-3 years in sandy soils and every 5-10 years in clay soils. The pH of alkaline soils can be lowered by adding calcium sulphate. In case of too high pH due to excess of limestone, it is advisable to choose cultivars resistant to ferric chlorosis.

Salinity of soils and waters - The olive tree is one of the most salt resistant tree species. Salinity refers to the concentration of dissolved salts in the circulating solution of the soil, which is measured as a specific electrical conductivity of the soil saturated extract expressed in dS/m: we can estimate a production reduction of about 10% if the electrical conductivity assumes values around 4 dS/m, about 25% with values around 5 dS/m and 50% and over with values around 8 dS/m. It should be considered that the different olive cultivars show substantial differences in terms of tolerance to salinity (e.g. cv. Frantoio is considered tolerant, Coratina, Carolea, Maurino and Moraiolo as medium tolerant and Leccino as susceptible).

The olive tree is also one of the most resistant species to sodic soils (expressed by the percentage of exchangeable sodium: PES), showing problems only when the PES reaches values of 20-40.

The olive tree has is more resistant to soil chlorides than most of the fruit tree species, in fact, it tolerates concentrations in the chloride saturated extract up to 10-15 meq/l, showing, under these conditions, a limited production reduction.

Excess of salt, sodium, boron or chlorides may depend on the use of irrigation water rich in such compounds. In case of strong accumulation of these elements, it is possible to intervene with abundant irrigations with good quality water that will bring the excess elements deep; this practice requires a large amount of water and is effective when the soil has good drainage power. However, the correction of sodium soils is rather difficult.

Soil and irrigation water pathogens - The presence of pathogenic fungi in the soil or in irrigation water, such as Verticillium dahliae or Armillaria mellea, very harmful for the olive, should be ascertained. As far as the Verticillium is concerned, it is not recommended to make a new olive plantation on a land where there were olive trees previously attacked by such pathogens or if the land was cultivated with species subject to this pathogen (such as solanaceous plants, cucurbitaceae, strawberry, etc.). Eventually, it is recommended to leave the land uncultivated or cultivated with grasses for a few years before establishing the new olive grove. Even in case of previous presence of tree plants with root rot caused by Armillaria mellea, it is opportune to postpone the plantation for some years, in the meantime cultivating herbaceous species.
In any case, when preparing the soil for the new plantation, to reduce phyto-sanitary risks, it is very important to remove as much as possible stump and root residues.

2.3 Orography and terrain exposure

The olive tree can be cultivated on flat, hilly or terraced land, the only limitation is the exposure and the possibility of access of the working machines.

In the case of land in the hills, for a convenient use of the operating machines, the slope should not exceed 15-20%.

Figure 12: at high latitudes, the hilly areas are the best to grow the olive tree thanks to the milder temperatures and lower atmospheric humidity

The olive tree prefers the coastal and sub-coastal areas, well airy and dry, but it grows and produces well also in the internal areas, of medium and high hills, preferably with slopes facing south, south-west or west, where the winter temperatures are less rigid than on the plain or on the mountain, and the risk of late frosts is reduced, and the brightness is high.

Plantation in the flat internal areas, with high air humidity and presence of persistent fogs, is not recommended.

Exposure to the east and south-east, due to the high excursion between day and night, can pose some risks in cold areas.

Exposure to the north is often unsuitable due to the strong reduction in light availability, low thermal levels and the increased risk of diseases.

2.4 Cultivar selection

The choice of cultivars to be used for the new plantation is strategic for obtaining good results and, therefore, it requires high attention. In case of error, in fact, there would be negative effects on the production and management of the olive grove for the entire duration of the grove.
The choice of the cultivar/s is functional to the type of olive grove:

- Plantation for the production of high quality, or typical, regional oils, or at low environmental impact;
- Intensive or super-intensive plantations aimed at increasing and providing the integral or semi-integral mechanization of cultivation operations (harvesting and pruning), for the production of standard oils.

2.4.1 General characteristics of the cultivars

The general characteristics of cultivars to take into consideration in all cases are the following:

- extent and level of fruit production and oil yield;
- tolerance to pedo-climatic constraints (frost, drought, salinity, etc.) and resistance to pathogens (Verticillium, peacock eye, olive knot, Xylella, etc.) and to insects (olive fly, black scale, etc.) endemic in the considered area;
- self- and inter-compatibility. In fact, most of the cultivars are self-incompatible and not compatible with many other cultivars, so, the inter-compatibility of the selected cultivars must be known. This requires the use of at least two inter-compatible cultivars in the same plot, but in general, it is advisable to use a higher number of cultivars (3 or 4), to avoid that the lack of flowering of a cultivar, and therefore the absence of fertile pollen, may reduce

fertilization of flowers of the other cultivar, and to take into account possible displacements in the flowering time among different cultivars.

- Oil characteristics, with specific reference to the fatty acid composition. In fact, in certain cultivation environments (when temperatures remain high along fruit ripening), some varieties may give an oil with a low percentage of oleic acid (< 70%); under these conditions it is very important to carefully select those cultivars able to guarantee the normal unsaturated/saturated fatty acids balance, as well as a high content in antioxidant substances (especially phenolic substances and tocopherols), and a good sensorial profile.
- Fruit pulp firmness and pigmentation, since the olives with high pulp hardness and limited or late pigmentation, in general, exhibit greater resistance to mechanical damage during harvesting and/or transport and/or possible preservation, which can cause alterations in the oil quality (increase of acidity and oxidation).

Figure 13: fruit branches of the Arbequina and Maurino cultivars, both characterized by a low vigor

For the realization of intensive plantations, the following criteria must be followed to select the most suitable cultivars:

- fitness to the mechanization of cultivation operations, with specific reference to harvesting.
- For optimal use of trunk vibrators for harvesting, cultivars with medium or high fruit weight (> 2.0 g) are required, with an almost contemporary ripening, to avoid the non-detachment of immature fruits, and medium resistance to fruit detachment.
- When using pneumatic or electric facilitators (combs, lashes, shakers, etc.), medium or low vigour varieties should be considered, otherwise it may be difficult to contain their height within the limits of 4.0-4.5 m, which makes efficient the use of such equipment. When using multiple cultivars, it may be useful to choose them with different maturation time, to harvest each of them at its optimal moment.

- The vigor of varieties, as well as their vegetative habitus (erect, expanded, weeping, etc.), other than influencing the harvesting systems, is also important for the choice of planting distances and canopy shape. Furthermore, it should be kept in mind that, in general, less vigorous genotypes have greater production efficiency and are more early bearing than the more vigorous ones.

If the goal is to obtain premium oils, that have particular compositional, sensory and/or health characteristics (e.g. high content in specific compounds), it will be necessary:

- to choose cultivars able to supply this type of product, also by considering the production of mono-varietal oils. To this end, an important role can be played by the so-called "minor" varieties, as they are characterized by an adaptation to specific areas with limited diffusion, which often produce oil characterized by peculiar and interesting compositional and sensorial characteristics, with a high degree of typicality.

If the objective is the production of typical oils, such as specific brands or those under protection (Denomination of Controlled Origin, PDO or Protected Geographical Indication, PGI), for the choice of the varieties it will be necessary:

- to refer to the rules set out in the relative production regulations, defining cultivars to be used and corresponding percentages for each of them. If the new olive grove is an extension, the choice must consider the varieties already cultivated in the farm, so that the final proportions will remain in line with the specified regulations.

Considering that it will be difficult to find cultivars that meet all requirements, priorities must be established. For each pre-selected cultivar with the above criteria, it must be considered that almost all cultivars have a very restricted geographical distribution, therefore to each area only correspond some local varieties, which show a perfect balance with the pedological, environmental and agronomic conditions of the area. So, the first varieties to be taken into consideration must certainly include those of the area where the olive grove will be established. In case local varieties do not correspond to the needs of the new plantation (too vigorous, not very productive, oil quality not meeting the objectives, etc.), varieties with a wider diffusion or suitable for intensive cultivation systems should be considered, for which agronomic behaviour is already known in a wide spectrum of environments.

If the olive grove is conducted according to the integrated or biological production method, particular importance must be given to the resistance to biotic and biotic adversities. Among these, the low susceptibility to fly attack is an aspect of fundamental importance, especially in the case of organic cultivation. In this regard, it must be considered that resistance to the attack of this pest is higher for small-fruited varieties, while the early-ripening varieties with penetration-resistant

epicarp can more easily escape late attacks. In cultivations conducted with biological methods, the presence of cultivars ripening in different periods or with small and big fruits is not recommended, as this would favour the succession of several fly generations.
More generally, when a new olive orchard has to be built in an area characterized by a high presence of a specific pathogen or parasite, the resistance of the cultivars to such adversity becomes the main factor to keep in mind. Often, varieties with particular characteristics of resistance can be found among those less common in the area, thanks to the strong and specific adaptation to that environment.

2.4.2 Choice of pollinators

When the cultivar of choice is self-incompatible, particular attention must be given to the choice of pollinators. Please, be aware that it has been recently demonstrated that there are two groups of inter-compatibility and cultivars belonging to one group are inter-incompatible and compatible to those of the other group and vice versa, so, it is necessary to know to what group belong the main varieties in order to select the best cultivars to work as pollinators.
If the most effective pollinators for that cultivar are known, the choice must focus on these, otherwise, cultivars usually associated with the reference one should be considered.
Pollinating cultivars also must have high flowering and abundant pollen production, with a flowering time as much as possible coinciding with the cultivar to be pollinated.
In general, even self-compatible cultivars benefit from cross-pollination and, therefore, intercropping with pollinating cultivars is recommended.

2.4.3 Choice of a cultivar spread in an environment different from that in which the new olive grove is to be built

If you intend to use a cultivar previously widespread in another environment, you should evaluate its vegetative and productive response in the new environment, also in terms of sensitivity to adversity and product quality. In general, the greatest problems can occur when a cultivar is moved from north-south or south-north. In the first case, due to the possibility of failure to meet the needs of cold for flowering, or for the shift of the flowering period, or for variations in the fatty acids composition. In the second case the cultivars may show problems of susceptibility to low temperatures. Therefore, before introducing a variety in an environment with climatic characteristics different from the original ones, it is advisable to carry out preliminary experiments to verify their response.

2.5 Choice of the plant

Plants available on the market may have been propagated by different systems:

- Grafted plants: they are generally grafted onto frank rootstocks (seedlings) because t for the olive are not yet available rootstocks able to confer particular advantages. However, grafting finds useful application for those varieties with low rooting capacity by cuttings. Grafted plants are generally put on the market one year after grafting. In conditions of water scarcity, they can perform better thanks to the initially deeper root system, but after a few years the root system will be the same as self-rooted plants.

Figure 14: grafted plants

- Cutting plants: they derive from the rooting of shoot portions. Rooted cuttings are then grown in pots and can be ready for planting after one year from rooting. Self-rooted plants are uniform, with a rapid entry into production and the cost is generally lower than the grafted ones. Furthermore, in case of need to raise the plants from the base (for example following cold damages), it is not necessary to re-graft.

- Micro-propagated plants: It is preferable to use in vitro propagated plants only in the case of purchase on the international market, because micro-propagated plants are more controlled under the phyto-sanitary point of view, thus reducing the risk of transmission of viral, bacterial or fungal diseases.

Figure 15: self-rooted plants

Regardless of the system they were propagated, the best plants are those of 1.0-1.5 years age (in the case of grafted plants we mean from the moment of grafting), with a minimum height higher than 80-100 cm, grown in pots (volume about 4 l), with a well-developed root system.

It is preferable to buy plants with a single stem, eventually branched laterally with short shoots or with some buds in the apical portion. Plants correctly prepared in the nursery can be raised in the field with any training form.

Smaller or larger plants can also be used, but over 2-2.5 years are not recommended. For small plants we must pay particular attention to the control of weeds along the row and to training pruning. For large plants, there is the major risk of a transplant crisis, especially if the plants were raised in too small pots, where the root system did not develop correctly.

Figure 16: grafted plant of 1 year and self-rooted plant of 2 years

In the European Union, plants must comply with the requirements imposed by the Community rules and, therefore, be accompanied by the Plant Passport and the marketing document with the indication "EC Quality", which requires the absence of the main parasites and varietal compliance. Having the possibility to choose, it is advisable to purchase certified plants from phyto-sanitary and genetic point of view, according to the National Voluntary Certification Service of plant propagation material (D.M. 16/6/1993), which guarantees a superior quality to the "EC Quality".
In case of organic olive grove, plants must come from nurseries that adopt the organic production method.

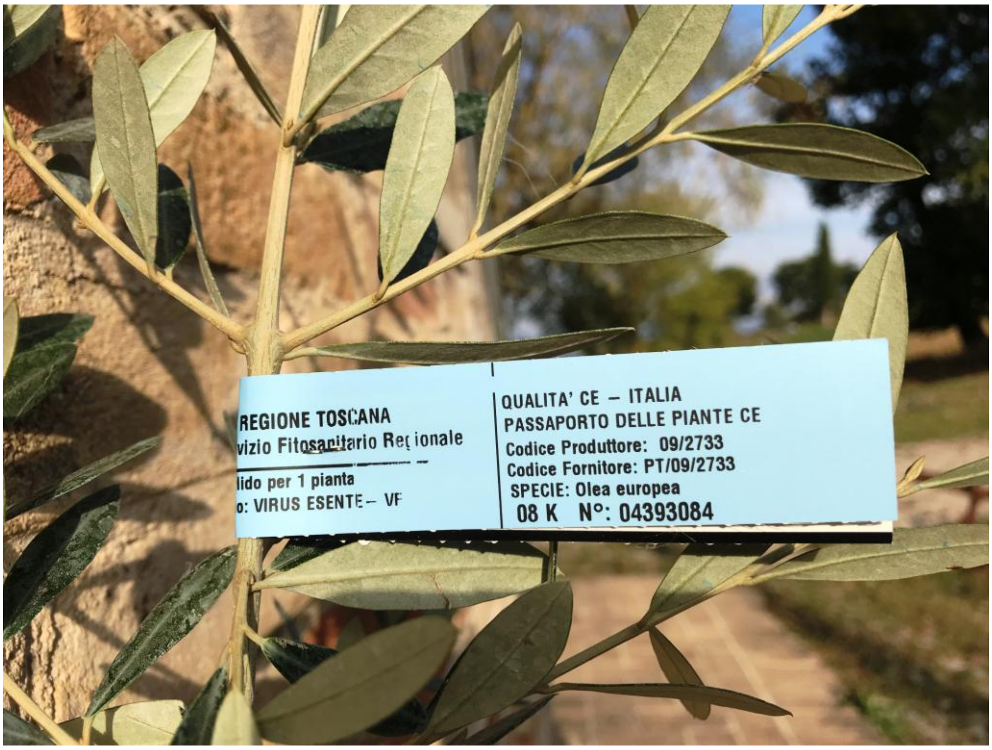

Figure 17: certified virus-free olive plant

2.6 Plant density

The planting distance among trees must be established according to the final size that plants will reach in the adult phase, depending on the vigor of the cultivars, the soil fertility, the climatic conditions, the adopted training system and the applied cultivation techniques, with particular reference to irrigation. The need to implement mechanization of cultivation practices, with particular regard to harvesting, will indirectly influence the choice of distances between rows and plants along the rows. At full growth, the tree canopies must remain well-lit and airy and, therefore, plant distances and distribution must be defined in such a way as to avoid mutual shading between neighbouring plants.
For the olive tree, unlike other fruit species, rootstocks able to induce a reduction of plant vigor have not yet been selected and very few cultivars are characterized by low vigor, therefore, except for super-intensive plantations, planting distances are usually relatively high.

The growth rates of plants are quite slow and, therefore, time needed to reach full development is relatively long (8-10 years). Therefore, in the first few years after plantation plants are quite distant and there is no optimal use of the available light energy. On the other hand, high plant densities may allow an initial better interception of solar radiation and therefore a higher production per hectare but, after a few years they may determine an excessive competition among plants, especially for light, with consequent production problems and the need to perform periodical drastic pruning to contain canopy width and height.

Figure 18: distance between plants in organic olive growing must be relatively large

In most situations detectable in Italy, the best results are obtained with a number of plants per hectare between 200 and 400: the highest densities are applied for relatively low-vigor cultivars, in favourable environments or in the presence of irrigation, vice versa, lower densities are used for more vigorous cultivars, in less favourable environments or when irrigation is not available, in order to exploit as much as possible the available environmental resources. At equal conditions, the monocone training system, due to the smaller lateral expansion of the canopy, may allow to use relatively smaller planting distances.

The most used plant densities are the following:

- Square, from 5x5 m to 7x7 m. It allows a uniform illumination of the crowns and the possibility of longitudinal and transversal movement of operating machines.
- Rectangle, with plant distances ranging from 6 to 8 m between rows and from 4 to 7 m along the row. A greater distance between rows can facilitate the transit of the mechanical means in the inter-rows. In general, the rectangular distribution is to be preferred with low-vigor cultivars, with upright vegetative habitus and with the monocone training, while the square one is more suitable for vigorous cultivars, with expanded habitus and with a vase or globe training form.

In the case of particularly vigorous varieties or in arid environments, characterized by limited water availability (rainfall ≤ 300-400 mm/year, without irrigation), the number of plants should be reduced to 100-150 plants/ha, with a square plant distribution at 8x8 or 10x10 m. In fact, by reducing the number of trees per unit area, the amount of soil available for each plant increases, as well as water and nutrient reserves.

To optimize the use of energy available during the initial development phase, the olive plant density may be increased by doubling the plants along the rows (e.g. 3 m instead of 6 m distance), then removing the plants in excess at the time of the appearance of competition phenomena. However, the advantages derived from this dynamic density, corresponding to a production increase in the first years of planting, can be cancelled by the initial double cost to buy the plants and the costs of thinning, which must be done when first shading problems between contiguous plants will appear, usually 10-12 years after planting.

For what concerns plant density referred to the mechanical agriculture operations (in particular harvesting) it should be considered that, for a smooth movement of trunk vibrators, it is necessary to have distances between rows of at least 5m and along the rows, in the case of use of intercepting frames such as inverted umbrella, spaces of at least 1-1.5 m between canopies, in order to avoid obstacles to the opening of the frames itself.
In olive groves cultivated according to the biological method it is preferable to have planting distances greater than 0.5 m than conventional olive groves, in order to allow better lighting and ventilation of the foliar system, thus counteracting the development of pathogens and parasites.

2.6.1 Density and distribution of pollinators

Pollinators, necessary for self-incompatible cultivars, which represent most of olive cultivars, can represent the 10-15% of total trees and should be evenly distributed within the plantation, or arranged on rows alterning those of the main cultivars. In this last case it is advisable do not go below 15-20% (1 row every 5-6).
If the plot is located in an area with prevailing winds during the flowering period, pollinators should be placed in such a way as to be well invested by the wind itself and thus ensure the best distribution of the pollen.
If the new orchard is built in an area where there are other olive groves, these can also contribute to the pollination of the new one.

2.7 Socio-economic aspects

To assess the suitability of the planting site to grow olives, it is also necessary to consider the presence of the necessary infrastructures for the cultivation, harvesting and oil extraction, such as:

- the presence of mills in the neighbouring area, taking into account the need to reduce the time from fruit harvesting to the milling, especially in areas with relatively high temperatures during harvesting (unless there are cooling systems for the fruits);
- the availability of skilled workers, able to perform the main cultivation operations in the olive grove, with particular reference to the more complex ones, such as the pruning;
- the presence of suitable technical assistance, meteorological and phyto-sanitary alert services, and those for the promotion of products and territory.

2.8 Soil preparation

2.8.1 Soil cleaning, surface arrangement and drainage

First, it is necessary to make sure that there are no hydrogeological and landscape restrictions to be respected and, if any, it will be necessary to request all authorizations from competent authorities (e.g. for soil movements that may change the hill skyline).

The soil must be cleared by any previous plant crop remains, taking care not to leave residues. Scrapers, mechanical shovels or excavators must be used for this purpose, also in case of replanting, after grubbing up the old olive grove and removing stumps and large roots, as the olive tree does not suffer for tiredness of the soil. Replanting is discouraged when there are outbreaks of Armillaria or Verticillium, as previously reported.

In lands with numerous shrubs, special horizontal-hedge trimmers can be used that cut and chop vegetation that can be used to enrich the soil with organic matter.

If stones of a certain size are present in the plot, it is necessary to proceed with the stone clearance. In the presence of not very large stones, it is also possible to use crushing machines that break them, but the economic convenience of this operation must be evaluated.

If the surface of the soil is irregular, it is advisable to level it, using high-powered scrapers or mechanical shovels, eliminating depressions and bumps, in order to facilitate the movement of the machines and avoid any standing water that, in addition to creating problems of root asphyxia, may favour attacks by agents of collar rot and Verticillium.

If for the soil surface modelling it will be necessary to carry out excavations that go beyond the active surface layer of the ground, to avoid bringing shallow fertile layers to the surface, it would be advisable to laterally accumulate the surface layer, then redistribute it on the surface once the operation of excavation is completed. This operation allows the maintenance of the most fertile layers of the soil close to the surface, where most of the roots develop, resulting in better and more regular growth of the plants. If the intervention is not practicable because it is excessively expensive, it is necessary to perform at least an abundant organic fertilization in the area where a deep sterile soil has been brought to the surface. In hilly areas, the excavation and carryover operations must be carried out avoiding worsening the stability of the slopes. To this end, it is important to ensure good cohesion between the land on site and the one reported, scarifying the soil and then progressively adding 30-40 cm thick soil layers, eventually pounding the ground with the passage of mechanical means.

The olive tree is particularly sensitive to water stagnation, also because it may favour fungal attacks (root rots). For this reason, good drainage of surface water must be guaranteed. In flat areas, in case of risk of water stagnation (e.g. poor permeability of clay soils and/or presence of high water layer and/or the occurrence of intense and long-lasting rains and/or where water flows with difficulty due to a poor slope), it is necessary to build a sewerage or drainage system (underground drainage pipes), which must guarantee a cultivation layer of at least 50-60 cm.

Drainage is generally made of polyethylene or corrugated and perforated PVC, placed with special machines at a depth of 1-1.5 m, 5-10 m apart in clay soils and 20-25 m in relatively loose soil. The slope of drains must not be lower than 3 ‰ and drains must flow into collectors able to dispose the collected water. In order to prevent the occlusion of drain holes, it is preferable to use tubes coated with synthetic fiber or coconut fiber.

In case of clay soils or where deep stagnations are envisaged, with risk of landslide, drainage installation may be useful. Eventually, it will be realized where the water tends to accumulate.

The sinking is effective in eliminating water in all situations that determine stagnation, while drainage may not be sufficient in soils with particularly low permeability (e.g. very clay soil), in fact, in this situation the flow of water towards the drains would be very slow, making them poorly effective. In the most difficult conditions, the distance between the ditches should not be greater than 20 m, while in rather permeable soils it can reach up to 35-40 m. Drains must pour the water in natural drains, such as ditches, rivers, lakes, etc., or in artificial ditches (foragers or collectors). Main drawbacks of sinking are the reduction of the productive tare, the need for frequent maintenance and the obstacle to the circulation of vehicles.

In hill areas, up to slopes of 5-10%, to reduce surface runoff and encourage the accumulation of water reserves in the soil, it is appropriate to arrange the rows transversely to the slope and, therefore, the operations related to soil management will be carried out crosswise.

Figure 19: olive grove terraced with stone walls

With higher slopes, rows must be arranged in the direction of the maximum slope (along which the cultivation operations will then carried out). In this case, the length of rows should not exceed 100-150 m if the slope is between 10 and 20%, and 50-100 m if it is greater than 20%.

When the slope of the land exceeds 10%, especially if the plot is long, it is useful to trace some temporary ditches according to the level curves, at a variable distance from 30 to 70-80 m, depending on the slope and the soil permeability. Ditches must have a depth of at least 15-20 cm, a slope ranging from 1% to 2.5% and a length not exceeding 200 m. These ditches must be constantly restored over the years, when managing the soil surface. In case of grass cover, it is not necessary to realize the aforementioned ditches. Water must be removed from the ditches by means of natural or artificial drains that convey the waters to the valley, preferably consolidated by green cover, laying stones or cement slabs in the bottom, etc.

In case of excessive length of the plot in the direction of the slope, it is advisable to reduce it by making transverse ducks.

In the case of confluence of surface water from above ground, it is advisable to build a guard ditch upstream of the plot, at least 50-70 cm deep, which collects the waters of the upstream slope and convoys them in the main hydraulic network.

When the slope of the plot exceeds 30%, terraces with wall fieldstone or embankments must be built. This operation, considering the high costs and the difficulties it creates for mechanization, can only be justified in particular cases, such as for the production of special valued oils or the need to consolidate the slopes.

Figure 20: embankments in olive grove

During soil preparation, it is also necessary to provide for the realization of the service infrastructures, such as farm roads, excavations for burying the irrigation system, ponds or tanks for water collection, wells and, where necessary, windbreaks.

2.8.2 Fundamental fertilization

Fundamental fertilization aims at bringing phosphorus (P), potassium (K) and organic substance into the soil layers where the root system of plants will develop. To perform it rationally, it is necessary to carry out soil analysis and compare the obtained values with the reference ones, in order to establish the quantities of fertilizers to be supplied. The background fertilization does not concern nitrogenous fertilizers that will be introduced annually.

In case the content of organic matter and nutrient elements of the soil is at levels lower than the reference ones, it will be necessary to perform the basic fertilization.

The thickness of soil taken into consideration to evaluate the amount of organic matter and nutrients to be made is that in which most of the roots develop (up to 60-80 cm depth).

Table 1: Ideal parameters of the land for the planting of an olive grove (Tombesi, 2002).

Parameters	Ideal Range
pH	7,0-8,0
Ca $_{exchangeable}$	1650-5000 ppm
K $_{exchangeable}$	50-150 ppm
P $_{assimilable}$	5-35 ppm
Mg $_{exchangeable}$	100-200 ppm
N	>0,1 %
Organic substance	>1%

In medium fertility media (Table 1), generally 150-250 kg/ha of phosphorus, 200-300 kg/ha of potassium and, if available, 40-60 ton/ha of mature manure are needed (in a poor land, up to 100 ton/ha can be distributed).

If the organic matter content of the soil is particularly low, it will need to be increased gradually over several years, by adding adequate amounts of organic substance, even with the crop in place. In loose soils the organic substance is rapidly mineralized and also phosphorus and potassium have a high mobility, therefore it is preferable to fraction over the years the intake of organic substance and fertilizers, in order to avoid phenomena of depletion.

Mature bovine manure is the most used organic fertilizer because it is excellent and relatively easy to find, but manure from other animals can also be used (horses, sheep, rabbits, chickens, etc.), as well as fertilizers obtained from composting various substances (pomace, straw, stalks, etc.), separated or mixed together, also deriving from urban solid residues (USR), but only if of high quality (low content of salts and heavy metals, in particular). Composting, compared to manure, should generally be used in 30-50% reduced doses compared to manure, considering that they have a relatively high dry substance content (from 35% to 55%).

In case the content of organic matter and nutrients of the soil is considered sufficient (Table 1), it will not be necessary to perform the basic fertilization. In the latter case, on the contrary, it must be considered in the management of fertilization during the juvenile and production of the olive tree grove, not by making or reducing the contribution of those non-leaching elements (e.g. phosphorus and potassium) present in quantities exceeding those of reference until their level has fallen to the level of sufficiency.

The thickness of soil taken into consideration to evaluate the amount of organic matter and nutrients to be made is that in which most of the roots develop (up to 60-80 cm depth). When using soil amendments available on the market, the economic convenience must be carefully considered, considering that large quantities must be used in order to significantly affect the humic balance.

Figure 21: fertilization with manure before planting

In the case of organic cultivation, within the European Union countries it is necessary to use the organic fertilizers permitted by Annex II of the EEC Regulation 2092/01.

If the fertilizers mentioned above are not available, a valid alternative to increase the organic substance is represented by the green manure, using mixtures of grasses and legumes, such as:

- with autumn sowing: barley (75 kg/ha) + vetch (Vicia villosa: 25 kg/ha or Vicia sativa: 50 kg/ha), or, alternatively, barley (50 kg/ha) + faba bean (100 kg/ha);
- with spring sowing: with the same essences and quantity of the autumn sowing or substituting the barley with oats (70/80 kg/ha) or with Italic ryegrass (15-20 kg/ha).

The vegetable mass produced must be buried on site in order to produce organic substance. The green manure can be done before soil preparation or after the planting, in this last case the burial must be more superficial. At the time of use, green manure generally provides 4-6 ton/ha of dry organic matter, equivalent to 0.4-1.8 ton of humus. It is good to remember that with the green manure practiced as background fertilization, the main objective is to have a good yield in humus, so it is advisable to do the mowing in a relatively advanced period, after the flowering of grasses and legumes, when the maturation process starts and, therefore, there is an increase in lignin and cellulose content in the plant mass.

As regards the phosphorus and potassium inputs, can be used simple superphosphate (19-21% P2O5) or triple (46-45% P2O5), Thomas slag (16-18% P2O5), potassium sulfate (48-52% of K2O) and potassium saline (40% K2O).

For orchards cultivated according to the organic method, fertilization is based on the contribution of organic matter, but also fertilizers of natural origin can be used. For phosphorus, natural soft phosphate (obtained from the phosphorus grinding), aluminum-calcium phosphate (Phospal) or Thomas slag can be used. In naturally acidic soils, natural phosphate and Thomas slag are preferable, while in calcareous alkaline soils it is better to use aluminum-calcium phosphate. Potassium raw salts and potassium sulphate containing magnesium salt can be used for potassium.

The background fertilization should be performed before the deep soil plowing, in order to bring fertilizers in the thickness of soil that will then be explored by the roots.

2.8.3 Deep soil tillage

The deep soil tillage before planting:

- encourages deepening of the roots and water percolation, also by removing any mechanical obstacles;
- improves the soil aeration;
- burying soil fertilizers and materials to correct the soil chemical composition and pH;
- improves the availability of nutrients;
- mix all different soil layers;
- completes the removal of root residues from previous crops.

Depth. Tillage operation is particularly important in compact soils, to favor plant root development, in this case it is necessary to reach a depth of 80-100 cm. On loose soils, if they have a good degree of natural aeration and do not have stagnant water, it is sufficient to reach a depth of 50-70 cm.

Methods. It is preferable to use the burrow when it is useful to mix different layers of the soil (e.g. clay and sand). In all other cases, since the surface layer of the soil is generally more fertile than the underlying ones, it is preferable to perform a double processing or two-layer processing, which consists of a 40 cm deep plowing, with which residues and fertilizers used for background fertilization are buried, followed by a dissent of the land with ripper up to the depth of 80-100 cm, that allows to break in depth the soil layer created by the burrowing plow. Excellent results are obtained also with crossed ripping, at a distance of 40-50 cm.

Figure 22: deep soil tillage

The two-layer processing is particularly good when the deep layer is rocky or stony, as it allows to till the ground without bringing too many stones to the surface. If the plowing will bring stones to the surface, they should be removed or shattered.
Other advantages of the two-layer processing are: to bring fertilizers in the soil layer where most of roots develop, avoid creating the compact layer, which can cause difficulties in water infiltration, with possible consequences also on the stability of slopes, reduce soil erosion that can occur in hilly terrains worked in the direction of maximum slope.

Time. The best period to perform soil plowing is the summer preceding the plantation, but it can also be done in other periods, if soil is at its best humidity condition. In the case of double processing, the two operations can be performed separately, for example one in spring and the other between late summer and early autumn.

2.8.4 Finishing of the ground surface

After the plowing and before to open the holes for planting, one or more surface finishing operations must be carried out, to refine and level the soil. For this purpose, harrows (with discs or teeth) or grubbers are used. This operation is also useful to complete the eradication of any remaining crop residues.

Figure 23: finishing of the ground surface

2.8.5 Spatial distribution of trees

Before planting it is necessary to exactly define the position of the rows and of the plants along the rows, based on the plant density previously decided.
The position of each tree can be established on the terrain with the help of different instruments, such as tacheometers, surveying squads, metric tapes, poles, wires, GPS systems, etc. As a first step, the orientation of the rows must be defined, by means of a reference base alignment drawn with poles, generally in a north-south direction or along the major side of the plot, after which, using a tacheometer or, more simply, a metric string, perpendicular to this will be defined main alignments at regular distances (usually multiples of the distance between the rows).
Once the main alignments have been identified, the square will be completed with the help of metric rope, poles and stakes, identifying the position of all the rows and, along these, of all the points where plants will be placed.

2.9 Plantation

2.9.1 Time

In mild winter climates, where the risk of cold damages is negligible, especially if characterized by limited spring rain, it is preferable to plant the plantlets in autumn, otherwise at the end of winter - early spring. In the latter case, in mild environments it can be done starting about a month before the end of winter, while in those at risk of frosts it is better to postpone it after the beginning of spring. With potted plants and where a good water availability is assured, it is still possible to plant later during the summer. In hot and/or arid environments, where the main problem is spring-summer aridity, planting can be conveniently done during the winter.

2.9.2 Dig the holes and plant the trees

Before digging the holes, to keep memory of the exact position of the squared reeds that will be removed, it is necessary to provide a reference system to plant the guardians exactly in the position of the barrel or at a fixed distance. For example, it can be used a 1-1.2 m long board with 3 marks, 2 at the ends and one at the centre. Before digging the hole, make the central mark coincide with the stake, placing two pipes at the 2 side signs, then remove the central stake and dig the hole. Then the same rod will be used again to plant the brace in the same position where the barrel of the square was located.

In correspondence of each plant a hole must be dug with a diameter and depth of about 40 cm. The operation can be performed manually or with a mechanical auger. Before opening the holes, make sure the soil is dry, especially if clay, to avoid the compaction of the walls. The holes could also be opened some time before planting, so that the atmospheric agents may improve the structure of the walls and the earth set aside around the holes, which will then be placed around the ground that contains plant roots.

Figure 24: auger for making holes

On the bottom of the hole should be placed the guardian pole (see next paragraph), placing it north of the plantlet, to prevent the pole from shading the tree leaves. In the case that basic fertilization was not previously performed, manure or organic substance can be added on the bottom of the hole, then covering with a thin layer of ground, to avoid roots directly contacting the fertilizer.

After ascertaining that the plant pot ground is well moist (watering plants the day before planting), potted plants will be placed along the rows near the holes where they will be planted. To extract the ground and roots from the pot, it will be necessary to turn it over, taking care not to break it, after which plants must be positioned so that the collar will remains no more than 5 cm below ground level, orienting the tile near the guard pole. Only in special cases, plants can be placed a little deeper: with self-rooted plants and loose soils, in order to deepen the roots, or with grafted plants and in areas at risk of frosts, to cover the grafting point and favouring the release (root emission in the area above the grafting point).

Figure 25: correct positioning of the plant

Once the plant has been correctly positioned in the ground, the hole will be filled by placing the earth set aside around the roots and ground, slightly compressing it so that it adheres well to the ground, avoiding root stress and break. To avoid runoff of rain or irrigation water, especially in case of sloping terrain, it is advisable to form with the ground a small basin around the plant.

Once planted, plants should be tied to the pole in 2 or 3 points, depending on plant height, with soft tubular plastic straps. To avoid direct contact between the plant and the support and make the knot more elastic, the wire should be placed as an 8, with a bending between the trunk and the post, avoiding tightening the stem.

Immediately after planting, plantlets should be irrigated by giving at least 10 l/plant of water, to improve the contact between soil and roots and to provide the water necessary for the good rooting of trees.

In the case of intensive plantations or for planting large surfaces, it is possible to use transplanting machines that, once established orientation and distance of the rows, can dig holes or furrows and plant the trees in succession along the rows.

Figure 26: tying plant to a pole

2.9.3 Tutors and framework

Tutor material. Different types of materials can be used. Wood poles are usually made from chestnut, but can also be of ash tree, hornbeam, pine or bamboo. Poles treated with products that prolong their life can be found on the market, or they can be treated on the farm, by dipping their basal part in a 1% copper sulphate solution for 3-4 days or they can be left in the natural state, accepting a shorter duration (5-6 years), considering that plant trunks during this time will reach sufficient strength for self-sustaining. The plastic poles should be reinforced (e.g. with hexagonal or octagonal stellata section). It is also possible to find on the market poles made with other materials (iron, recycled materials, etc.) whose choice depends on price and technical characteristics.

The galvanized iron poles are available in various types, they are practical and easy to handle. They usually have thread loops. They can also be covered in plastic (more expensive, but sometimes with a minor visual impact). It is also possible to apply mixed solutions: use wood or prestressed reinforced concrete for the headboard poles, and galvanized iron for the intermediate ones.

Figure 27: ***the brace in knurled iron rod can damage the plant***

For the construction of the irrigation system support structure, wooden poles, prestressed concrete or iron can be used.

Guardian size. The guardians, driven into the ground at a depth of about 0.5-0.7 m, must have a height above ground of 1.5 m for pot-grown plants and m 2-2.5 for those raised to monocone . The wooden poles must have a diameter of about 8 cm, while the plastic ones may have a width of around 6 cm, and those of bamboo of 3.5-4 cm.

If the new olive grove is equipped with a drip irrigation system supported by a structure made of poles and wire, on which the dripping lines are attached, braces can be attached to the wire itself, to increase the overall stability of the support structure, and less robust piles can also be used. It should however be remembered that, in all cases, the installation of suspended irrigation wings can cause problems for the harvesting equipment's, especially when using trunk vibrators and inverted umbrella interceptors.

2.9.4 Mulching

To avoid the growth of weeds close to the olive trees, mulches can be carried out along the rows (before planting the plants), for a width of 1-1.5 m. Mulching, besides facilitating the management of the soil along the row, favours the initial development of plants, due to the lack of competition with the weeds and for creating better conditions for the root growth.

In areas where attacks of rodents (voles, hares, etc.) may occur, it is advisable to apply shelters to the plants, made by rigid plastic pipes (generally in polypropylene). Shelters also facilitate soil management operations along the rows, reducing the risk of damaging the plants by mechanical tools, while, when using herbicides, they can avoid the risks of a direct product contact with the olive plants. The shelter should be about 70-120 cm high, if used for plants 60-120 cm tall that will be raised at vase and branched at 1.0-1.2 m from the ground, because they determine a more rapid increase in height and an easy pruning.

Figure 28: olives protected with shelters

2.10 Post-installation operations

After planting, at the vegetative sprouting, or, in the case of spring planting, after 10-15 days from planting, we recommend the following operations:

- localized nitrogen fertilization (2-4 times during the spring, for a total quantity of about 50 g/plant, avoiding the direct contact of the fertilizer with the tile);
- emergency irrigation, in case of drought and in the absence of an irrigation system;
- elimination of weeds by terrain treatments or herbicides;
- elimination of any sprouts that develop along the plant stem and removal of lower shoots, with summer interventions;
- possible phyto-sanitary treatments, in case of attack of pathogens and/or pests, with particular regard to margaronia, olive moth, black weevil, peacock eye and knot disease; in particular, insects damaging the tips determine the interruption of growth and the development of lateral shoots, with consequent slowdown of growth and greater difficulties in the formation of the crown;
- replacement of dead plants.

Figure 29: during the spring-summer season, to facilitate irrigation, a small basin can be created around the plant

Figure 30: weed control in the first years after planting is very important

3 SOIL MANAGEMENT

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The priorities pursued through land management are:

- enhance water resources, increasing the formation of reserves thanks to a better infiltration and conservation of water in the ground;
- preserve nutritional resources;
- eliminate/limit soil erosion;
- improve the structural conditions of the soil, also to avoid water stagnation;
- facilitate the execution of other orchard operations.

Land management can involve the elimination of grasses through soil working, chemical weed control or mulching, or limiting the infesting vegetation through controlled green cover. Considering the purposes of this handbook, chemical weeding will not be taken into consideration.

3.1 Soil working

3.1.1 Advantages and disadvantages of soil working

Superficial ground working, performed with different tools (plows, grubbers or harrows), at different depths and at different times of the year, are very effective for:

- control of weeds, which exert strong competition with the olive trees, especially during the summer-autumn season; in fact, it represents the most common technique in dry areas, while its importance is reduced in areas with good natural water availability or in irrigated olive groves, especially with adult trees;
- the possibility to bury fertilizers and pruning residues after shearing;
- the action of contrast to the development of soil pests, as they expose insect larvae to the action of insectivorous birds and, in summer, nematodes and fungi to dehydration;
- the destruction of any rodent dens.

Figure 31: in young olive groves, soil tillage is important to eliminate risks of water competition

On the other hand, soil working may cause several problems:

- in the hills, it favors superficial erosion; the severity of erosion and its impact on the productivity of trees are often not adequately considered, as the continuous leveling of the surface of the ground implemented with the work can mask the phenomenon that, in fact, with steep slopes, can cause considerable losses of soil per hectare every year (in hilly terrains the erosion can easily reach and exceed 20-30 ton/ha/year of soil), equivalent to a thickness of several millimeters; therefore, with slopes greater than 5-10%, it would be advisable to choose alternative systems of land management; in fact, even if in a freshly worked soil the infiltration speed of water is higher, due to relative rains intensity, can form an impermeable surface "crust", which reduces rainwater infiltration to determine, in the case of frequent rains, surface sliding phenomena similar to those encountered with weeding;
- it can cause, above all with the use of plows, the formation of the "compacted layer", i.e. a thin impermeable layer that forms beneath the layer worked in the relatively rich soils of clay or silt, which reduces the water infiltration in the deep layers of the soil;
- it prevents the roots from growing in the surface layer of the ground, forcing them to develop more deeply, under conditions, therefore, of lower aeration and low content in nutrients; this is more severe in heavy soils, and therefore insufficiently ventilated. In these conditions it is therefore necessary to reduce the working depth; the absence of roots close

to the surface of the ground (where they are destroyed by the work) also prevents water from being absorbed during low intensity and intermittent rains, such as those that often occur in summer, which wets only a few centimeters of land;

- it induces wounds to the roots causing, in addition to direct damage, also the risk that, through the wounds, could penetrate pathogens;
- it determines a reduction of the organic substance in the soil, because exposure to air and sunlight accelerates its mineralization;
- it constitutes a rather expensive land management technique in terms of necessary machines, fuels and labor (on average 8-12 hours per hectare per year);
- it reduces the lift, the capacity of the ground to bear a weight without suffering structural damage; consequently, the transit of machineries when the soil is wet determines its compaction and this prevents being timely in the execution of orchard operations (e.g. pesticide treatments, harvesting, etc.).

Figure 32: in the slopes, to reduce the risk of erosion, grooves can be applied transversely to the slope

In soils that tend to be compact, it is advisable not to work when they are very dry and avoid the use of operating machines that excessively chop the clods (some types of cutters).

In order to avoid the formation of a working layer, it can be used the sub-soiling, which consists in making a periodical (every 3-4 years) groove in the center of the inter-row, by means of a subsoiler, up to 40-50 cm of depth.

Figure 33: subsoiling technique

Soil compaction is deleterious because, decreasing permeability, it increases the risk of erosion in hilly areas or stagnant water in the plain, and causes root asphyxia due to the lack of oxygen and the accumulation of substances (e.g. ethylene) that inhibit root development, which result in reduced plant vigor and productivity, leaf yellowing, root rot, etc. For this reason, in processed soils, it is preferable to avoid the use of heavy mechanical means during rainy periods. Therefore, in soils generally compact, it is advisable to replace the autumn processing with a temporary green cover.

3.1.2 Frequency, timing and depth of tillage

During the year, normally, 2-3 (3-4 in hot environments) land working are sufficient, in spring/summer.

An autumn soil processing could possibly be useful both for burying the organic fertilizers and the mineral ones that are not very mobile (phosphorus and potassium), and to facilitate the infiltration of the autumn-winter rains, also breaking the eventual manufacturing layer.

In environments not particularly drought, when it is not necessary to bury fertilizers and especially when erosive phenomena are expected, autumn tillage must be replaced by a temporary autumn-winter green cover.

The spring-summer workings, destroying the weeds, reduce the water consumption from the plant soil cover, usually high since the beginning of the spring because herbaceous plants, with a very superficial root apparatus, start growing early, at the raising of ground temperature, before the olive trees. However, in many olive-growing areas, water competition during this period may be not relevant, as it occurs concurrently with heavy rains.

Figure 34: autumn tillage in an olive grove

The number of interventions needed during the spring-summer period depends on the climate course.

- A first soil processing must be carried out before inflorescence emission (April), at the end of the rainy period. This intervention should be done with caution because damages to the root system during this period can have negative effects on shoot growth and on flowering.
- In June-July a second soil work should be carried out and, if new plants grow in the meantime, another one should be done in August.

Despite the inconveniences associated with soil processing, this system of land management is very useful for young plants and in environments under severe water shortages, where it is therefore important to completely minimize the water competition exerted by herbaceous plants.

In any case, in order do not negatively affecting the physical characteristics of the ground, you must avoid working when the ground is too wet or too dry: the best condition is to "tempera", that is when, taking a little soil, it shatters easily without pulverizing or kneading.

Figure 35: temporary natural autumn-winter green cover

Taking into account the superficial distribution of the olive root system, deep processes must be avoided, especially when the olive grove is young or during the growing season. The intervention depth should not exceed 10 cm for spring-summer processing and no more than 15-25 cm for the eventual autumn processing.

3.1.3 Soil processing tools

For the first spring soil processing, light tillers or disc harrows are more suitable, while for the successive ones, toothed harrows are preferred. In particular, the disc harrow is used when, due to the spring rains, which oblige to delay processing, it is necessary to intervene on weeds already very developed, whereas it should not be used later, as it would cause high water losses due to evaporation and would favor the formation of the processing layer.
The use of milling machines (rotary hoes) should be limited as much as possible, as it promotes the spread of weeds and causes the formation of the processing layer. However, today there are models of drills ("nail", "straight knife") that strongly limit this risk. In some areas, there is a tendency to reduce the depth and the number of processes, often using exclusively the vibro-

cultivator that, through the vibration of the teeth, improves the disruptive effect, reduces the flooding caused by plant residues and avoids the breaking of the working organs following the impact against stones. With this machine, the greater the width of the teeth, the better the mixing of the soil and the action against the weeds.

For eventual autumn processing, plows, grubbers or harrows are used. Plows (except for rotary ones) and disc harrows allow the fertilizer to be buried but can determine the formation of the processing layer. To reduce this risk, in soils that are subject to the problem, in addition to using tools equipped with cutting members not shaped as "L", it is advisable to operate in conditions of adequate soil moisture, vary the working depth from one year to another and perform a rip-off up to 40-50 cm in depth every 3-4 years at the center of the inter-row. An alternative is represented by the digger, which works well also in hard soils and hills, allows to bury the organic substance and does not cause the formation of the processing layer.

Figure 36: in the first few years after planting, local soil processing is less risky than going processing

With adult trees, it is possible to use machines (cutters, grubbers, disc harrows or small plows) equipped with lateral displacement devices, controlled by a feeler to retract at the trunk, which allow to operate also on the row, even if sometimes in summer, when branches are hanging for the fruit load, it can be difficult to pass under the canopy with this equipment. However, if the equipment that may operate near the trunk is not available, the inconvenience is not particularly serious, because the shading of the foliage hampers the development of weeds and their presence near the trunk may damage very little the activity of the adult plants.

In the first few years after plantation, localized processing around the trees (with rotary cultivators), associated with mowing or weeding in the inter-row, is better than the complete processing (i.e. on the whole surface of the ground). In fact, with heavy vehicles used for complete soil processing, trees are often damaged, or grass may remain around the trunks, coming into competition with the roots, still very superficial. As an alternative to localized processing, mulching can be carried out in the early years after plantation.

3.2 Green cover

The green cover practice derives from the evidence that the weed flora, if properly managed to reduce its competitive power, can represent a resource able to increase soil fertility and biodiversity.

3.2.1 Advantages and disadvantages of green cover

Green cover is particularly suitable for organic or integrated crops, but can bring advantages in every olive grove, because:

- It reduces or eliminates the inconveniences related to soil processing and chemical weeding and improves the agro-ecological characteristics of the olive grove, which thus acquires a greater equilibrium and stability, with a consequent reduction of external inputs and environmental and health risks;
- it considerably limits the risk of landslide and erosion, especially when grasses are mainly represented by graminaceous plants;
- it increases the water infiltration speed (the roots of the herbaceous plants form preferential channels and the porosity increases by 15-20% compared to the worked soil), thus favoring the establishment of water reserves with respect to a bare soil, and reduces the flow rate;
- it reduces the risk of water stagnation, especially in the spring (but increases the need for water in drought periods and, therefore, it is not suitable for olive groves where water resources are too scarce);
- it allows the development of roots also in the superficial layers of the ground;
- it increases the lift of the soil and, therefore, reduces the compaction caused by the circulation of mechanical means, making it possible to carry out cultivation operations even with wet soil;

- it reduces the risk that the olive fruits get dirty from the ground during harvesting,
- generally, it increases the presence of useful mites (predators) while reducing the number of harmful insects;
- it promotes a better vegetative-productive balance of trees, thus improving the regularity of production and reducing susceptibility to diseases and physiopathies;
- thanks to the decomposition of the plant material from periodic mowing and the continuous renewal of the turf roots, it provides organic substance that, although modest (between 0.6-2.1 ton/ha per year of humus, with a release of 80-100 kg of N, 20-25 kg of P and 130-150 kg of K) and limited to the first centimeters of the soil, is the fundamental premise for an intense biological activity; in this regard, an increase in microflora and terrestrial fauna has been found in favor of species, such as earthworms, that improve soil structure and increase the rate of humification;
- it improves the landscape, mainly during weed flowering.

But green cover presents some inconveniences:

- the main one is water competition, particularly harmful at fruit set and during the first stages of fruit development, in fact green cover can consume even 200 mm of water per year. Therefore, in droughty environments and/or in soils poor in organic matter and light, to practice green cover it is also necessary to have adequate water availability for irrigation;
- with respect to the bare ground, it determines higher temperatures during the day and lower ones during the night, thus increasing the danger and the gravity of late frosts;
- may cause "allelopathic" effects due to phytotoxic substances produced by the roots of some weeds (e.g. spear grass) that, especially on young trees, may inhibit plant development and production;
- green cover does not seem to affect plant health related to cryptogamic diseases, except for higher incidence of wilt attacks.

3.2.2 Strategies to optimize green cover

Local rainfall can guide to choose the green cover method:

- with an annual rainfall higher than 700-800 mm and a fair amount of summer rainfall, there are no obstacles for permanent (all year) and total (on the entire surface) green cover;

- with rainfall below these levels, but above approximately 600 mm, and/or in the presence of rainfall of at least 150 mm during the period of May-August, partial (only in the inter-rows) or total green cover may be carried out; but doing frequent mowing;
- In rainy areas, with less than 600 mm/year rainfall, grass cover entails serious risks due to water competition and, therefore, is generally not advisable, however, even under these conditions, green cover by assiduous control of weeds also during the winter period can be practiced, thus favoring the settlement of a flora with limited water consumption or by implementing a temporary autumn-winter green cover with graminaceous plants (barley, oats) or legumes (vetch, fodder bean), possibly sown in inter-row or alternate inter-rows.

Figure 37: **natural green cover with alternating inter-rows**

To avoid nutritional stress that could occur in particular at the beginning of the vegetative season following the strong contemporary request for nutritive elements from the olive trees and from the turf it is necessary to intervene with fertilization. Therefore, to favor the action of the demolition microorganisms of the grassy biomass and to compensate for the temporary subtraction of nitrogen from the same, it is always convenient, within the normal nitrogen fertilization, to administer about 40-50 kg/ha of N (ammonium nitrate), immediately after mowing the grass. The green cover does not allow the burial of phospho-potassic fertilizers. This disadvantage can be remedied by carrying out a sufficient phospho-potassic fertilization for 2-3 years (depending on soil endowment, 100-300 g/plant and 500-1500 g/plant of P_2O_5 and K_2O, respectively). After this period, the elements coming from the decomposition of the herbaceous plants residues will be available and then proceed with the normal annual fertilizations. Alternatively, it can be carried out a fertilization in concomitance of a harrow every 3-4 years, but performed in alternate rows, in order to avoid damaging excessively the root system of the trees.

3.2.3 Types of green cover

- Permanent natural - when wild herbs are grown, trying to favor less demanding species (this is achieved with frequent mowing in the first years of green cover, in order to avoid that species that develop more in height, and are therefore more competitive, do not end their own vegetative cycle unlike the low and creeping ones that are less competitive).

Figure 38: soil management with permanent natural green cover

- Artificial permanent - obtained by sowing specific herbaceous species that are rustic and not very competitive with trees (see below);
- Natural temporary - taking place in droughty environments, where permanent green cover can cause excessive water competition, allowing the green cover to take place only when the amount of water is sufficient, then eliminating the weed plants before the dry season with a soil processing (see above: The temporary autumn-winter green cover).

Moreover, the green cover can be extended to the entire surface of land (total) or limited to inter-row (partial), thus leaving clean, through processing, a strip of land along the row of 60-120 cm, so the grassed surface it is reduced to 60-80%. Partial green cover can also be carried out in inter-row alternating with inter-row worked: this allows to reduce weed competition and an easy passage of machines in the grassed inter-rows.

Taking into account water and nutritional competition, green cover should not be carried out in the first years (3-4) after planting, as it could slow down the growth of young trees. Starting from the 4th or 5th year of planting, partial or total green cover can be carried out, but generally, it would be preferable to implement the latter after the 6th-7th year.

Only where water is not a limiting factor and with vigorous trees green cover can be carried out already from the first year of planting but leaving a strip of fairly large (1.2-1.5 m) layer, freeing it, or working it or, better, mulching it (partial green cover).

3.2.4 Artificial green cover

To enhance the benefits of green cover and reduce the negative effects, artificial green cover can be implemented by sowing species:

- able to quickly and homogeneously cover the ground;
- rustic, competitive towards weeds, but not very competitive (especially for water) towards the crop and, therefore, with a short development cycle, which ends before the beginning of spring, and with a relatively low size;
- with good tolerance to trampling and shadowing;
- long-lived and with abundant production of seeds that ensure the perpetuation of the species;
- that produce a high amount of organic substance;
- with easily available and low-cost seeds and well-known cultivation techniques and, in any case, with a simple maintenance (above all a reduced number of cuts).

Artificial green cover presents economic and management limits: in addition to the difficult selection of species and the cost of sowing, normally after 4-6 years the lawn must be replenished, as the spontaneous species take over.

It is preferable to sow mixtures consisting of 3-5 species with complementary characteristics (with particular reference to settlement speed and duration).

In general, the best essences for a stable lawn are grasses (e.g. *Lolium perenne*, *Festuca rubra*, *Festuca ovina*, *Poa pratensis*, *Lolium multiflorum*, *Bromus wildenowii*) and, to a lesser extent, legumes (e.g. *Trifolium repens*, *Lotus corniculatus*). In a mixture, the percentage distribution among the different species can be very free, but it is advisable that at least 50% be composed of perennial ryegrass and fescue.

Figure 39: soil management with artificial green cover with Trifolium subterraneum

Grasses are rustic and efficient in the control of erosion because they combine the rapid coverage of the soil and fasciculate roots, with an optimal mulching thanks to the long lasting and abundant mowing residues.

Leguminous plants, thanks to the nitrogen fixation, enrich the soil in nitrogen, allowing to obtain an almost self-sufficient grass cover in relation to the nitrogenous needs. In general, however, they should not be used in purity, since they give rise to a slightly resistant, non-walkable, rather long-lasting cover, rather competitive for water and with mowing residues of poor persistence. In fact, as the years go by, seeded and/or natural grasses tend to take over the legumes.

On the market there are many mixtures already prepared, but it would be preferable to make them independently by choosing the essences, and the relative percentages, more responsive to the specific pedo-climatic conditions and the requirements listed above.

The sowing of the lawn should preferably be done at the end of August-September because there is good water availability in the soil and, in addition, competition with annual weeds is avoided.

The sowing must be carried out on well-prepared and well-matured, with random or striped seed drills; in sloping soils it is better to random sow, in order to avoid forming small channels with rows of seed drills, which would favor rainwater runoff with consequent erosion.

The sowing must be quite shallow (about 1-2 cm deep). Rolling is useful to make the seed better adhere to the ground and, thereafter, it is advisable not to enter mechanically any more in the arboretum until the good settlement of the rind; also, for this reason it is preferable to sow at the end of summer.

In the first years, frequent mowing (height of the plants at 15-20 cm) favor the grass tillering and reduce pollution by weeds.

When possible, the mowing should be performed after seed formation, in order to promote the propagation of the essences.

3.2.5 Frequency of mowing and equipment

We insist that, in the first years of green cover, it is appropriate to frequently mow the lawn to favor the development of essences with a low, creeping vegetation and with limited development, to the detriment of the more developed and competitive ones.

When the lawn has stabilized, in order to effectively limit the water-nutritional competition towards the trees, 2-4 annual cuttings are usually sufficient. The first cut should be done in April, when usually there are good water availability, even when the herbaceous plants are relatively tall, and this is better in order to create a good mulching layer. Other mowing must be performed when the grass reaches 15-25 cm in height.

Figure 40: green manure

In general, a second cut must be made in June and a third cut in July. To facilitate the movement of the nets intercepting the fruits, a further mowing can be useful before harvesting.

The mowing can be done with a mower or with a flail mower; the latter also allow the shredding of pruning residues. The mower, working a few inches from the ground, does not damage the ground, requires less power and is faster. Among the flail mowers, those with articulated knives and with automatic retracting devices (climbing over), operated by a probe to easily eliminate weeds even near the trunk, give a better quality of work. The cut must be performed 5-6 cm from the ground in order not to reduce the "reclaiming capacity" of the lawn. So, even when the pruning residues have to be minced, the shredder must be kept a few inches above the ground. In this way, there is also the advantage of not compacting the ground. An intermediate solution between processing and green cover consists in using a flail mower-parchment machine that, affecting 2-3 cm of soil, slows down the receding of the lawn and, consequently, reduces the number of interventions for its control; clearly, however, also the benefits connected to the green cover are reduced.

If the lawn cover becomes insufficient, leaving uncovered areas of bare soil, it may be useful to perform light harrowing followed by random seeding and a rolling of species suitable for specific environmental conditions. The mowing can be performed in alternate rows, to have throughout the growing season flowering plants that offer nourishment (pollen and nectar) and shelter for useful insects.

Figure 41: temporary artificial green cover

In practice, it is necessary to anticipate the first cut about half of the inter-row by about 15-20 days, cutting the grass in the remaining ones only when there is a fairly good presence of flowers in the grass previously cutted. In this way, the lawn functions as a potential reservoir of useful fauna, as well as hedges, trees, ditches and ditches, with the advantage that herbaceous essences do not grow too much in height. Mowing is also appropriate before any insecticide treatments if the essences are in bloom. During the period of late frosts, it is important to mow or keep the turf.

Organic residues, if left on the soil surface, undergo slower decomposition processes than when incorporated into the soil (green manure). In general, the decomposition of plant residues is faster if they are shredded. In the winter period every 3-4 years a scarification of the lawn is useful to accelerate the oxidation processes of organic residues.

In some cases, particularly when the mechanical control of the lawn is made difficult by the slope of the land, grazing can represent an effective alternative. In this case, sheep are suitable (preferably with dwarf breeds because the sheep eat the olive leaves, otherwise it is necessary to keep tree branches high from the ground), the equine, the chickens and the rabbits. The load of animals per hectare should be well established, in order to avoid the excessive impoverishment of the rind, the superficial compaction of the ground and the risk of erosion. Watering points must be set up and, when the grass is scarce, it is necessary to provide a supplementary food to avoid that the animals, if hungry, eat the tree leaves.

Figure 42: management of the green cover with sheep and horses

An important aspect is the reversibility among soil management systems: it must be possible to switch from soil processing to green cover without particular problems for the trees (taking into account the strategies described above). On the other hand, the transition from grass to processing must be carried out with caution, starting with very superficial processes (a few centimeters of depth) and then progressively deepening them in the following years; this in order to limit the stress resulting from the damages caused to the roots previously developed in the surface layers of the soil.

3.2.6 Mulching

Mulching is a ground management technique that can be implemented along the row in the first 3-4 years from the olive plantation. In the inter-row, the ground must be worked or grassed.

Mulching has spread thanks to the limited cost of plastic materials, good durability (3-4 years) and the possibility of laying mechanical work. However, the problem of recovery and disposal of plastic at the end of the cycle remains.

Advantages

- mulching prevents the development of weeds, reduces water evaporation and increases soil temperature. The intense microbial activity in the mulched area, due to the favorable temperature and humidity conditions, and the reduced leaching processes, result in a greater availability of nutritive elements compared to other management techniques;
- eliminating the need to work the soil along the row, mulching avoids the risk of mechanical damage to young plants and acts positively on the soil structure (porosity);
- it allows the development of tree roots even on the surface;
- all the effects listed above determine a greater growth of young trees and a consequent early production.

Disadvantages

- the main drawback associated with mulching is the high construction and disposal costs;
- it can promote the proliferation of rodents and moles, which can undermine the newly planted plants and damage their roots and the collar;
- in case of accidental mulch cracks, weeds can develop imposing periodic and burdensome manual weeding;
- visual impact can be unpleasant in valuable landscape settings.

Figure 43: mechanical management of the green cover

Mulching operation

The mulching is carried out by stretching along the row, in pre-plantation, strips of plastic film (polyethylene, ethyl vinylacetate, etc.) of 60-100 microns thick and 100-160 cm of width. The film should be provided with holes of 0.5-1 cm, spaced 50 cm, to allow rainwater to infiltrate.

The film is put into operation with the help of a mulcher brought by a tractor in case of medium-large plants or manually in small orchards. The film is buried on the sides for 8-10 cm.

Simultaneously with the film laying, it is possible to arrange a hose for irrigation under the mulch (dripping wings) which will also allow to carry out fertigation.

3.3 Temporary autumn-winter green cover

It consists in forming a turf during autumn and winter, that is then removed with a spring process. The temporary autumn-winter green cover guarantees a certain protection of the ground during the autumn-winter, when the abundant rains that generally occur could accentuate the erosive processes, avoiding problems of water competition.

Moreover, the temporary green cover facilitates the movement of machines during the harvesting and pruning operations and may enrich the soil in organic matter, but in a very reduced way compared to permanent green cover. In particularly dry environments, the autumn-winter green cover is not recommended, as it can reduce the formation of water reserves in the soil. Anyhow, during the winter, if the growth of the herbaceous vegetation is excessive, a mowing can be performed.

Figure 44: temporary autumn-winter green cover

At the end of winter - early spring, when grasses are in the groove phase and leguminous plants start to bloom, a soil process must be performed to eliminate and bury the weeds. Before this work, it is convenient to chop the herbs together with pruning residues. This work must not be delayed, either to avoid an increase in water and nutritive consumption and because plant material incorporated in the soil initially causes nitrogen immobilization phenomena, condition that may become dangerous when it coincides with the flowering-setting period of the olive trees. Approximately one month after plant material burying, nutrients will start to be released.

To avoid the risks associated with the temporary immobilization of nitrogen, especially when the herbaceous vegetation does not contain leguminous plants, part of nitrogen fertilizers (about 30%) should be distributed at weed burying.

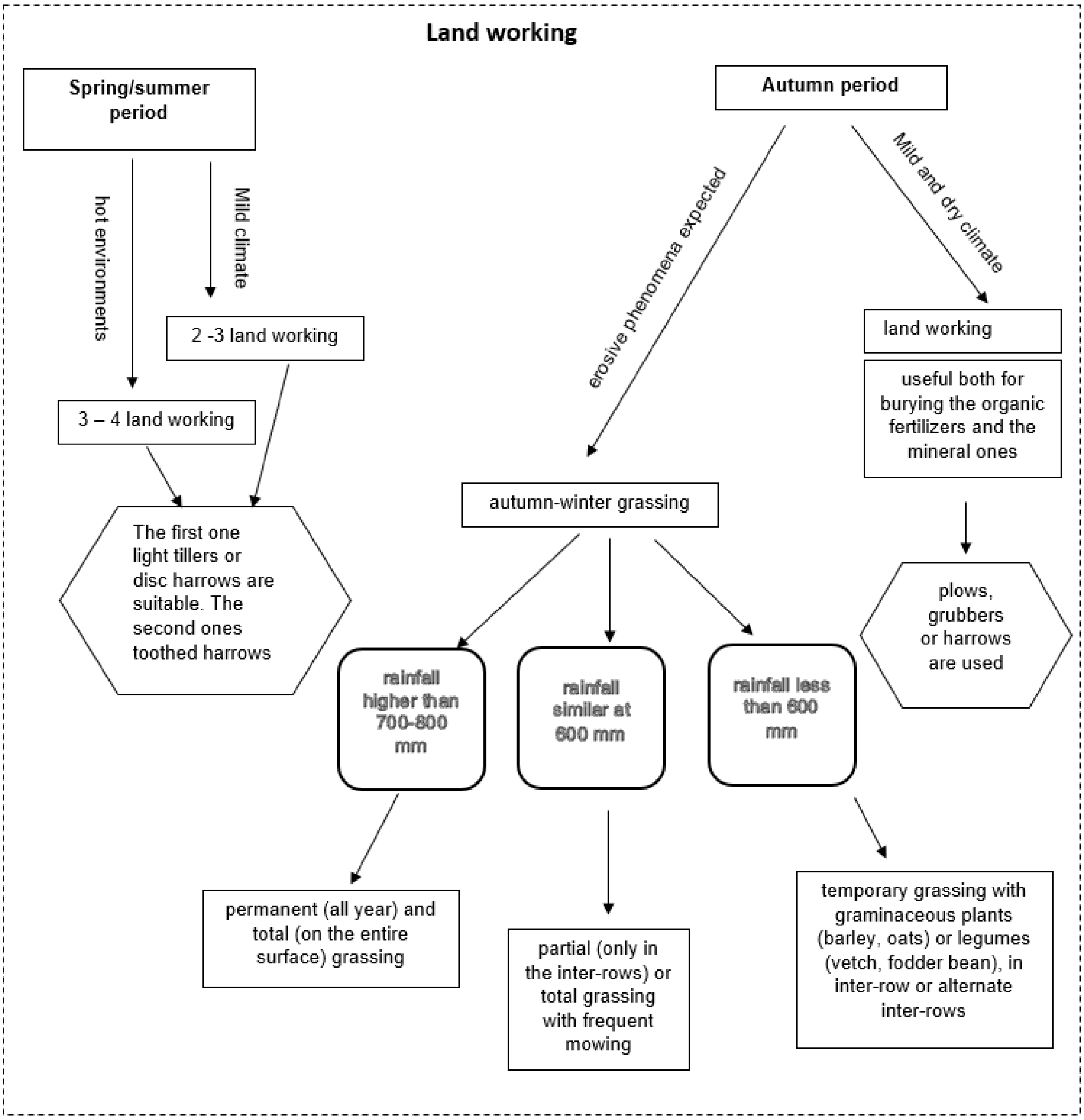

Figure 45: land working guidelines

4 FERTILIZATION

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Plant nutrition is guaranteed by chemical or organic fertilization. During first years after planting fertilization must favor the rapid growth of trees, then it must maintain adequate fertility in the soil to ensure an equilibrated vegetative activity, high production, constant and high quality of products and good resistance to pathogens and environmental stress.

4.1 Type of fertilization

4.1.1 Training fertilization

For young plants, not yet in production, nitrogen is the main element to ensure tree growth. However, in soils poor in phosphorus and potassium, it is also necessary to use phospho-potassic fertilizers, considering that these elements favor root growth and resistance of trees to nutrient shortage. A well-balanced fertilization may anticipate the fruit set in olive trees.

Fertilizers should be distributed around the canopy spread but avoiding the soil closer to the trunk. Regarding nitrogen, before the spring onset of vegetation (February-March), two to three treatments should be performed for a total quantity of 50, 100, 150 and 200 g/plant of nitrogen, respectively from the first to the fourth year. In areas with cold winter, it is advisable to avoid nitrogen application later than June, considering that a high nitrogen availability may extend the vegetative growth, making tissues more succulent and tender and therefore more sensitive to thermal stress. In fact, in order to avoid serious cold damages, trees should face low winter temperatures when vegetative activity has stopped, and branches are sufficiently lignified. On the other hand, in areas with mild winters, nitrogen fertilization can be carried out also in autumn, to prolong the growing season.

In the first years after planting, it might be preferable to use nitric or ammonia fertilizers rather than urea, which, due to the high concentration in nitrogen, if not well distributed (e.g. unequal distribution with consequent granular formation or direct contact of the fertilizer with the bark of young trees) could give phytotoxic effects.

Figure 46: localized distribution of manure

When is necessary to use also phosphorus and potassium, the quantity of fertilizer for each tree should be, from the first to the fourth year, 15, 25, 35, 50 g of phosphoric anhydride (P_2O_5) and 30, 50, 100, 150 g of potassium oxide (K_2O), respectively (to be adjusted based on the soil analysis results). In subsequent years, when roots of the olive tree will reach the layers of soil fertilized before plantation, the phospho-potassium fertilization can be carried out every 2-3 years.

As for the organic substance, it can be distributed as manure annually around the trees (avoiding contact with the trunk) (figure 46), starting with 5-10 kg per tree from the second year of plantation to reach progressively 30-40 kg in the fifth year. The use of manure or slow release fertilizers before winter should be carefully planned in cold areas because, stimulating the vegetation in conjunction with strong thermal lowering, could make plants more susceptible to cold. Alternatively, a fresh manure can be applied but, in order to avoid competition, must not involve a strip of land along the row.

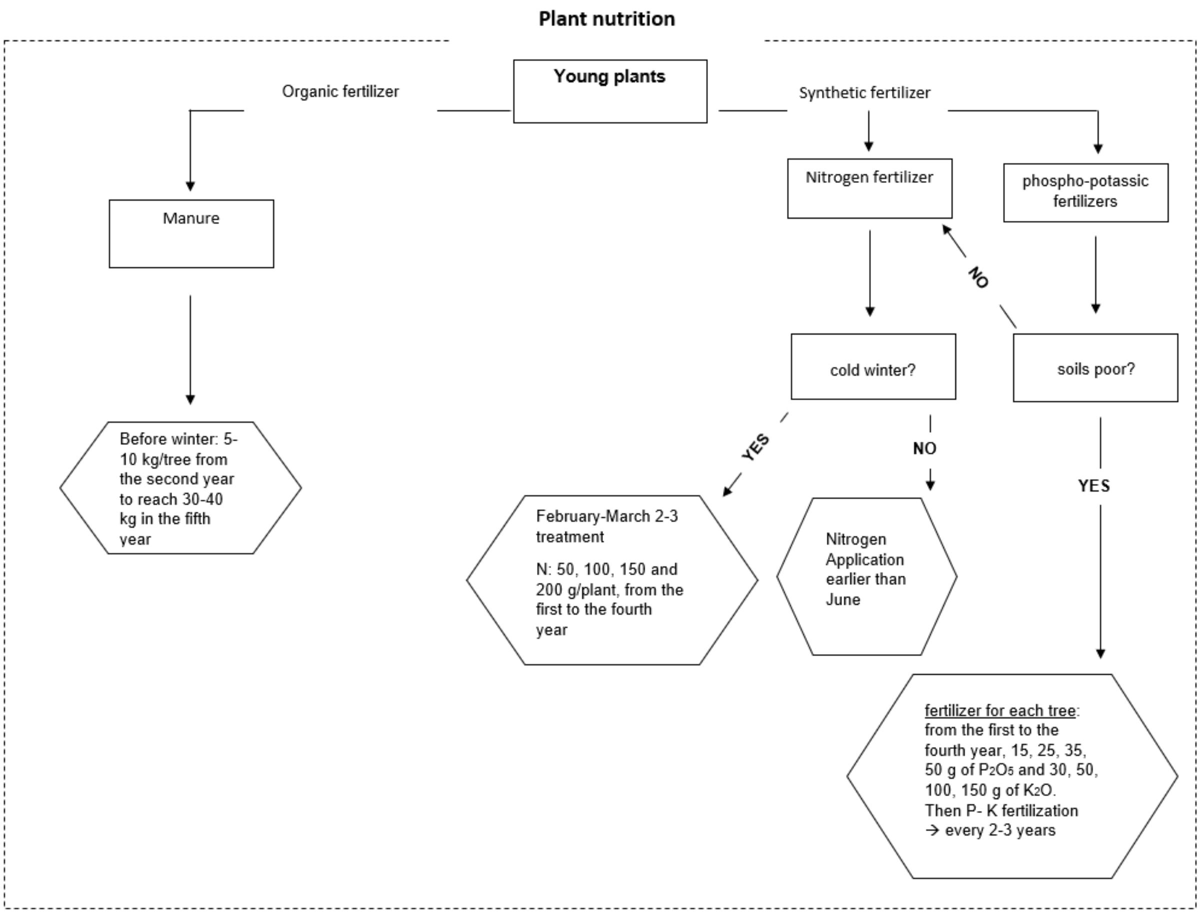

Figure 47: training fertilization guidelines

4.1.2 Fertilization for production

The availability of nitrogen, potassium and phosphorus in the soil is necessary throughout the entire vegetative season, however, the nitrogen requirement is higher from spring to the early stages of fruit development and also in the phase of seed hardening (from mid-July to mid-August). Then, until the autumn, nitrogen is still important for a regular fruit growth and development and for the formation of nutritional reserves in the tree, necessary to support the vegetative growth of the following year.

The nutrient requirement of the olive grove can be estimated based on soil analysis, foliar diagnostics, calculation of nutrient removal and/or visual examination of plants.

The soil analysis, used to estimate the amount of assimilable nutrients and organic matter present in the soil, should be repeated every 3-5 years. The soil sampling should be done a few months after the last fertilization. The technical protocol and the sampling time should be done following the instructions provided by the reference analysis laboratory.

The foliar diagnostics (the analysis of leaf nutrient content) makes it possible to evaluate the nutritional state of plants and, therefore, the actual use of nutritive elements present in the soil by the olive tree. It is a particularly useful technique for highlighting magnesium, manganese, potassium, nitrogen and boron deficiencies and sodium and chlorine excesses. Foliar diagnostics should be performed annually, but the relatively high costs lead to use it only in few cases, especially to highlight nutritional imbalances.

The sample to analyze should contain around one hundred adult and healthy leaves, taken in specific periods (winter dormancy, beginning of flowering, seed hardening, fruit maturation), and for each of them it will be necessary to refer to the relative reference values. The leaves should be detached from the middle part of branches placed in the external part of the canopy and from four parts of 10 trees (about 10 branches per tree). Obviously, if there were unequal conditions in the olive groves (differences among cultivars, tree age, soil, cultivation techniques, etc.), it would be necessary to separately collect and analyze a sample of leaves for each homogeneous tree block.

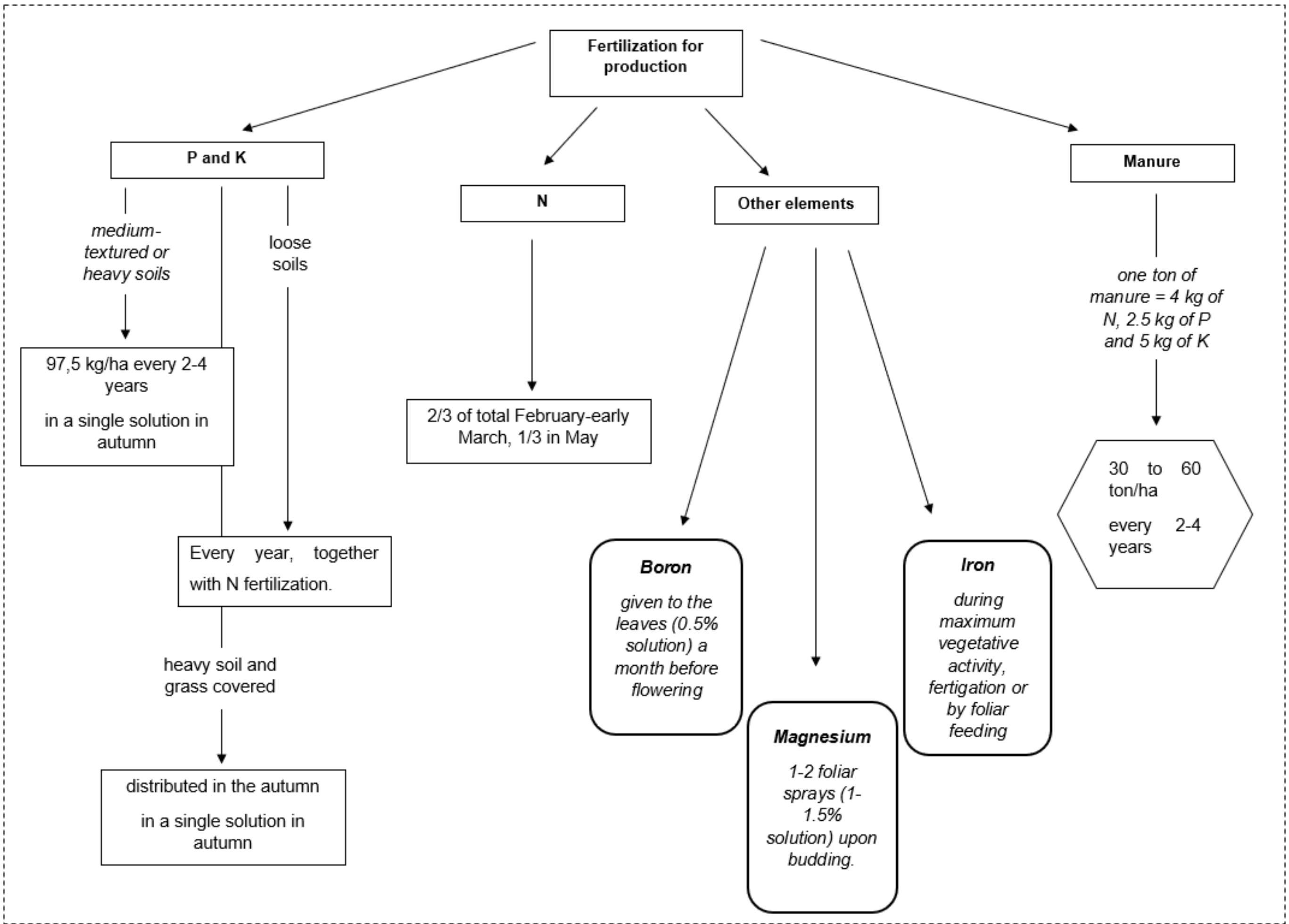

Figure 48: fertilization for production guidelines

Since there are several variations in the sampling methodology, it is advisable to ask in advance which one will be adopted by the laboratory that will carry out the analysis. The efficiency of this method is related to the availability of reference values, which should have been obtained from olive groves in excellent vegetative-productive state, similar to that examined for cultivar, age, climate, soil, etc. In fact, the main limitation of this technique is the lack of specific reference values for the studied area. Through the calculation of the nutrient removals, it is possible to estimate the amount of nutritive elements removed from the olive grove by fruit harvesting and plant pruning (if pruned material is not cut up and left in the olive grove) and the quantity of "immobilized" nutritive elements into the permanent tree structures (stems, branches, roots); in addition, the elements lost due to leaching, immobilization in the ground and volatilization must be considered. The estimation of the quantity of elements to reintegrate per hectare will be obtained by multiplying the quantity of elements removed for each quintal of olives per hectare and for a coefficient to correct the value, taking into account both, losses (run-off, immobilization, etc.) and intakes from mineralization of the organic substance (decomposition and release of mineral elements), precipitation and fixation of atmospheric nitrogen.

The visual examination of the vegetative vigor of trees and the possible presence of symptoms of deficiencies or excesses on leaves, shoots and drupes is another useful method to evaluate the nutritional status of plants and to set the fertilization. It is cheap, quick and highlights shortcomings/excesses when the repercussions on the tree have already started. Moreover, visual examination can sometimes cause errors in interpretation, since similar symptoms can occur with deficiencies of different elements and also as a result of non-nutritional stress.

In medium-textured and medium-fertile soils, the annual doses of nutrients for an adult olive grove with about 250 plants per hectare and a potential production of olives around 4 ton/ha are: 90-150 kg/ha of nitrogen, 20-30 kg/ha of phosphorus, 70-120 kg/ha of potassium. Based on these guideline values, the olive grower can manipulate the quantities of nutritive elements of the olive grove according to both, the maximum productive potential in a specific environment and cultivation conditions (also based on the production of olive groves present in the same area with excellent vegetative-productive status, considering the tree age, cultivar, eventual irrigation, etc.), and also the results of soil analysis (with particular reference to phosphorus and potassium). Obviously, the greater the productive potential of the olive grove, the more we move towards the higher doses of nutrients, especially if the soil is lacking.

The applied quantities should then be progressively adjusted over the years, on the basis of the vegetative-productive response of trees, taking into account the quantities considered as suitable for obtaining an adequate production in the specific conditions and, at the same time, allowing an adequate vegetation renewal (formation of a large number of shoots of 20-60 cm in length, without the emission of too many suckers), to ensure an adequate production in the following year.

4.2 Nutritive elements

The nutrients uptake by the root system are distinguished, according to the tree requirement for macroelements (nitrogen - N, phosphorus - P, potassium - K, calcium - Ca, magnesium - Mg - and sulfur - S) and in microelements (iron - Fe, manganese - Mn, boron - B, copper - Cu, zinc - Zn, molybdenum - Mo and chlorine - Cl).

Macroelements

- **Nitrogen - N**: it stimulates the growth of shoots, branches, trunk and roots, the development of fruits and, if is not in excess, also the flower induction, fertilization and fruit setting.
  Its *deficiency* causes a limited growth, due to the scarce vegetative vigor (length of the shoots lower than 10-20 cm, reduced production and a greater alternating production, leaves remain small, with a pale green color on the whole tree, but without necrosis, as it occurs for other deficiencies, and fruit abscission is precocious, while the differentiation of flower buds is limited and there is an increase of imperfect flowers, the fruit fall is high and the fruit size is reduced.
  The N excess determines an abundant vegetative growth, also expressed as the presence of numerous suckers, a poor flowering/setting, with a consequent reduction in production, a greater sensitivity to cold, drought and parasites (especially olive scale), reduction in the potassium uptake, with consequent delay in fruit ripening and reduction of pulp firmness.
- **Phosphorus - P:** it stimulates the formation of the flowers, the setting, the ripening of the fruits, the growth of the shoots, the development of the root system and the lignifications of the tissues.
  The *deficiency* presents by the reduction of vegetative and productive activity and a greater sensitivity to parasitic attacks. The small leaves with dark green color tending to purple, chlorotic leaf with necrosis which starting from the apex and senescence of the leaves (ferroptosis) especially the older ones. However, in general the effects of phosphorus deficiency are not much evident, since the need of phosphorus is generally satisfied by the natural endowment of the soil even if in acidic or calcareous soils the uptake of phosphorus

can be problematic, especially if the organic matter content of the soil is scarce or there is the presence of stagnant water or the soil is shallow.

The *excess* determines a reduced absorption of potassium, calcium, iron and boron.

- **Potassium - K:** it stimulates the formation of flowers and oil synthesis, the accumulation of reserves in the tree, the lignification of tissues and the resistance to thermal changes, droughts and parasites; consequently, it determines a reduced resistance to cold and to some parasites, a reduced flowering and low fruit size and a low oil content.

  The symptoms of *deficiency* occur first in the older leaves, then also in the young, with discoloration of the lamina starting from the apex and subsequent appearance of necrotic spots in the terminal part and in the edges of leaves that progress towards the internerval areas; in the most serious cases there is a phylloptosis. The shoots have apical necrosis and short internodes. The deficiency is not usual because, in general, potassium is present in good quantities in the soil, however, it can be found in sandy, superficial, acid or clay and poorly drained soils.

  The *excess* causes problems in the uptake of magnesium and boron.

Microelements

- **Magnesium - Mg**: it promotes photosynthesis and has a positive influence on production.

  The *deficiency* determines chlorosis (starting from the apex or from the margins of the basal leaves of shoots in autumn) also in stripes, while the central rib remains green, necrotic areas appear, and leaves may fall, except for the apical ones (buds have a plume-like appearance). Magnesium requirements are moderate and are generally met by the natural endowment of the soil, however, deficiencies can occur in sandy or acid soils or due to excess of calcium and potassium.

  The *excess* is very rare, but when occurs it affects the absorption of potassium.

- **Boron - B**: it stimulates flower induction in flower buds, fertilization, fruit set and reduction of summer fruit fall.

  The deficiency can reduce flowering, setting, production and oil synthesis. Moreover, deformations and necrosis of the apical portion of fruits can occur, internodes can shorten in the apical buds, eventually presenting numerous short early shoots (proliferation), chlorosis and necrosis of the apex and margins of the terminal leaves (which then may fall), and short roots. During summer, fruit fall may appear. Symptoms of B deficiency may occur in basic soils, with a pH higher than 7, sandy or with a low content of organic matter.

- **Iron - Fe**: it stimulates photosynthetic activity.
  The *deficiency* may give similar symptoms to those of boron, to which it is often associated: apical leaves are small, with apical chlorosis, deformations (crumple of the apex) and early abscission. It is also possible to verify the abscission of buds, necrosis of the shoot apices and presence of early buds with very short internodes and appearance of chlorotic fruits. It can occur in soils with a high content of active limestone or in the presence of backwater or when the content of organic matter is low or with an alkaline pH.
  The *excess* generally does not make defects.
- **Calcium - Ca**: it increases the mechanical resistance of tissues, the lignification of shoots, the consistency of fruits and the resistance to stress.
  The *deficiency* determines a reduction in the development of root system and fruiting and, although quite rare, it can occur in acidic soils and very poor of organic matter.
  The *excess* causes a lack of absorption of iron, magnesium and boron.

4.3 Distribution of fertilizers

In olive groves still young or with a plant density lower than 200 plants per hectare, it is preferable to distribute fertilizers only around the plant, in a strip below the rim of the canopy, but avoiding the area near the stem. If canopy projection on the ground involves more than 50% of the total area, fertilization must affect the entire surface of the olive grove, possibly excluding a strip of about one meter wide in the sub-line.

Regarding the organic substance, if availability is limited, it would be preferable to distribute it along the line (always avoiding the area close to the trunk) rather than on the whole plot (Figure 49).

In any case, it is necessary to distribute fertilizers evenly, avoiding the formation of piles that could cause damage to the roots due to excess

Figure 49: incorrect method of fertilization distribution

Specifically:

- **<u>Nitrogen</u> - N**

Nitrogen can be supplied with urea, which has a low cost per unit fertilizer, a very high nitrogen content (46%), a neutral reaction, a rapid and relatively prolonged effect over time.

Other nitrogen fertilizers are:

- *Nitrates*, which have a very rapid effect (and therefore are preferable when nitrogen must be readily available for plants, for example in spring, especially in cold areas (where nitrification processes are slow), but they are also very susceptible to leaching losses. One of the most used is calcium nitrate (nitrogen content 15%), suitable for acidic soils.
- *Ammonia*, it has a more prolonged effect (a few weeks or, with rather low temperatures, a few months). The ammonium sulphate may be cited, with a nitrogen content of 20-21%, suitable for alkaline soils.
- *Ammonium nitrate*, which has intermediate characteristics. It has a nitrogen content ranging from 26 to 33%, suitable for alkaline soils. Part of the ammonium nitrate, turning into ammonia, is lost by volatilization. A slight landfill of urea or ammonia fertilizer, or an irrigation or a precipitation after their distribution may reduce the losses due to volatilization (Table 2).

Nitrogenous fertilization in dry crop should be fractionated, giving 2/3 of total amount just before the vegetation restart (February-early March), and the remaining part after 1-2 months (May), before flowering (with poor flowering this intervention should be omitted or reduced, in order to avoid an excessive vegetative activity) and, in any case, before the end of spring rains. In fact, these fertilizers to reach the olive tree roots must infiltrate into the soil by rains, otherwise, on the soil surface, they are mainly used by weed plants. If there is a risk of lack of rainfall and it is not possible to irrigate, it is preferable to distribute all the nitrogen at the vegetative restart, eventually resolving any subsequent deficiencies with foliar fertilization. The fractionation in 3 doses instead of 2, always with distribution included in the period that goes from the vegetative restart to the end of the spring rains, is useful to allow to reduce the losses, but it determines an increase of distribution costs. In mild areas, where the vegetative season is longer and where there is no risk of winter cold damage, it may be appropriate to distribute a part of the fertilizer (1/3) (by foliar treatment if there is not good water availability in the soil) in late summer-early autumn, to encourage the accumulation of nitrogen reserves in the tree, useful for the subsequent vegetative growth and flowering.

- **<u>Phosphorous and Potassium</u> – P and K**

The management of phospho-potassium fertilizers, and in particular of phosphate ones, can be omitted if the soil analysis indicates an adequate allocation in the soil, since only in situations of insufficiency there are significant responses from the trees. In general, phosphorus and potassium are almost always lacking in loose soil.

The thickness of soil to be taken into consideration to evaluate the amount of nutrients to be given is that where most of roots develop.

Considering this thickness, referring to one hectare, the soil mass (with a specific weight of 1.3 ton/m^3) to be fertilized is equivalent to: 10,000 m^2 x 0.5m x 1.3 ton/m^3 = 6,500 ton

therefore, to increase by 1 ppm (1 g/ton) the availability of phosphorus and potassium, 1 g/ton x 6,500 ton/ha = 6,500 g/ha = 6.5 kg/ha of each element should be administered.

Therefore, if for a medium mixture soil the analysis has shown that the assimilable phosphorus is equal to 15 ppm and we want to bring it to 30 ppm, it will be necessary to give (30 ppm - 15 ppm) x 6.5 kg/ha = 97.5 kg/ha.

Usually, in medium-textured soils or slightly heavy (clay soils), where these elements may deepen slowly (only a few millimeters the phosphorus and a few centimeters the potassium per year), the phospho-potassium fertilization can be carried out in a single solution, in correspondence with the eventual autumn plowing, which should be relatively deep (15-20 cm), or otherwise, if the autumn plowing is not practiced (as is generally advisable), in correspondence with the spring one. Phospho-potassic fertilization in these soils can also be done every 2-4 years. In loose soils, on the other hand, to avoid losses by leaching, it is advisable to perform the phospho-potassic fertilization annually, together with nitrogen fertilization.

If the soil is heavy and a solid grass cover is established, the phospho-potassium fertilizers should be distributed in the autumn, as the subsequent rains will facilitate their penetration through the turf and then the roots of weeds will determine the transfer in depth. Alternatively, fertilization can be performed by associating it with a harrow, every 3-4 years, on alternate inter-rows. The above applies also for loose grassed ground.

Among phosphate fertilizers, the most used are the *simple perphosphate* (content of 18-21% phosphoric anhydride, suitable for alkaline soils, ready effect, also containing sulfur) and the *triple superphosphate* or *perphosphate* (content of 42-50% phosphoric anhydride, suitable for alkaline soils, prompt effect).

Among potassic fertilizers, the most used are *potassium sulfate* (content of potassium oxide of about 50%, suitable for alkaline soils, it also contains sulfur) and *potassium nitrate* (content of potassium oxide equal to 44-46%, content in nitrogen equal to 13%, neutral reaction), while *potassium chloride* (content in 50-62% potassium oxide, cheap, neutral reaction) should only be used in loose soils with high water availability, because otherwise problems due to excessive salinity may occur (Table 2).

- **<u>Boron</u> – B**

Boron deficiencies, which can sometimes occur in alkaline and loose soils, can be corrected with 200-300 g/plant of *sodium borate* (borax) brought to the ground, possibly broadcasting and incorporating it into the soil at the end of winter; it can also be given to the leaves (0.5% solution) a month before flowering. As a result of fertilization, the symptoms of boron deficiency quickly disappear.

- **<u>Magnesium</u> – Mg**

For the resolution of magnesium deficiencies, it is advisable to carry out 1-2 foliar sprays with *magnesium sulfate* (1-1.5% solution) upon budding.

- **<u>Iron</u> – Fe**

Iron deficiencies, generally due to a high content of active limestone soil and high pH, can be corrected by the annual application, during maximum vegetative activity, of iron chelates to the soil (fertigation) or by foliar feeding. The olive tree, however, is one of the tree species less prone to iron deficiency.

- **<u>Calcium</u> – Ca**

In acid soils, in case of calcium deficiency, it is necessary to intervene with substantial amounts of limestone or calcium. Care must be taken, as it can easily pass from a deficiency to an excess.

- **<u>Complex fertilizers</u>**

They contain a *combination of elements* like nitrogen, phosphorus and potassium. These fertilizers are to be administered shortly before the vegetative restart and, in general, it is also necessary to carry out a subsequent nitrogen fertilization. In fact, a drawback related to the use of complex fertilizers is the impossibility of differentiating the distribution period of the different nutrients. It should also be considered that complex fertilizers, including those marketed as specific products for the olive grove, generally do not contain the elements in the ratio required by the olive tree, therefore, they should always be associated with other simple or complex fertilizers to balance the contribution of different elements.

Table 2: Fertilizing units contained in the different types of fertilizer

Type of fertilizer	Fertilizing unit (%)
Nitrogen	
Urea	46
Ammonium sulfate	20-21
Ammonium nitrate	26-27
Calcium nitrate	15-16
Phosphates	
Simple superphosphate	19-21
Triple superphosphate	46-48
Potassic	
Potassium sulphate	48-52
Complex	
Nitrophoska Blu	12-12-17+2+15
Olive grove	12-8-8+3+0,2

- <u>**Slow release fertilizers**</u>

Among complex fertilizers there are also those controlled-release (CRF), consisting of granular inorganic fertilizers coated with materials (resins, waxes, etc.) able to reduce solubility, and therefore to limit losses by leaching and to prolong the duration of the action, also for several months (for the different types of fertilizers, the estimated duration of action is shown on the label). The use of these fertilizers, which reduces the number of interventions and the quantities of brought elements, is made problematic by the high cost and by the difficulty in establishing the real duration and extent of the action, as this is influenced by several factors. Among the most known CRF are the *Osmocote* (N-P-K: 18-11-10 or 15-12-12) and *Nutricote* (N-P-K: 16-10-10).

4.4 The organic matter

The organic matter in the soil is mineralized at a rate of 2-3% per year in loose soils and 1-1.5% in compact ones, so it is necessary to reintegrate it.

When possible, it is always advisable the administration of manure (solid and liquid nimals dejections mixed with litter, generally straw) which, if well mature, is among the best organic materials (60 to 160 kg of humus per ton of manure, depending on water content and degree of ripeness). On average, one ton of manure supplies 4 kg of nitrogen, 2.5 kg of phosphorus and 5 kg of potassium to the soil. From 30 to 60 ton/ha of manure can be distributed every 2-4 years, with largest intervals in humid climates. Unfortunately, the use of manure poses some difficulties due to availability, loading and transport costs, in consideration of the high quantities required, and the need for suitable equipment for distribution.

Figure 50: organic fertilization

Chicken manure, containing about 15 kg of nitrogen, 15 of phosphorus and 15 of potassium per ton, can be used both as a supplement to the manure in the dose of 2-3 ton/ha or alone (4 ton/ha), with the warning, in the latter case, to integrate it with straw or corn stalks or, better, with a fresh manure.

Liquid manure, deriving from the liquid dejections of animals kept in stable without litter, do not produce stable humus.

Table 3: composition of different types of manure (weight %)

Composition	Cattle manure	Swine manure	Equine manure	Sheep manure
Dry substance	20-40	15-35	25-40	30-40
Nitrogen	0.3-0.6	0.4-0.7	0.4-0.7	0.5-0.7
Phosphorous (P_2O_5)	0.1-0.4	0.1-0.3	0.2-0.3	0.2-0.5
Potassium (K_2O)	0.4-1.0	0.6-1.6	0.5-0.8	0.5-1.5
Magnesium (MgO)	0.1-0.3	0.2-0.3	0.2-0.4	0.3-0.4

When is not possible to apply the manure, other types of organic matter may be used, preferably available at the farm at low cost: *green manure* (700-800 kg of humus per hectare), or shredded pruning residues (300-700 kg of humus per hectare), this practice is recommended also in case of manure, *fresh pomace compost* (13-14 kg of humus per quintal of pomace), *waste from oil mills* (organic matter content varying from 3 to 15% depending on the extraction system adopted, with a reasonable content of nitrogen, phosphorus and especially potassium), good quality *animal wastes* and/or *compost*, used in doses ranging from 20 to 40 tons per hectare every 2-4 years (10 ton/ha per year) (Table 3).

4.4.1 Fresh manure

For the fresh manure, species with superficial root system (faba beans, lupine, trefoil, vetch, oats, barley) with autumn-winter cycle are preferred.
The choice of species for green manure must also consider the cost of seed and the adaptability to specific pedo-climatic conditions (to satisfy this last requirement, it would be better to choose essences that are widely present in the cultivation area). Fresh manure carried out only with legumes and buried at blooming guarantee excellent nitrogenous inputs (up to 150-200 kg/ha of nitrogen) with very rapid release times (about 50% of the nitrogen is available during the vegetative season following the landfill).

Figure 51: legumes growing for fertilization

This type of green manure is useful for young olive groves, not yet in full production, which need a good availability of nitrogen to promote rapid growth. Crucifer manure with crucifer, e.g. rapeseed, makes available significant quantities of phosphorus. If with the green manure a greater resistance to trampling (unavoidable during harvesting and pruning) needs to be achieved, or a biomass with a longer lasting effect (stable organic substance), up to the fruit growth period, it is necessary to move towards mixed crops of legumes and grasses (e.g. vetch or clover with oats and/or barley), cutting the grass a little after flowering.

In general, anticipating mowing favors a rapid and more abundant availability of nutrients, delaying mowing favors a better yield in stable organic matter.
The green manure must be sown after the first autumn rains, on adequately prepared soil, and must be buried in March-April, before the spring rains have ended. The shredding simplifies the burial of the biomass, which should be done with clods (better if with two crossed passages, in that case you can omit the chopping) rather than with milling machines.
Obviously, fresh manure cannot be implemented on land managed through permanent green cover. In this case, however, a good supply of organic matter is guaranteed by the periodical mowing: about 600-1,500 kg of humus per hectare (300 kg in case of temporary green cover).

4.4.2 Residues of pruning and lawn mowing

To the pruning residues (2-5 ton/ha, with the release of a ton of residues with about 4 kg of nitrogen, 0.5 of phosphorus, 4 kg of potassium and 1 kg of magnesium), to make up for the temporary subtraction of nitrogen from microorganisms destroying woody materials, it may be appropriate to combine a green manure with legumes (e.g. faba bean or vetch), or a specific fertilization that supplies nitrogen readily available (about 10 kg of nitrogen per ton of residues, on average corresponding to 30 kg/ha of nitrogen). This nitrogen will then be made gradually available in the soil in organic form.

4.4.3 By-products of the olive mills

For the use of by-products of the oil mills (pomace and vegetation waters), it is necessary to respect the specific legislation, which establishes the limits of acceptability and how to use them. Also, for the use of livestock wastes it is necessary to refer to the specific regulations.

4.4.4 Organic matter supply and fertilization

Whatever organic material is administered, the amount of nutrients that may bring to the soil should be estimated in order to proportionally reduce the quantities of mineral fertilizers added. In this regard, it must be considered that the elements deriving from the green cover will mostly be reused for its maintenance, except for cases where there is a significant presence of leguminous plants among the herbaceous species that can enrich the soil in nitrogen. Also, the green manure that includes legumes makes available a certain amount of nitrogen.

In relation to the quantity of nutrients deriving from the mineralization of manure or other similar soil improvers, it is necessary to consider that only one part is made available annually for the culture (65% if the administration is carried out every year, 30% if the administration is carried out every 2 years, 20% if the administration is performed every 3 years). So, for example, in case of administration of manure containing 4.5 kg/ton of nitrogen, 2.5 kg/ton of phosphorus and 7 kg/ton of potassium, for each ton of manure will be made available for culture 2.9 kg of nitrogen, 1.6 kg of phosphorus and 4.6 kg of potassium, if added every year, and 0.9 kg of nitrogen, 0.5 kg of phosphorus and 1.4 kg of potassium, if made every three years.

- *When administering the organic matter*

With the exception of permanent green cover, the organic matter should be buried, especially in areas with low rainfall. It can be distributed in winter (recommended time if the organic substance is not well composted), after harvesting and before autumn processing. When green manure is being applied, the administration of the organic substance, and of the phospho-potassium fertilizers, can be done in concomitance with the sowing of the green manure (after the first autumn rains) or, alternatively, if well composted, after the mowing, in concomitance of the interment of the biomass. Fertilization in this last phase may be important for the availability of phosphorus in soils with high pH (> 7.5) and high content in limestone where, without the contribution of the organic matter, the phosphorus could be scarcely available.

4.5 Fertigation

In olive groves with a localized irrigation system, soil fertilization can be completely or partially replaced by fertigation, which consists in supplying the nutritive elements with the irrigation water. Fertigation involves several advantages:

- allows the nutrients to be administered in small doses almost continuously and, therefore, to promptly and continuously meet the needs of the trees, to limit the "luxury" absorption, the percolation of the most mobile elements, the phenomena of immobilization in the soil of phosphorus and potassium and antagonism in the absorption among various elements;
- it frees the effectiveness of fertilization from rainfall and avoids trampling of the ground due to the transit of fertilizer spreaders;

- localizes the nutrients near the roots, which are concentrated under the water dispensers, with consequent greater efficiency in its use (since there are fewer losses due to leaching and volatilization); consequently, the quantities of elements can be reduced (-25-30%);
- it allows to easily solve sudden deficiencies, such as those that occur as a result of phenomena of nutrient immobilization by degrading microorganisms, when consistent amounts of organic matter are incorporated in the soil with high carbon/nitrogen ratio (e.g. shredded pruning residues);
- reduces administration costs and simplifies the operation as it can be completely automated, with consequent economic and management advantages.

The main drawbacks of fertigation are the need for a more expensive irrigation system (adding the equipment for the injection of fertilizers in the distribution lines and filtering systems) and its constant maintenance.

Considering that fertigation involves limited portions of soil, it is good that this technique is used right after planting, in order to allow the root system of the olive tree to adapt its development to this type of administration. For the same reason, it is not advisable to suddenly switch from fertigation to soil fertilization.

The concentration of nutrients should not exceed 3‰.

With fertigation, about 50% of nitrogen, phosphorus and potassium should be administered during the vegetative growth period - fruit set, 20-25% in correspondence with the first phase of fruit growth and the remainder afterwards, up to fruit ripening.

4.5.1 The useful fertilizers for fertigation

Urea is the most used nitrogenous fertilizer for fertigation, thanks to its inexpensiveness and solubility.

Calcium nitrate can produce precipitates that alter the operation of the implantation, especially if mixed with phosphate fertilizers and when the water pH is greater than 7.

For phosphorus, phosphoric acid, monoammonium phosphate (PMA), diammonium phosphate (PDA) or liquid formulations can be used. It should be noted that, when irrigation water contains high amounts of calcium or magnesium, with the use of PMA and PDA, there are great risks of precipitation of insoluble phosphates, with consequent problems of occlusion of valves and dispensers. The use of phosphoric acid causes a lowering of pH and cleans the pipes. PMA and PDA have less solubility than phosphoric acid, but also allow nitrogen to be administered.

Potassium nitrate, which also contains nitrogen, is recommended for potassium. Potassium sulfate and chloride are less used because the former has a lower solubility than potassium nitrate and the latter contain chlorine, which can create problems with the trees.

Phosphate and potassium granular fertilizers can give rise to precipitates in waters rich in calcium and magnesium.

To overcome possible deficiencies of microelements (copper, iron, zinc, manganese, boron and molybdenum) then chelates and sulfates are used.

4.6 Leaf fertilization

The olive leaves can absorb nutrients. The absorption takes place within 24-48 hours after the treatment, and in particular in the early hours, especially through the lower page of the leaves.

The foliar fertilization can usefully integrate that to the soil to obtain some advantages:

- very rapid effect and released from the soil moisture and therefore quick solution of sudden deficiencies;
- possibility of carrying out targeted interventions in critical phases (pre-flowering, setting, core hardening, etc.);
- reduction of the quantities of fertilizers needed (up to 2/3).

Considering the modest quantities of nutrients that can be administered with each single intervention and the limited absorption capacity of the leaves in relation to the needs of the tree, it is generally not advisable to use the foliar fertilization in total substitution to that on the ground. Eventually, only in olive groves with not high production potentialities, it is conceivable to completely substitute the fertilization to the soil, carrying out 4-5 leaf treatments, but the limit can be of an economic nature.

To implement foliar fertilization, solutions can be made from simple salts, which are quite cheap, or buy commercial solutions, including multiple elements, to be diluted appropriately. The spraying should be interrupted when the nutritive solution starts dripping from the leaves.

To reduce costs, it is possible to associate foliar fertilization with any pesticide treatments, making sure before preparing the solution that there are no incompatibility problems (this information is usually reported on the label of the various products).

4.6.1 Fertilizers for leaf fertilization

Among nitrogenous fertilizers, *urea* is assimilated, translocated and metabolized very rapidly. Nitrogenous foliar fertilization with urea solutions (1-4%) can be particularly useful in dry olive groves to release nitrogen even with a low availability of water in the soil, during the critical period of pit-hardening. This type of fertilization can also be useful in other periods when temporary deficiencies occur, for example when there is a competition with the turf in the grassy olive groves, or during dry summers. The leaves within a day absorb more than half of the administered nitrogen.

In dry conditions or after a year of charging or in soils with low potassium content, it may be useful to administer, with foliar treatments, *potassium nitrate* (1-3%), which is highly assimilated.
The fertilization with phosphorus (*phosphoric acid* or *monoammonium phosphate* 12-61-0) can rarely be useful. In some cases, treatments with *potassium monophosphate* (1-2%) may be appropriate.
The magnesium deficiencies can be overcome with 1-3% solutions of *magnesium sulfate*.
Foliar fertilization is also very useful to solve possible deficiencies of microelements, boron in particular (1 g/l of borax) with treatments to be carried out at the end of April and subsequently, after flowering, every 2-3 weeks until fruit set.
The addition of wetting substances (readily available) to the fertilizer solution increases the effectiveness of the treatment.

4.7 Fertilization through an integrated method

In general, for the cultivation with the integrated method, the specifications provide for constraints and indications both on the time of administration and on the maximum annual quantity of the main nutrients and on the maximum quantity of mineral nitrogen that can be applied for each administration (dose fractionation).

In general, the analysis of the soil (in particular for phosphorus and potassium) and sometimes even the leaf (in particular for microelements) is mandatory at regular intervals to determine nutrient requirements and justify the applications. The maximum doses of nutrients allowed are relatively low compared to the needs of intensive olive groves (for example for nitrogen the maximum permitted dose is 15 kg / ha per ton of olives harvested per year), therefore it is necessary to minimize losses through a suitable fractionation of the doses also using, when possible, fertigation. Furthermore, you can make use of soil improvers (i.e. manure), because, in some disciplines, their contribution in nutritive elements is not counted in order to comply with the prescribed limits.

4.8 Fertilization with biological method

For organic olive groves, where the use of products deriving from chemical synthesis is prohibited, fertilization is based on the contribution of organic substance, possibly integrated with natural fertilizers. On the label of these products must be written the words "Allowed in organic farming". Many of the products envisaged can be used only after control body recognition. Using only the manure or other similar fertilizers, it is necessary to give a quantity that tends to satisfy the nitrogen needs of the crop.

If natural fertilizers are used, keep in mind that the cost of the fertilizer units is higher than that of chemical fertilizers and that, due to the greater quantities required, distribution is also more expensive.

Regarding the quantity of fertilizers to be supplied in an organic olive grove, it is necessary to refer to the productive potentialities. By way of example, with a production up to 2.5-3.0 ton/ha, in the absence of green cover, fertilization can be carried out by cutting off shredded pruning residues and adding 20-30 ton/ha of manure. For olive groves with higher yields, the proportion of manure must be proportionally increased or, based on soil and/or leaf analyzes, supplemented with fertilizers and/or other soil improvers. The manure must come from extensive farms.

Figure 52: organic fertilization with manure

The alternation of manure and green manure, possibly supplementing with specific fertilizers, is a very balanced solution. Chicken manure could be used as a supplement of a dung or alone.

To overcome temporary nutritional crises (especially during the flowering period), which may occur in the early years from green manure establishment or the temporary immobilization of nitrogen due to the activity of microorganisms that decompose pruning residues, excellent results can be obtained with foliar fertilizers allowed by organic production, also administered several times in periods of greatest need. Microelement deficiencies can also be solved by foliar fertilizations.

5 CONTROL OF INSECT PESTS AND DISEASES

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In the last years, agriculture deals with adaptation to the multiple effects of climate change and the consequent need to develop mitigation strategies aimed to reduce the carbon footprint of anthropic activities. This adaptation involves also the development of innovative pest management strategies for crop protection, in order to reduce agricultural inputs and increase the sustainability of the entire productive chain even in terms of amount of carbon absorbed. The olive grove is generally considered a stable agro-ecosystem, in which, despite the occurrence of more than 100 species of phytophagous insects and disease agents, only few species usually causes damages of economic interest. This stability is essentially due to the fact that the olive is native to the Mediterranean and potentially harmful phytophagous insects are limited by numerous natural enemies in the same environments. Many of the most common phytopathogens are usually present and asymptomatic in Mediterranean olive growing, and the most frequent infections depend mainly on favourable climatic conditions and by inadequate agronomic practices. However, in the last few decades, climate change is causing the recurrence of diseases not frequent in the past and the emergence of new ones, related to the introduction of new pathogens and/or the increased virulence of those already present.

5.1 Olive fruit fly (*Bactrocera oleae*)

The olive fruit fly, a carpophagous and monophagous species, is the key pest in most Italian olive groves. Olive fly damages occur mainly in coastal areas, where control interventions are needed almost every year. The attacks of the olive fly are influenced by the climate conditions of the year rather than by the level of the overwintering population. In fact, in presence of favourable environmental conditions, the high biotic potential of the fly, the longevity and mobility of adults allow a sudden growth of populations. The susceptibility of the different olive cultivars is very diverse, as the fly females prefer to lay the egg on large, spherical, green and hard olives (Rizzo et al., 2012), attacking also the less susceptible cultivars when preferred ones are not available.

Natural biological control does not adequately contain the olives fly population. In the past, larvicidal control was effectively achieved by treatments carried out with cytotropic products, in most cases without a preliminary monitoring of the infestation and thus often overestimating the damage. Fertile or sterile oviposition punctures and the presence of eggs and larvae in the fruit do not cause significant damage both in terms of quantity and quality of the oil. When the larvae drill the cuticle before leaving the infested olive, a more or less rapid degradation of the oil components occur, particularly in the presence of a wet climate. The drop of infested olives can be particularly relevant. Limiting the negative effects of fly attack may be more important than limiting the infestation. In fact, the olive drop, and the worsening of oil quality do not occur immediately after the insect oviposition, but only when exit holes are made by mature larvae.

Figure 53: female of Bactrocera oleae

In order to obtain quality oils, the intervention thresholds adopted so far indicate that drupe holding less than 10% exit holes can produce excellent oils, especially if oil extraction takes place shortly after olive yield. However, oil parameters can fall within the levels characterizing high quality extra virgin olive oil even if the percentage of olives bearing exit holes is 40-45% (Caleca et al., 2017). Therefore, early harvesting and timely oil extraction (within 24 hours of collection) are useful to reduce the negative effects of fly attack on oil quality.

Infestations may be limited by adult control with the "attract and kill" method, but its effectiveness is directly proportional to the size of the olive orchard and/or its isolation. Such control method is carried out by placing traps for mass trapping, or devices that attract and kill adults without capturing them. Traps/devices should be placed in each olive tree on the olive grove edges and every two trees within the orchard.

Poisoned protein bait can be applied for adult control too, by treating part of the plants (for example one row out of three, or on alternate trees) with a product containing both attractant and insecticide products, when attack percentages on olives are higher than 2%. Treatments can be applied on the south face of olive trees foliage, using an insecticidal product together with a proteic bait, in order to attract adult flies. As several treatments are needed in each productive season, this method can be useful in conventional olive growing, but it is not recommended in organic farming because too many interventions should be required to ensure an adequate control of the insect, due to the low persistence of authorized products. In order to assess the time of the first treatment, samplings of 100 olives per homogeneous olive grove can be collected and examined under stereomicroscope starting from July, adopting an intervention threshold of 15-20% active infestation (living stages of the fly). Olive samplings should be continued in the following month, adopting increasing intervention thresholds.

Copper and kaolin products, which can also be used in organic farming, exert a clear deterrent activity. However, the repellent and antiovipositional action of copper decreases with increasing relative humidity and fruit maturation, so late infestation can be observed in copper-treated olive groves. Two or three copper or kaolin treatments can achieve excellent results in reducing olive fly damages, also when high infestations occur. Moreover, good results were obtained in small plots by using traps and applying 1-2 copper hydroxide sprays at the same time. Treatments should start when a 3-5% active infestation is reached, and they have to be repeated after a month, only if infestation is above the same threshold.

Monitoring the olive infestation by recording the live stages and the exit holes is the only method allowing a precise assessment of the infestation trend, as data on adult catches of the fly have been demonstrated to be not related to the infestation in the olives. Nevertheless, traps can be useful to assess the timing of first olive sampling, when 3-5 adults/tap/week are collected. Thus, adopting the olive monitoring can help olive growers to carry out treatments only when necessary, to assess the real risk of olive drop and to plan the optimal harvest time.

5.2 Olive moth (*Prays oleae*)

The species is present in all olive-growing countries of Mediterranean Basin and some Black Sea countries. Olive moth biology is strictly linked to the physiological phases of the host plant, on which it preforms three generations per year. The first one feeds on flowers, the second is the most harmful, as feeds on seeds inside fruits, and the third on leaves, developing within them during the winter period. Early olive drop occurs during larval penetration into the endocarp (June-July) and can be considered not harmful, while a late fruit drop, from the end of August to the autumn, can cause serious damage, involving up to 50% of the production.

Pheromone traps allow detecting flight peaks of males, but correlation between catches and risk of infestation in the fruits is very low. Therefore, direct sampling of olive fruits is the only valid monitoring technique in order to evaluate the infestation due to the second-generation larvae and to predict the autumn fruit drop level.

Figure 54: Larva of Prays oleae in flowers

In conventional olive culture, treatments with translaminar products can be applied to control the second generation of the insect. Fruit sampling (100 olives/Ha) should be carried out in the first week of July. The percentage of infested olives can be used to estimate the potential loss of olives due to the fruit drop, adopting a prudential reduction index of 2.5 (% infested olives / 2.5 = foreseen % drop olives). Damage threshold depends on the foreseen yield per tree, the oil yield of each cultivar and the market value of production.

In organic olive cultivation, as no translaminar product is permitted, monitoring and control should be carried out on the first generation (flower feeding), as larvae develop mainly out of plant tissues Literature reports that in several cases no correlation between the population level of first generation and damage due to the second generation on fruits occurs. Nevertheless, considering the low dispersion ability and short life span of adult moths, treatment against larvae of the first generation represent the only possibility to control the insect. An empiric strategy can be applied, involving a preliminary inflorescence sampling (100-150/Ha) carried out 7-10 days after the peak of captures in the pheromone traps, and a treatment with *Bacillus thuringiensis* var *kurstaki* (BT) when a prudential threshold of 50% of infested inflorescences is recorded.

Mating disruption method using sex pheromone diffusers has provided in some cases good results, nevertheless, this control method is not commonly adopted, either because it can achieve a gradual reduction of populations only after 2-3 years, and because cannot prevent economic damage due to abundant moth population, even when mating rate decrease up to more than 90%.

As far as natural biological control, *P. oleae* has a complex of many natural enemies, among them the predator *Chrysoperla carnea* Stephens and several parasitoids: *Ageniaspis fuscicollis* (Dahlman), *Apanteles xanthostigmus* (Haliday) and *Habrobracon crassicornis* (Thomson). Overall, the natural control by biological enemies is variable in the different geographic areas and over the years, and it related to the complexity of the agroecosystem and to the availability of alternative preys/hosts for the olive moth enemies. Despite this, often the natural control is not satisfactory to prevent the economic damage caused by the second generation of the moth.

5.3 Minor olive pests

Black scale (*Saissetia oleae*), olive psyllid (*Euphyllura olivina*)

Black scale and olive psyllid infestations can be effectively prevented adopting adequate cultural techniques, such as pruning, in order to enhance air circulation that lowers relative humidity and increases heat exposure of insects. If the insect population exceeds the intervention thresholds, treatments should target first instar nymphs. Mineral oils can be applied at the beginning of the summer, avoiding mixing them with insecticides in order to prevent side effects on natural enemies. *S. oleae* monitoring is carried out by sampling at the end of April leaves and branches, and a treatment, at the end of June - beginning of July, can be performed when the threshold of 1 female per leaf or per cm of sprout is reached in the April monitoring. Treatments against *E. olivina* are usually unnecessary, mainly depending on the infestation probability on newly set fruits.

Figure 55: black scale

Figure 56: olive psyllid

Olive weevil (*Otiorrhynchus cribricollis*), olive leaf moth (*Palpita unionalis*)

Olive weevil and olive leaf moth are the main insect pests in nursery and on young plants; the same control methods are recommended for the two insects both in conventional and organic olive cultivation. For both insects, the attack on sprouts should be carefully evaluated in relation to the expansion of tree canopy. Adult olive weevils emerge in June and are nocturnal feeding insects. They hide around the base of the plant during the day and move up the tree to feed at night. Placing glass wool bands on the trunk of young plants can prevent the weevil movements and consequently the leaf damage. In addition, soil treatments with entomopathogenic nematodes, performed at a high soil moisture, can be used to control the weevil larvae in nurseries.

Figure 57: placing wool bands on the trunk as a weevil prevention

As regards *P. unionalis*, the control of larvae living on external surface of olive plants can be achieved by treatments with products containing *Bacillus thuringiensis,* which do not adversely affect the natural enemies of the moth. Intervention threshold is set to 1% of infested fruits for table olive production, while on adult plants for oil production no treatment is usually needed.

Figure 58: olive leaf moth

Leopard moth (*Zeuzera pyrina*)

Mass trapping is considered effective both in conventional and organic olive cultivation, to reduce leopard moth populations year-by-year. In olive groves where damage was recorded, 7-8 pheromone traps per hectare can be placed in the higher part of olive canopy, to catch the flying males. Local control of larvae can be achieved by injection of a suspension containing entomopathogenic nematods (*Steinernema* spp.) or fungi (*Beauveria bassiana*) into the galleries bored in tree stems or branches, nevertheless this control method is considered expensive.

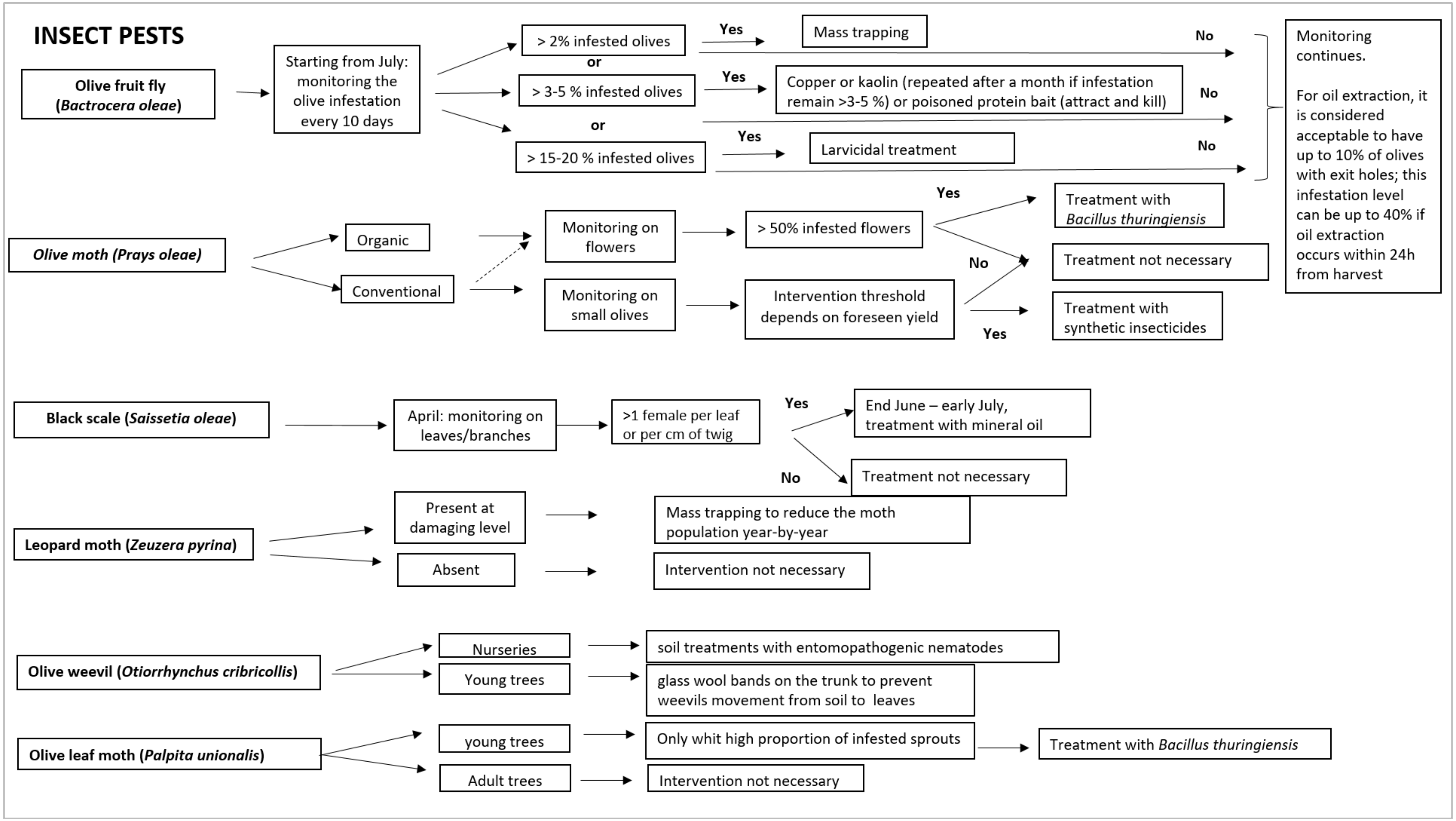

Figure 59: pest control guidelines

5.4 The main olive tree diseases

Peacock eye spot or olive scab (*Spilocaea oleaginea*)

Peacock eye spot is the most important olive fungal disease affecting green organs, especially leaves, but also petioles, twigs and fruits. Symptoms consists of gray-brown spots of about 10 mm, with a yellowish contour and the most infected leaves and fruits fall to the ground. The fungus grows at temperatures between 15 and 25 °C and infection is normally associated with high humidity and winter conditions (cold, low light intensity), whereas a long summer and winter stasis occurs in cold areas. Climatic conditions are also important in determining the occurrence of the symptoms, which are visible a few weeks to a few months after infection. The inocula (conidia) causing the primary infections appear during winter or summer on the infected leaves, on the branches or fall to the soil and spread by rain, wind, but also by some species of insects. Conidia present on the potential host, in favourable environmental conditions, germinates producing a pre-micelium that can actively penetrate the cuticle. The mycelium develops at a subcuticular level, where it establishes trophic relationships with the host. At the end of its biological cycle, the pathogen produces conidiophores emerging from the cuticle and holding bicellular conidia; these structures, in mass, give a velvety appearance to the spots. In order to reduce the impact of the disease, agronomic strategies as suitable pruning and, in the new olive groves, opportune implant distances of less susceptible varieties are appropriate. The protection is carried out with preventive treatments by cupric products, performed when seasonal conditions are favourable to the pathogen, usually at the end of winter-early spring and in late summer-early fall. In conventional agriculture, more or less specific synthetic formulations against the pathogen, such as dodina, can be used.

Olive anthracnose (*Colletotrichum gloeosporioides*, *C. acutatum*, *Glomerella cingulata*)

The first symptoms of the disease, as chlorosis and necrosis of leaves, defoliation, and dieback of twigs and branches, appear in the autumn, with the beginning of the rains. The most serious damages are on the fruits, affected during maturation: dark and depressed spots (antrachnose), often associated with the fruitifications of the pathogen producing pink or brown pustules. Infected olives fall or mummify on the twigs, thus becoming a source of inoculum for the following year, and supply poor quality oil (high acidity, perishability).

Figure 60: dark and depressed spots in fruit

The pathogen spreads through conidia by rain or wind and penetrates the host by stomatic or lenticular way. The aeration of the foliage, a good drainage, and preventive autumnal cupric treatments can limit the infections.

Cercospora leaf spot (*Mycocentrospora cladosporioides*)

The pathogen cause, on the lower surface of the leaves, irregular greyish spots, more or less extensive in function of climatic conditions and cultivation areas. The upper surface of the same spots is first chlorotic, brown and finally necrotic. The shoots of the infected olive trees defoliate, generally in spring, with negative effects on both the production and the vegetative activity of the plant.

The agronomic practices that ensure both the airing of the crown (pruning) and rational vegetative growth (irrigation, fertilization) are useful to limit the disease. Generally, the copper-based treatments applied against the peacock spot and the anthracnose allow to control the disease.

Figure 61: Cercospora leaf spot

Verticillium wilt (*Verticillium dahlie*)

This is a serious tracheomycotic disease spread in all Mediterranean countries, because the pathogen is able to infect also spontaneous and cultivated species and survive for a long time in the soil by the production of resistant wintering structures (microsclerotia). The symptoms of the disease are loss of turgor, chlorosis, leaf necrosis and defoliation, associated with typical darkening of xylem tissue of the symptomatic organs, followed by death of twigs, branches or whole plants, usually within few vegetative seasons. The pathogen infects the host through wounds (also due to xylophagous insects) and develops inside the vascular tissue, producing enzymes and toxins that can debilitate the host plant. The pathogenic process is facilitated by the production of conidia in the vessels following the lymphatic flow. The intercropping of the olive tree with other cultures,

Figure 62: Xylematic darkening by verticillium

particularly horticultural plants which are highly susceptible to attacks of the same pathogen, is one of the most common causes of infection. Adult and vigorous plants can tolerate the infection, while for the young or debilitated ones, the only preventive control strategies are essentially agronomic. In fact, it is useful to apply the best cultural strategies and burn the removed infected twigs and branches.

Olive knot (*Pseudomonas savastanoi* pv *savastanoi*)

Openings are necessary for the penetration of the bacterium in all the epigean organs, particularly twigs, branches and trunks.

Figure 63: olive knot

The affected organs show characteristic alterations, initially consisting of small, smooth subsphaerical green galls that evolve in greater tumors with a highly cracked brown surface. The pathogen is favoured by injurious events (hail, wind, dew, etc.) in the presence of high spring rainfall and mild temperatures.

The olive grove can be protected with preventive strategies. All practices which may cause wounds in woody tissues (the point of entry of the pathogen), should be avoided, in particular when the temperature and humidity conditions are favourable to infection, such as during the olive harvest.

Figure 64: cultivar Frantoio is very sensitive to Pseudomonas savastanoi

In these cases, timely treatments with copper or other disinfectant products may prevent new infections. In the presence of the disease, all infected parts must be removed by pruning and applying the most appropriate hygienic practices, as disinfecting the wounds and the tools with sodium hypochlorite or copper sulphate and burning the removed branches.

In the most serious cases, it may be necessary a drastic topping and grafting with more resistant cultivars.

Xylella fastidiosa

From October 2013, the bacterium was reported in Italy associated with a rapid decay of olive trees and detected in the xylematic vessels of the infected plants. Several strains of the pathogen are known which can infect more than 150 plant species, including cultivated, ornamental, forest and spontaneous species, mostly herbaceous and shrubby. The bacterium transmission, associated with the “Complesso del Disseccamento Rapido dell'Olivo” (CoDiRO), occurs through vectors represented by some xylem-feeding suctorial leafhoppers, that, during feeding activity can transfer the pathogen from infected to healthy plants. The large diffusion and the polyphagous habits of most leafhoppers make difficult to ascertain which species are potential vectors of the bacterial disease.

The typical and most common symptoms of the disease are drying of the apical and marginal part of the leaves, more or less extended to the twigs and spread to the entire branches or whole tree. To limit the spreading of *X. fastidiosa*, the European Union has issued “Implementing Decision 789/2015”, as amended by the next “Implementing Decision 2016/764”, reporting **measures to prevent the introduction into and the spread of the bacterium within the Union.**

Among the measures envisaged by European Union, there are obligations to activate monitoring for timely detection of new outbreaks and to eradicate infected plants.

Recent surveys conducted in Puglia showed a different sensitivity of olive cultivars to the disease. New strategies based on the cultivation of selected resistant / less susceptible olive cultivars seem to be decisive for converting the crop, even if they cannot avoid the loss of some ancient olive trees and of a unique landscape heritage.

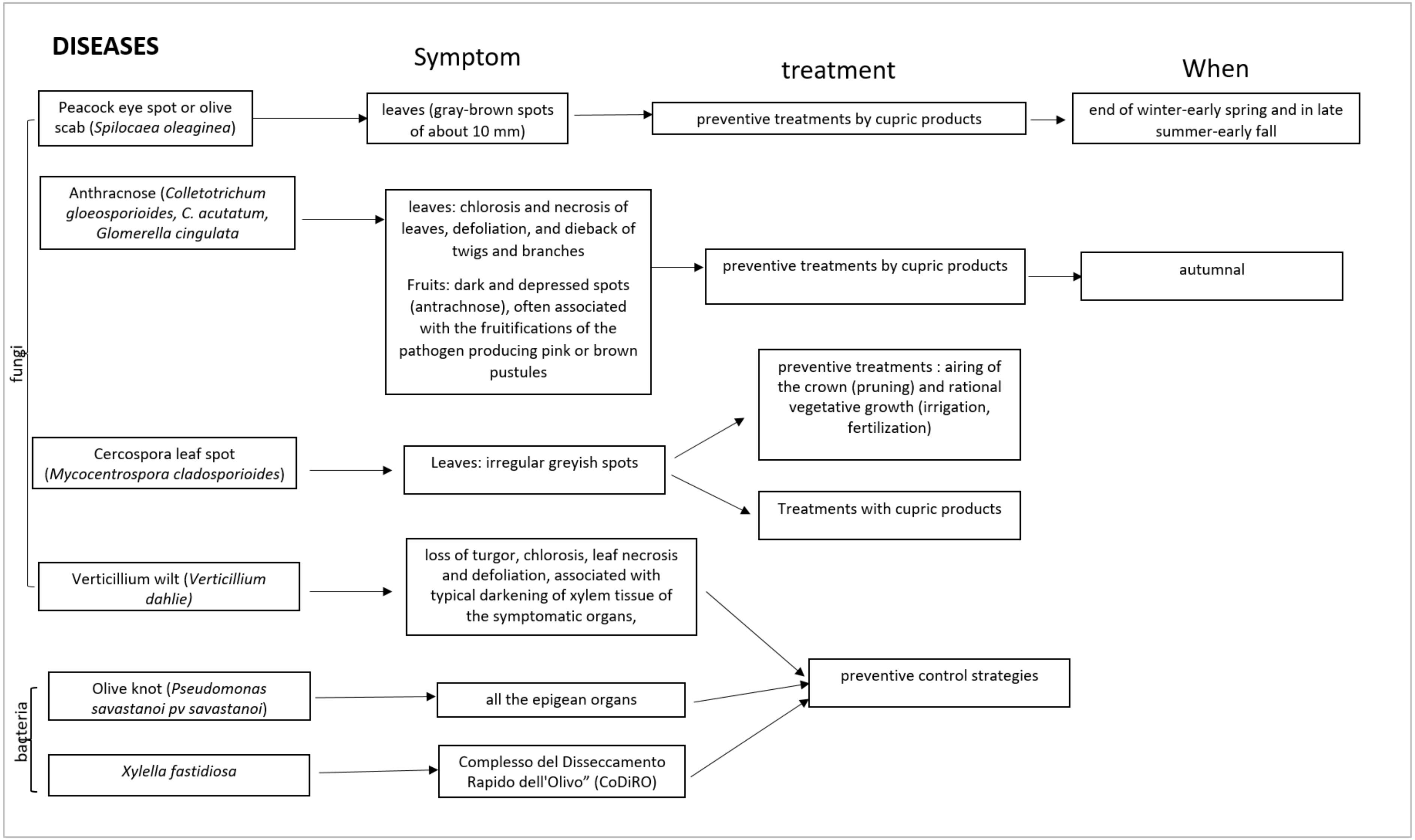

Figure 65: diseases control guidelines

6 IRRIGATION

Giovanna Sala, Tommaso La Mantia, Francesco Paolo Marra, Tiziano Caruso

Mediterranean countries, where about 95% of olive cultivation is practiced, are characterized by hot and dry summers. The combination of these climatic factors usually leads to the interruption of biological processes that govern the growth and development of several plant organs resulting in yield losses.

The olive tree, among the temperate climate species, is a drought tolerant, able to survive with no or small amount of water through the activation of biological processes, such as the closure of the stomata, the reduction of gas exchanges, e.g. transpiration and photosynthesis in particular, the modulation of root growth and aerial vegetation and the osmotic adjustment. With this adaptation, the olive is not affected by severe water stress also when the plant water potential reaches significantly low values compared to those found for other tree species (e.g. -3.0 MPa compared to -1.5 MPa).

Figure 66: drip irrigation system

The irrigation effects positively the vegetative and yield activity. Overall, the olive tree is cultivated in rainfed condition, often with consequent low and alternating yields. In Italy only 14% of the olive orchards are irrigated. Irrigation can improve the performance of traditional olive groves and it is essential for high density orchards. In the new orchards, the irrigation allows early bearing, while during the yield phase several are the advantages such as the reduction of alternate bearing, the increase of yield, the size of fruit, the pulp/pit ratio and the final amount of oil. Regarding the quality of olive oil, irrigation is one of the most important agronomic practices; the concentration of phenolic compounds is inversely proportional to the water status of the plant; indeed, it increases with the increment of water deficiency. The composition of fatty acids is less influenced by irrigation, on the contrary the unsaponifiable fraction which determine the sensory characteristics of the oil, are significantly influenced by irrigation.

It is very important, from the economic and environmental sustainability point of view, to determine the water requirements in different olive-growing environments. The excess of irrigation, in addition to causing unjustified waste, can cause adverse effects such as an inappropriate vegetative growth, a strong emission of suckers and a lower resistance to low winter temperatures. The development of irrigation techniques based on controlled water deficit is an important goal in olive groves management.

6.1 When to irrigate

The aim of irrigation is to satisfy plant water requirements, and at the same time to avoid waste of water and nutrients and development of adversity.

The olive tree uses water throughout the year and in some years, especially in dry environments, the rainfall cannot completely restore the water reserve of the soil volume explored by the roots. The water requirement of the olive also changes according to the different phenological phases (Table 4). Conditions of water stress must be avoided in order to preserve the yield between the flowering and fruit set phases, which in the dry regions occur in May (about a month later in the area characterized by cooler temperatures in spring). Suitable water availability is necessary during the initial phase of fruit development to support the differentiation and cell division processes. Water is fundamental during the phase of cellular distension and oil formation that correspond to an increase of the size of the drupes and an accumulation of oil; this phase occurs in warmer areas between the end of July and the beginning of August.

It is important to know the amount of water available for the plants in order to ensure with irrigation the proper quantity to avoid stress or waste. To determine the start time of irrigation, several techniques are available and are based on the soil water content, plant water status and on the evapotranspiration (quantity of water that evaporates directly from the soil and transpired from the plant).

Table 4: Effects of water deficit on crop production processes in relation to biological phases

Time of the year	Phenological phase	Effect of water deficit
February - early June	flower bud development bloom fruit-set	reduced flower formation reduced number of flowers and ovary abortion poor fruit set
early June - July	fruit growth due to cell division	reduction in fruit size (fewer cells/fruit) important for table olives
August - Harvest	fruit growth due to cell enlargement oil build-up	small fruit size due to reduced cell expansion lower oil content/fruit

Several methods can be used to evaluate the soil water content such as the gravimetric method. This method is not very efficient because it requires many samples, intensive labour and it is unsuitable for automation. Other methods are the time domain reflectometry (TDR) and the frequency domain methods (FDR). These methods can measure the dielectric constant of the soil and provide a moisture content reading in units of volume. However, they require many sensors and they are indicated only for the measurement of the surface layer. Furthermore, the result is strongly conditioned by the characteristics of the soil (for example, these methods are difficult to apply for soil with rich skeleton and clay soil). More efficient are the tensiometers which are permanently installed in the soil and indicate the excess or lack of water in the soil. These are very simple tools, cheap and easy to use. Unfortunately, they can be only used with water potentials between 0 and -0.08 MPa, while their use with higher values is not advisable because they determine the entrance of air into the capsule.

Table 5: Water potential values and corresponding water stress levels for the olive tree.

Water potential ψ (MPa)	Stress level
<-1.9	absent
between -1.9 and -2.5	moderate
>- 2.5	high

The water status of the plant can be evaluated with methods that consider the whole plant or part of it such as the leaf (e.g. porometers, pressure chambers, etc.). These systems are most of the time unsuitable for use not only for the cost of the instrumentation, but also for the need of qualified personnel and the continuity of the surveys that must be done frequently and in well-defined moments of the day. Currently the most reliable method for assessing water potential is the pressure chamber (also called Scholander chamber). Numerous scientific investigations have made it possible to define the threshold values of water potential beyond which, in order to avoid damaging states of water stress, irrigation should be scheduled (Table 5).

Figure 67: effect of drought stress on olives

To define the water requirements with the purpose of scheduling irrigation it is essential to measure the crop evapotranspiration (ET, mm). Evapotranspiration represents the amount of water dispersed in the atmosphere through evaporation processes from land surface and transpiration from the plants. Water losses must be reintegrated by rain and/or irrigation to avoid water stress. Evapotranspiration can be measured by direct or indirect methods. The use of direct methods (e.g. lysimeters, eddy covariance) in plot scale is generally not applicable for the high costs and labour-consuming tasks for the determination and management of the equipment. The indirect estimation methods are preferable such as the method recommended by FAO based on the Penman-Monteith equation. This method is based on the meteorological data of the site.

In the farms, the CROPWAT 8 model can be used. It is a free program from FAO website, which allows to determine the irrigation requirements by using the evapotranspiration data, the rainfall and the available water reserve in the soil.

The evapotranspiration data, maximum and minimum temperatures and rainfalls can be obtained from the meteorological stations or from the agro-meteorological public services. Generally, in intensive orchard (200-400 plants/ha) the irrigation requirement is 1000-3500 m^3/ha while for a super-intensive orchard (1100 - 2500 plants/ha) it is among 2500 m^3/ha/year. Since the letter method is inclined to overestimate the quantities of water, water volumes are generally reduced to avoid waste and excessive vegetative activity.

6.2 Regulated deficit irrigation

Regulated deficit irrigation (RDI) is a strategy that reduce the amount of irrigation without or with low reduction of the yield. Under this strategy crops are able to sustain some degrees of water stress during specific crop development stages when the tree is not or is less sensitive to it increasing (higher water stress / its growth), hence the water use efficiency. Water stress must be avoided during critical phases such as flowering, fruit setting and cell distension of the fruit.

> *The RDI technique consists in monitoring, at short-time intervals (no longer than 7 days), the values of the stem water potential, rather than of the leaf, by using the pressure chamber (Scholander bomb). The water potential should be constantly maintained at values between < -1.8 MPa during the drought period (usually May-September, at our latitudes).*
>
> *On the contrary, applying RDI strategies, near the phase of hardening of the core of fruit (second half of July, at our latitudes) the irrigation contribution could be reduced (lengthening the time of water management or reducing the volumes supplied) until the plant reaches water potential values close to -2.2 / -2.5 MPa. After this phase, and near the beginning of the cellular distension phase (early August, at our latitudes), the regular water supply should be resumed, in order to restore, for the following growing season and up to the harvest time, the values of plant water potentials at regular levels ("good water status" / "no stress”) (i.e. -0.5 / -1 MPa).*

The application of this strategy, in addition to ration the water resources, can help control plant's vigour and reduce trees’ vulnerability to the parasites due to an excess of vegetative activity with low lignification. It is important to identify the maximum level of stress that can be reached by the trees. Some studies have showed that applying 70% of seasonal requirement is often sufficient to achieve the highest numbers of fruits and oil yield. The reduction of water can also induce an increase of the quality of the olive oil. In olive trees, the deficit of irrigation leads to an increase of the concentration of polyphenols. The oil yield, related to the fresh weight of the fruit, can probably increase because of the lower water content in the fruit. Therefore, the current trend in the irrigation of olive trees is to provide less water compared to the requirement, through the method of the evapotranspiration, with small reduction of the yield. Recent studies conducted in super-intensive orchards (about 1600 plants/ha) in Sicilian environment characterized by an average annual rainfall of 450 mm, have shown that a seasonal water volume of 1600 m^3/ha it is sufficient to keep the plants well-hydrated. Applying lower water volume can negatively affect the fruits and shoots growth and facilitate the alternate bearing phenomenon.

Different solutions can be had for different environments and different water status of plant.

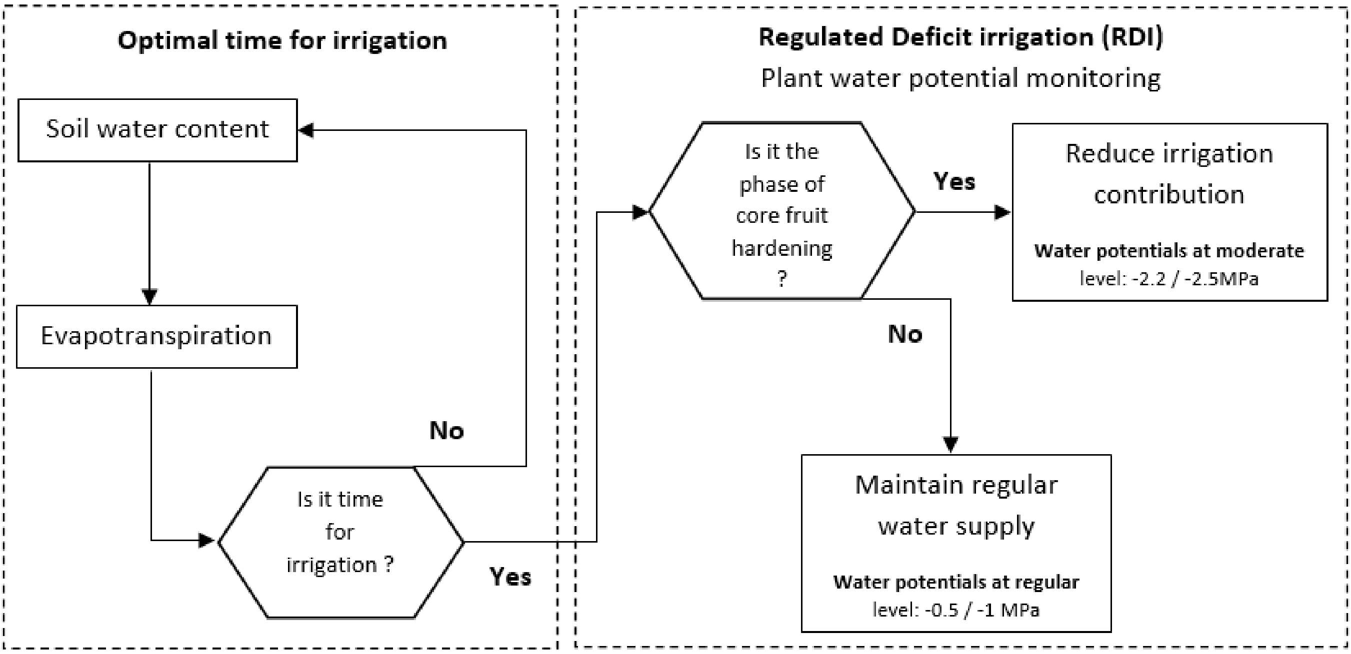

Figure 68: irrigation management techniques

6.3 Irrigation methods and type of irrigation systems

To maintain the water volume and rationalize the distribution of water the localized irrigation method can be used (e.g. drip and sub-irrigation methods). By applying these methods, only a small area of the soil affected by the root zone is wet. This allows to evaluate exactly the volume of water given to the trees and to optimize its use, with consequent improvement of the efficiency of irrigation. Localized irrigation has a high efficiency rate (amount of water that is really used by the tree), sometimes higher than 90%, due to the reductions of water loss by evaporation from the soil and water absorption by weeds.

Other direct and/or indirect advantages are the elimination of water losses through run-off and percolation, the possibility of fertigation, the reduction of leaching fertilizer losses, the low energy consumption, the possibility of automation and the low humidity in the crown.

Furthermore, the use of emitters at low pressure ensures a constant moisture of the soil profile, and with advantage for the radical activity, and to use moderately saline water. The less wet soil surface induces a less soil surface of evaporation and low formation of areas with a high concentration of salts. The short interval between irrigation shifts also determines a confinement of the saline crown at the edges of the wet volume (with lower concentration inside)

The main disadvantage of the localized irrigation method is the clogging of emitters due to the very small diameter of the nozzles and the low pressures. To avoid this, the use of a filtration system for the irrigation water is recommended. This system is also characterized by low flow rates and it is not suitable when irrigation takes place in "rescue" mode or water is available with very long shifts.

Figure 69: drip irrigation system

The localized irrigation system shall be used when the soil is still wet (60-70% of available water), because the early beginning of the irrigation season allows indirectly to preserve, in the deeper layers and in the points not affected by emitters, a sufficient water reserve. This system uses drippers which allow water to be supplied in an optimal position with respect to the root systems; the water supply devices are in fact represented by drippers or sprayers emitters. There are irrigation systems with wings dripper above-ground, set down soil surface and micro-sprinkler. The dripper above-ground methods are characterized by a quick and simple installation, but their drawbacks consist in creating driving effect of water, lacking stability in the wind, creating a holdup to the mechanical operations, uneven irrigation.

The irrigation system with drippers arranged on the soil surface have as advantages the uniformity of water distribution, the high efficiency of irrigation, but it is a system that interferes with soil management and can be exposed to external damages. Its installation is however simple but needs great attention to the wings of the irrigation system.

Figure 70: irrigation system with dripper arranged on the soil surface

On the contrary the use of micro-sprinklers has the advantage of distributing water on a larger soil surface and this method is applied mostly in traditional olive orchards. This method has the disadvantage of greater water losses due to the evapotranspiration, causing also weeds development, which can then compete with the trees with less efficient irrigation.

The number of drippers depends on the climatic and soil conditions, the orchard density (plants / ha) and the water needs of plants.

Generally, in sandy or gravel soils (permeable) where water percolation is rapid, and the wetted area has a narrow and elongated shape ("carrot shape"), the right ratio between wetted soil and roots is achieved by positioning a large number of emitters and by irrigating frequently applying small volumes. In clay soils, where water permeability is low, and water tends to expand first on the surface and then downwards ("potato shape") small number of emitters should be installed.

The flow rate of emitters range from 1.6 to 3.8 L/h and it is chosen based on the trees spacing, the type of soil and the water quality. In intensive orchards (5x6 or 6x6 m apart) one or two drippers for row with drippers spaced between 60 and 125 cm can be used, while in super intensive orchards (3.5x1.5 m apart) it is advisable to use drippers spaced with 40 cm in order to have a continuity of the wet area to support the water of plants with reduced root system. In traditional orchard (8x8 m apart) the in-line drippers with flow rate of 8 L/h can be used, with an appropriate number for each tree.

A new localized irrigation method is the sub-irrigation with the dripper positioned under the soil surface. This system has the advantage to dip directly the roots (the loss of water by evaporation is smaller and fertigation is more efficient) and it is easier for machinery to manoeuvre without creating barriers to soil cultivation. The efficiency of this method is more than 95%. The depth of the dripping in the soil should be about 35 cm, while the choice of the number of dripping wings and the distance within the row depends on the pedoclimatic characteristics of the soil. In loose soil, it is convenient to position the drippers at very small intervals (40-50 cm), while in clay soils the drippers can be spaced even with 90-100 cm. If the distance between the rows of the trees is bigger than 3 m it is advisable to use two dip-lines per row in order to lead a balanced development of the root system.

Sub-irrigation system involves a complex installation with a high initial cost, careful controls and a periodic maintenance of the water filtration system to prevent occluding drippers. An efficient practice to avoid occlusion by soil particles is to prevent low pressures. The solution to this problem can be achieved by positioning double-action air relief valves at the highest point of the irrigated area and by fitting an outlet channel at the end of the dripper lines. Furthermore, a chemical treatment of irrigation water or washing the drippers by using diluted acidic solutions can be envisaged. It is fundamental in these systems the installation of counters that allows the control of the volumes actually delivered for each line / sector allowing to monitor possible occlusion of the drippers.

As above-mentioned, to schedule the irrigation it is fundamental to know the characteristics of the soil, the estimation of the climatic variables and the depth of the root system. Once this information is known, it is possible to schedule the water volumes to apply. In the case of young trees, the pipes must be sized, and the number of drippers be increased according to the needs imposed by the development of the plants.

6.4 Water quality

In addition to the water availability, it is fundamental to evaluate the type of water; this aspect is decisive in the selection of filtration and / or chemical treatment systems to avoid obstructions in the irrigation systems. It is therefore advisable to analyse the chemical and physical quality of irrigation water before designing the irrigation system. The presence of sand in the water must not exceed 3 p.p.m, otherwise it will be necessary to design an appropriate filtration system.

The olive tree is able to tolerate salinity; the first damages show up when the conductivity of irrigation water is higher than 2.5 dS m but the response to salinity varies with the cultivar used.

The use of urban wastewater could increase water availability in areas where water is limited. Through an adequate purification plant and treatments for the reduction of the bacterial load, it could increase the water volumes available for irrigation and make irrigable olive areas characterized by scarcity of water. The problems that may arise from the use of these waters is the presence of dangerous pollutants due to their phytotoxicity, so it is fundamental to ascertain their agronomic suitability. In addition, when drawing up the fertilization program, it is important to consider that the use of treated urban waste water can be assimilated to fertigation as it ensures a supply of mineral elements, so that the contribution of fertilizers must be adequately reduced.

7 PRUNING

Primo Proietti, Franco Famiani, Luca Regni, Luciana Baldoni

We distinguish two types of pruning: on growing plants, to give the desired shape to the tree, and on producing mature trees, to renew the vegetation and ensure maximum production capacity.

7.1 Pruning growing plants

Pruning growing plants includes all operations to obtain a predetermined shape of the tree.

7.1.1 Purpose of pruning growing plants

The tree shape should:

- respect the natural way of vegetating ("tree habitus") of plant, according to the different cultivars;
- facilitate the fast growth of the tree and therefore the early entry into production;
- favor the interception of light, which is at the base of the vegetative and productive activity, exposing the largest leaf surface to the solar radiation, adequately exploiting the available space and avoiding the shading of the leaf apparatus within the same crown and between adjoining hair;
- maintain a high ratio between leaves and wood;
- favor an excellent state of health of the tree, counteracting attacks by cycloconio, cochineal, mange, etc., ensuring both the airing and lighting of the entire crown and the effectiveness of any pesticide treatments;
- guarantee a solid scaffold to support the weight of the fruit and reduce the risk of breakage of the branches due to accidental excessive loads (snow, wind);
- facilitate the execution of cultivation operations, with particular reference to harvesting, pruning and land management.

7.1.2 Pruning principles and techniques

To pursue the above objectives, it is necessary to adopt the following measures:

- Choose the form of farming that you intend to adopt and prune the plants from the moment of implantation, to avoid drastic interventions.

- For the first few years the top of the plant will have to be constantly tied to the brace, to guarantee its vertical growth.
- Limiting the cuts to the minimum necessary because the removal of the branches, reducing the already limited leaf surface and inducing a vigorous vegetative response, slows down the growth and entry into production of the tree. Light pruning causes the vegetative growth to be spread over a large number of shoots which, consequently, do not acquire excessive vigor and thus predispose more quickly to fruiting. The weak and pendulous branches should be left on the stem so that it can increase in thickness more quickly, while the vigorous buds present on the stem are cut to weaken them, and those very vigorous and with vertical growth, with vigor similar to the stem, must be removed otherwise, due to the tendency of the basal branches of the olive tree to develop more than the apical ones (basitonia), they would depress the development of the upper part of the tree. In the following years we will proceed to a gradual elimination of the branches left, starting from the bottom (rising about 15 cm each year), to free the stem up to the desired height (trunk). Both on the stem and on the branches and on the secondary branches it is always necessary to avoid the growth of two opposite branches on the same node, since they would take too much force to damage the top. In these cases, it is advisable to remove one of the two branches.
- Eliminate suckers and suckers annually.
- In the pendulous variety, to form the main branches choose the relatively more erect branches, to avoid the formation of an excessively hanging crown; vice versa in the assurgent varieties, to favor the opening of the crown, choose the branches inclined

Figure 71: elimination of the suckers

towards the outside. To form branches, take advantage of any branches already present, avoiding, if possible, to resort to the trimming of the stem (as was done in the past), which should be done only if there were no branches used to set the main branches.

Figure 72: it is very important to manage the upper part of tree crown that must be very evident, but not too vigorous

- By means of appropriate interventions (inclinations, return cuts), favoring the balance between the main branches (e.g. a too vigorous branch should be inclined more and vice versa); in parallel, identify the secondary branches, so as to fill the existing spaces. Among these, with cimature or thinning, we must favor those better inserted, avoiding leaving nearby branches overlapping each other, since the upper one would shade the one below. The secondary branches must be weaker than the main branches.
- The top of the tree, and subsequently those of the main branches, must be freed from lateral branches, without undressing it excessively. If the top is weakened, it must be promptly renewed by making a return cut (cutting performed just above a branch that will form the new top). Avoid forming the top with a suction that, being too vigorous, would assume an excessive force, or with a fruit branch (only flower buds), because it would be necessary to renew it immediately after the fruiting; instead, it is necessary to choose a mixed branch (that is with flower and wood buds) or wood (wood-like gems) of medium vigor.
- Protecting the health of the leaves, resorting, if necessary, to pesticide treatments.

Recommendations on pruning growing plants

The following measures for a balanced and rapid growth of the tree are particularly important:

- ✓ limit as much as possible the removal of the leaf apparatus;
- ✓ favoring the balance between the main branches;
- ✓ in order to form the branches for a vase shape in pendulous varieties, choose the relatively more erect branches, while for the rising varieties, choose those inclined towards the outside;
- ✓ avoid any bifurcation (dichotomy) of main and secondary branches;
- ✓ keep the tops light;
- ✓ eliminate the suckers unless they are used to make up parts of the crown;
- ✓ guarantee plant health.

7.1.3 Select the final tree shape

Among the forms of tree training, the most widespread in traditional olive growing are the vase and, to a lesser extent, the monocone.

➢ *Vase*

The vase can be made with many variations (free vase, polyconic vase, inverted cone vase, etc.), which differ in the inclination of main branches, the distribution of vegetation around them and the height of the trunk. Currently, in order to limit the pruning operations and support as much as possible the natural way of vegetating of each variety, the free-form shape is favored, thus reducing the necessary interventions to force the plants into precise geometric shapes.

Structure of the free vase shape

The vase consists of a trunk with a height that can vary from 50 to 120 cm, depending on the harvesting system. Compatibly with the need to manage the soil under the trees, it must be contained at 50-80 cm in the case of manual or facilitated harvest, while it must be 100-120 cm in the case of mechanical harvest with trunk vibrators. From trunk top 3-4 main branches should be selected, inclined of about 45° with respect to the vertical for manual harvesting, and 35-40° when using trunk vibrators. It must be taken into account that, to ensure good penetration of light into the foliage and adequate solidity, the branch inclination should be between 35° and 45°. Again, in order to guarantee adequate mechanical strength, the main branches should be inserted at a distance of about 10 cm vertically. For an optimal exploitation of space, the three main branches should be inserted around the trunk at an angle of 120° (or 90°, in the case of four main branches). Laterally and below the main branches are inserted secondary branches, with a length decreasing from the base towards the apex. The secondary branches carry the fruiting branches (2-3 years of age). Towards the inside of the crown on the primary branches there should not be secondary branches but only weak branches, so that light and air can easily penetrate. Thus conformed, each branch assumes a semicone shape. Therefore, the foliage presents empty spaces (windows) among main branches (full crown at the bottom and discontinuous at the top) and is almost empty internally.

Figure 73: olive grove with vase training system plants

To increase the efficiency of the trunk vibrators for harvesting the vessel must have:

- straight trunk, regular and with height of 100-120 cm;
- linear main branches with a narrow insertion angle (35-40°) with respect to the vertical;
- numerous secondary branches, inserted laterally to the main ones, not overlapped at short distances, short and without sudden changes in direction (goose necks);

- limited presence of long, elastic branches hanging at the base of the crown (pendants), which are abundant in some varieties, since these would be scarcely stimulated by the vibrator.

How to form the vase (figure 76)

1. During the growing phase, the planted olive tree must be insured to a guardian pole and left to develop freely for 2-3 years, avoiding that basal ramifications take excessive vigor on the stem, therefore, branches that are excessively erect and too vigorous must be eliminated.

2. For the formation of the main branches it is preferable to exploit suitable branches already present, including the possible central axis, progressively eliminating the others. Cutting the stem apex may favor the formation of new vigorous shoots below the cut, thus remains necessary if there are no suitable side branches to form the main branches. According to this method of traditional pruning, after 2-3 years from plantation, the stem should be topped just above the area where the main branches must grow. When many shoots will appear, initially leave 6-7 and then select 3 or 4, suitable for the constitution of the main branches, all the others must be progressively removed, starting with the more vigorous ones.

3. Branches naturally too upright or too vigorous must be progressively inclined by shortening their axis at well-directed branches insertion, in order to obtain a suitable angle with respect to the eliminated part. So, if a branch is too open, a cut will be made to replace the top with a rising branch, and vice versa. Only in the case of branches highly unbalanced or not adequately inclined, it may become economically acceptable to resort to drastic interventions to obtain the right inclination of the branches, such as for example the trestle, formed with rods stuck in the ground and crossed and tied to each other and to the stem at the crossing point, or the use of a metal ring, positioned in the basal and internal part of the main branches and fixed by means of a diametric pin to the brace, or spreaders to force between two branches, or the use of slurs which force the branches at the desired inclinations. The adoption of these systems, given the laboriousness and therefore the cost, should be done only in extreme cases, when other simpler methods have not worked and compatibly with branch flexibility.

Figure 74: formation of the vase in the juvenile phase (Tombesi, 2002)

4. Main branches must be grown until they reach the pre-established crown height (generally no more than 4-5 m above the ground), after which they will periodically return to this height by means of shortening cuts (return cuts) carried out above a mixed branch (with flower and wood buds) or wood (only with wood buds, but not suckers, that are too vigorous and vertical), rightly positioned and of medium vigor. The apical branches (tops) are very important because they have the function of determining the balanced development of the whole branch, reducing the emission of too vigorous side shoots and of promoting an adequate inflow and a uniform distribution of the lymph. It is necessary to avoid that tops of the main branches become too thick to guarantee a balanced development of the secondary branches below.

5. During the formation, each main branch must be covered with secondary branches laterally and externally, adequately spaced from each other, avoiding overlapping at a short distance, while only short and weak branches should be left inwards. The latter are necessary to guarantee a rather uniform diametrical growth of the main branches. The length of secondary branches must be decreasing from the bottom to the top, to contain the mutual shading and thus ensure the good lighting of the whole branch.

Figure 75: **the primary branches must be covered with secondary branches of decreasing length from the base towards the apex**

Advantages of the vase shape

- Thanks to the distribution of vegetation on several vegetative axes, the vase shape allows a greater volume of space to be explored compared to other forms, following the strong development of medium / high vigor varieties in favorable environments and allowing to intercept a high amount of light with a good uniformity of illumination throughout the coma, also useful for reducing the susceptibility to parasitic attacks.
- The vase shape facilitates the maintenance of the balance between vegetative and reproductive activity;
- It also facilitates manual harvesting and that with facilitators, allowing easy exploration of the entire crown.
- It adapts well to mechanical harvesting with trunk vibrators.

Disadvantages of the vase shape

- The initial growth may be slower than in other forms, mainly if a drastic intervention is necessary for the formation of the main branches, while this drawback does not exist if plants have been set-up in the nursery, therefore shoots are already present to become main branches.
- The vase shape is not suitable for mechanical pruning, for which a wall-shaped vegetation along the row is necessary.

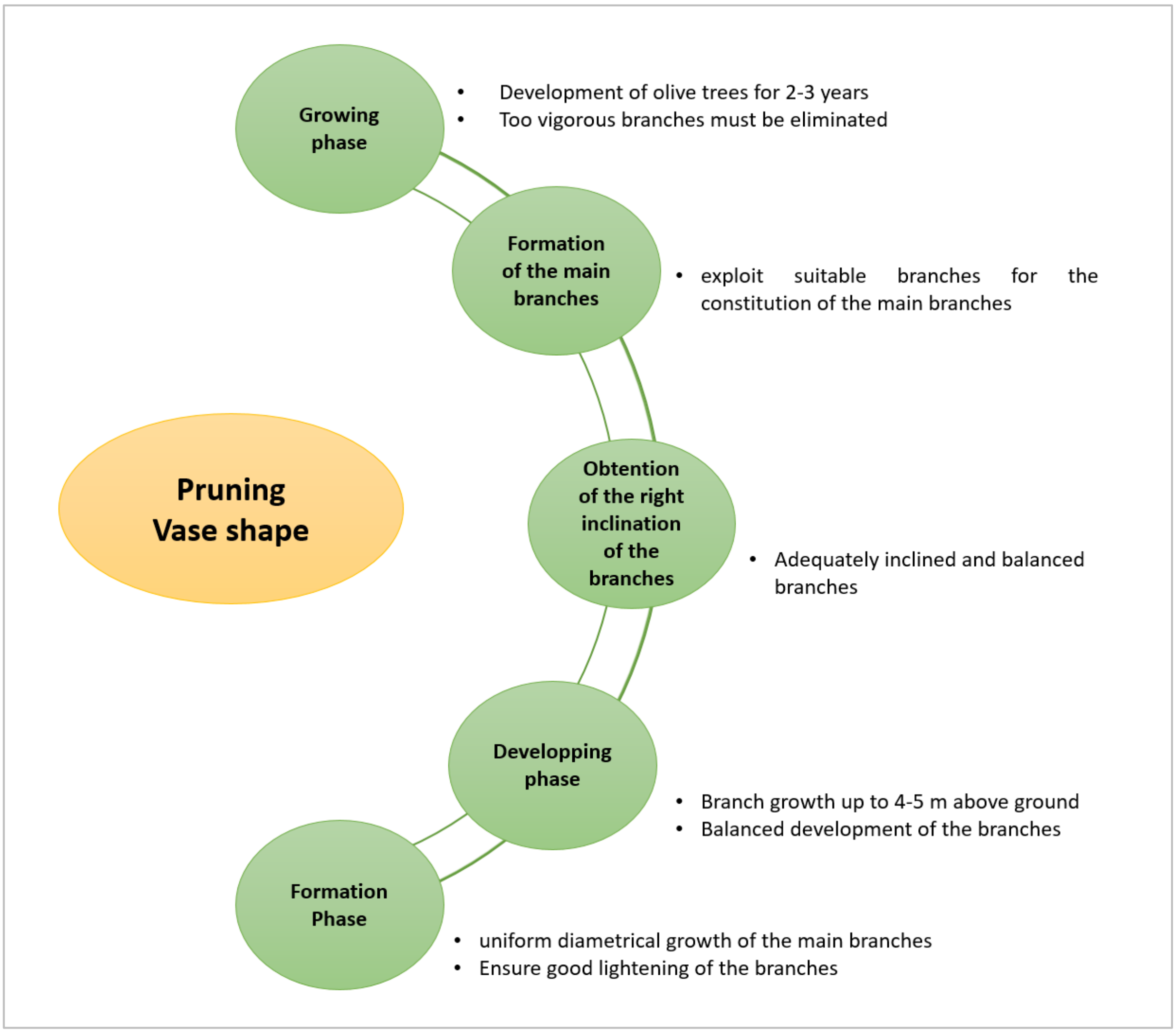

Figure 76: vase shape pruning guidelines

➢ *Monocone*

The monocone is a form proposed in order to reduce the lateral size of the trees and increase plant density, as well as to facilitate harvesting and allow mechanical pruning.

Structure of the monocone shape

Plant vegetation is distributed on a single vertical axis (stem) on which are inserted, with a very open angle, the primary branches, with a length decreasing from the base to the top of the canopy, which thus assumes a cone shape, whose wideness depends upon the length of basal branches. Main branches should be spirally arranged on the stem and overlapping branches should be spaced at least 1 m apart to avoid mutual shading. The lower branches should be stacked on the stem at a height of at least 1 m and the overall height of the trees should not exceed 4-5 m.

Figure 77: olive grove with monocone training system plants

How to form the monocone

The olive trees must be secured to a robust guardian pole. During the first 3-4 years, it is necessary to stimulate the growth in height of the stem, controlling the lateral vegetation with summer interventions to eliminate or shear the shoots too vigorous or inserted too vertically on the stem, particularly those near the top that tend to compete with it. It is necessary not to leave more than one twig on each node of the stem, to avoid that opposite shoots assume too much force compared to the main trunk. It is necessary to favor the formation of main branches with a wide insertion angle, eventually by substitution with other more inclined lateral branches.

It is very important that the top of the stem is always kept very evident, through appropriate thinning, and when it is damaged or weakened, it should be promptly replaced with the more vigorous branch below, tying it vertically to the brace.

Every year, ramifications of the basal part of the trunk must be progressively removed, up to a height of at least 1 m.

Each main branch should be covered with secondary branches and small branches, eliminating by a summer pruning any sucker that may have formed on the upper part of the main branches.

Figure 78: monocone after pruning

Advantages of the monocone shape

- The monocone, following the natural vegetating way of the olive trees, especially for the rising cultivars, requires more limited pruning compared to the vase and allows the mechanization, at least partial, of pruning and harvesting with trunk vibrators.
- The monocone shape occupies a narrower surface than the vase, so it allows to adopt higher plant densities.

- Since it is a narrower shape with no gaps inside the crown, it allows the use of pruning machines, as well as for harvesting, spraying and soil processing.

Disadvantages of the monocone shape

- To obtain the monocone shape is more difficult with pendulous varieties, since the lower branches tend to take the upper hand, and with very high or very vigorous varieties, with which it is necessary to frequently replace the top, weakened by other rising branches or by a remarkable presence of suckers.
- As the size of the canopy increases, there is a gradual increase in shading in the internal and basal portions, which may progressively deteriorate, while the tree tends to form new vegetation in the peripheral better-lit parts. Consequently, to avoid that the top of the stem grows too much in height and that the primary branches become too long, it is necessary to intervene with progressively more energetic pruning, which further stimulate the vegetative activity to the detriment of the productive one.
- In the case of manually operated pruning and harvesting, the monocone prevents the stable positioning of the stairs, putting the operators at risk and making the operations more difficult.

➢ Bushy vase (or poly-stem vase)

Widely used in the past in central Italy, it is now only present in old plants and is not recommended, for the difficult control of weeds at the base of the tree, the troubles in positioning the sheets for harvesting and the inadequacy to mechanize harvesting with trunk vibrators. It consists of 3-4 plants spaced 80- 100 cm among them around a common center, each with a semi-cone shaped vegetation (shorter branches inside), forming a single crown. This form of growing was widely used to replenish olive plants badly damaged by cold, through the growing of suckers developed from tree stumps cut at ground level (generally three, two of them in the row and one towards the inter-row).

Figure 79: bushy vase

7.2 Production pruning

The production pruning consists of a series of operations to keep in balance the vegetative and productive activity of the trees, preserving the shape and optimizing the density and the size of the crown.

In particular, a correct pruning must allow:

- improve the quantity, constancy and quality of production, by proportioning the quantity of branches left on the tree (and therefore the production potential) to its nutritional status and favoring the lighting and aeration of the entire crown;
- maximize the period of production maturity of the tree, delaying the senescence, both maintaining the vegetative-productive balance, favoring a high ratio between foliar and woody mass, and ensuring the air circulation in the foliage and eliminating the parts damaged or attacked by pests;
- to facilitate cultivation operations.

7.3 Necessary knowledge to prune properly

To pursue the above objectives, some knowledge is needed on the relationship between pruning and vegetative and productive activity of the olive tree.

7.3.1 Illumination of the canopy

The good lighting of the leaves is essential to guarantee a high vegetative-productive activity of the tree. Leaves that are in a shaded position, in fact, reduce the production of carbohydrates that are used for the vegetative and productive activity of the tree. Leaves shaded for most of the day even become a cost to the tree, since the amount of carbohydrates they produce through photosynthesis is lower than that they consume with respiration. In this case, leaves fall precociously, and the shaded parts of the foliage may remain undressed, wasted and dried (a sort of natural pruning).

The good availability of light also acts positively on the formation of flower buds and on fruit development. In fact, the portions of the crown where lighting falls below 30% of the full sunlight, generally do not form flowers and, therefore, fruits.

Olives placed in the most illuminated areas of the canopy have a greater size and a higher oil content than those grown in the shade, even if the overall availability of assimilates is high in the tree. The exposure of the fruits to direct light also seems to improve the qualitative characteristics of the oil.

To promote the vegetation of basal portions of main cladding branches due to the shading, it is necessary to reduce the height of the trees and/or to thin out the upper portions to favor the light penetration. On branches well exposed to light, in fact, in a few weeks new sprouts (suckers) may be formed, among which it is possible to choose those suitable to form new producing shoots (not very vigorous and inserted laterally or below the branch).

Therefore, pruning must ensure adequate illumination of the entire canopy, avoiding that some portions remain constantly in the shade.

7.3.2 Balance between vegetative and productive activity

In the olive tree, inflorescences are formed on the wood of one year, on the shoots formed in the previous year. When the productive activity is excessive (high fruit load), the vegetative activity (formation and development of the shoots) is reduced, thus lowering the production of the following year. On the other hand, in case of excessive vegetative activity, the productive activity is reduced (poor formation of flower buds and low fruit setting). Consequently, to achieve maximum productivity over the years, pruning must tend to balance these two activities.

The balance favors the formation of the best sprouts for a good production, as those of medium vigor (20-60 cm length), with semi-assurgent, horizontal or pendulous bearing, and positioned in well-lit areas. Too vigorous or too weak branches have an excessive vegetative character and a low productive potential (since they have few buds).

In relation to the above, it should be considered that:

- any intervention that reduces the shoot growth rate promotes the production activity;
- in young trees intense pruning accentuates the vegetative activity and delays the entry into production;
- by modifying the growth direction of shoots and branches, variations in their vegetative-productive balance are induced, since as the inclination of the vegetative axis moves away from the vertical position, its vigor decreases to the advantage of the productive activity, and vice versa;
- a tree with poor nutritional availability will react mildly to pruning, even if intense, thus, it will be difficult to obtain an adequate formation of new vegetation.

7.3.3 Balance between canopy and roots growth

In the tree, a relationship is established between crown and root system size: following the removal of a part of the crown, the tree tends to restore this relationship by increasing the formation and lengthening of the shoots, while growth of the trunk is reduced, as well as the formation of new roots and productive activity. In fact, the most evident reaction to intense pruning is the emission of several suckers or very vigorous and vertical shoots, unable to flower for several years.

By reducing the size of the foliar apparatus, pruning may decrease, in proportion, roots development, since these take the substances necessary for the formation of their tissues and the energy for their activity from the products of leaves photosynthesis. This relationship is particularly important in the olive tree, for which the interaction between portions of the root system and the corresponding portions of the crown is sectoral, so that each main branch has a corresponding portion of roots. As a consequence, the elimination of a main branch can cause the decadence of the corresponding part of the root system. This makes it necessary, when replacing a branch, to select a sucker in advance that can replace it.

Figure 80: in the olive tree there is a sectoral relationship between main branches and main roots, as evidenced by the formation of ribs on the trunk

When in the tree a lot of wood is accumulated, due to the age and/or irrational pruning, the resources necessary for its maintenance increase strongly and consequently the ones available for the formation of new shoots and roots decrease. In extreme situations, with a large amount of wood compared to the leaves, the tree's activity decreases and a progressive weakening (senescence) of the tree is established. Then pruning must tend to maintain a high ratio of the foliar/wood mass, above all proceeding to the renewal of the aged wood structures and avoiding the removal of the vegetation from the main tree structure.

About this last point, it should be considered that in the olive tree, branches tend to fructify in the median and basal portion and to emit buds in the apical part, so, if this growth method is not corrected by pruning, in addition to an excessive development of the canopy (with consequent problems of mutual shading and difficulty in the execution of cultivation operations), you would have an increase in vegetation in the peripheral parts of the canopy and therefore a progressive accumulation of wood.

***Figure 81: in this* tree there is an excessive quantity of wood due to a high number of main branches**

To counteract this tendency, the exhausted fruiting shoots (defoliated and with few short shoots) must be renewed, using one of the suckers or one of the small branches formed at their base, in order to bring back the vegetative portion.

Figure 82: typically, fruits are formed in the middle part of the branch, while the shoots in the terminal part

7.3.4 Pruning intensity

It is very important to apply a suitable intensity of pruning to balance vegetative and productive plant activity. To identify the best pruning intensity in the context in which it operates, it is necessary to observe the shoots vigor at the next vegetative restart.
For orientation, it should be considered that:

- if the pruning has been too mild, there will be the formation of a few weak shoots (length lower than 10-20 cm), the quality of fruits will reduce (lower unit weight and low oil content), the vegetative activity will be reduced, the fruiting branches will weaken, and production will tend to decrease over the years, also due to a greater damage caused by pests;
- if the pruning has been excessive, vegetation will be too vigorous, with the formation of shoots over 60 cm long and many suckers; the strong vegetative reaction causes a considerable depletion of tree reserves, consequently reducing the productive activity;
- if the pruning has been balanced, many shoots of medium vigor (20-60 cm), semi-assurgent, horizontal or pendulous will appear, the best for the production and for the establishment of a good vegetative-productive balance, with an adequate vegetative development and fruiting proportionate to the nutritional availability.

It must be said that a rather widespread error is the adoption of a too intense pruning compared to the real needs; this error is often caused by the desire to achieve a well-defined geometric shape of the canopy. In general, the amount of vegetation removed with annual pruning should not exceed 20-30% of the foliage.
To define the appropriate pruning intensity, the following aspects should be considered.

- *Tree age*

In the early years after planting, the olive trees have a high vigor, grow rapidly in height, in stretching the branches and thickening the trunk, therefore, considering that the light can easily penetrate into the still small crown, the pruning must be very light, in order not to accentuate the vegetative reaction to the cuts and not to delay the entry into production.
In the phase of full fruiting, as a result of the expansion of the foliage, trees tend to reduce the vegetative activity in favor of fructification and then the intensity of pruning must increase (medium intensity), to provoke an adequate vegetative reaction to the cuts.
In the senescence phase, the production activity tends to prevail, in relative terms, on the vegetative one, with consequent poor sprouting, for which intense pruning is necessary, through a few big cuts, associated with adequate nitrogen fertilization and eventually irrigation, so that,

leaving few buds, the available nitrogen will determine a greater development of the shoots and, therefore, a sufficient renewal of vegetation.

Figure 83: in old plants, pruning must be more intense to stimulate the formation of new shoots

- *Tree vigour*

It is necessary to evaluate the overall strength of the entire tree rather than that of individual branches.

If the tree is vigorous (long sprouts, dark green and shiny leaves, many suckers), it is advisable to perform light pruning and, by appropriate cuts (i.e. making the return cuts at a side branch), deviate branches from the vertical direction to allow lateral expansion of leaves, avoiding excessive bundling of the vegetation with consequent shading. However, severe pruning should be carried out on the most vigorous branches.

In very vigorous plants, therefore, pruning can be limited to the removal of suckers, to some thinning cuts to limit the shading and to the elimination of out-of-place, sick or deteriorated branches, or it can even be possible to skip the pruning for a year. In general, light pruning is recommended, not only to contain costs, but also because the intensification of cultivation

(fertilization, irrigation, absence of intercropping crops, chemical treatments, plant renewal), helps to make the trees more vigorous and to increase their productive potential.
If the tree is weak (short shoots, light and opaque green leaves, exhausted small branches), it is advisable to perform a severe pruning, to restore a good illumination of the whole canopy and stimulate the production of new shoots of medium vigor. At the same time, it is also necessary to intervene with adequate fertilization, possible irrigation and, if necessary, anti-parasitic treatments.

- *Amount of previous production*

To avoid that pruning may imbalance the vegetative-productive activity of the trees, leading to the alternate bearing (a high productive year followed by another with low production), the pruning must be severe after low-production, to reduce the amount of blooming buds and stimulate the vegetative activity, vice versa, in the year in which a low production is expected it is preferable to reduce the intensity of pruning. However, particularly in the olive-growing areas of central and northern Italy, olive growers often act on the contrary, pruning less after the year of discharge, hoping for a high production, but this may increase alternation. This choice can only be justified when the production potential can be compromised by recurrent adverse seasonal trends, preferring to exploit the favorable conditions when they occur. Also pruning at biennial shifts, after the year of charge, can raise alternation.

- *Local conditions*

Since in each environment and for each variety, different reactions to pruning may occur, it is very important to rely on local experience, taking as an example the intensity of pruning adopted in olive groves similar to the one to prune with high production performance, present in the same area or in similar ones.

Whit doubts about the optimal pruning intensity to practice, a little experimentation can be performed: for example, three different pruning intensities can be applied (light, medium and strong) on groups of four plants each, evaluating their productive and vegetative response over the years, and then extend to all the olive grove the intensity of pruning that has provided the best results.

7.3.5 Pruning period

Pruning is carried out essentially during the winter vegetative stop, possibly intervening in the summer to eliminate the suckers.

- *Winter pruning*

Winter pruning can be performed from harvesting time to spring budding. However, early pruning (November - mid February) in relatively cold environments can expose pruning wounds to cold damages, delays wound healing and induces an early sprouting (thus making the trees more sensitive to possible spring frosts) and, therefore, it should only be done in areas not subject to intense winter or spring cold. On the other hand, a late pruning (mid-April - May) may alter the physiological balance established in the tree in preparation for flowering, with possible negative impact on it, and may reduce shoot development, because with the pruning material get lost a substantial part of nutrients already displaced from the reserve sites (roots and trunk) to the foliage. The late pruning, therefore, is justifiable only for very vigorous olive trees and in fertile soils (to contain the vigor).

Taking this into account, in the milder areas, pruning should be carried out from harvest time until March, while in relatively cold seasons from mid-February to early April (optimal period in March), after the colder period.

- *Summer pruning*

The summer removal of basal and canopy suckers, particularly needed when severe winter pruning has been carried out, is carried out in July-August, when the sucking capacity of suckers has ceased, and they can be easily removed without cutting, but with a hand snap (better using work gloves).

- *Spring pruning*

Compatibly with farm organization, the removal of large branches could be done in the spring, to facilitate the wound healing, since in winter low temperatures can delay cicatrization, while in summer the burning rays can dehydrate the cutting surfaces compromising the scarring.

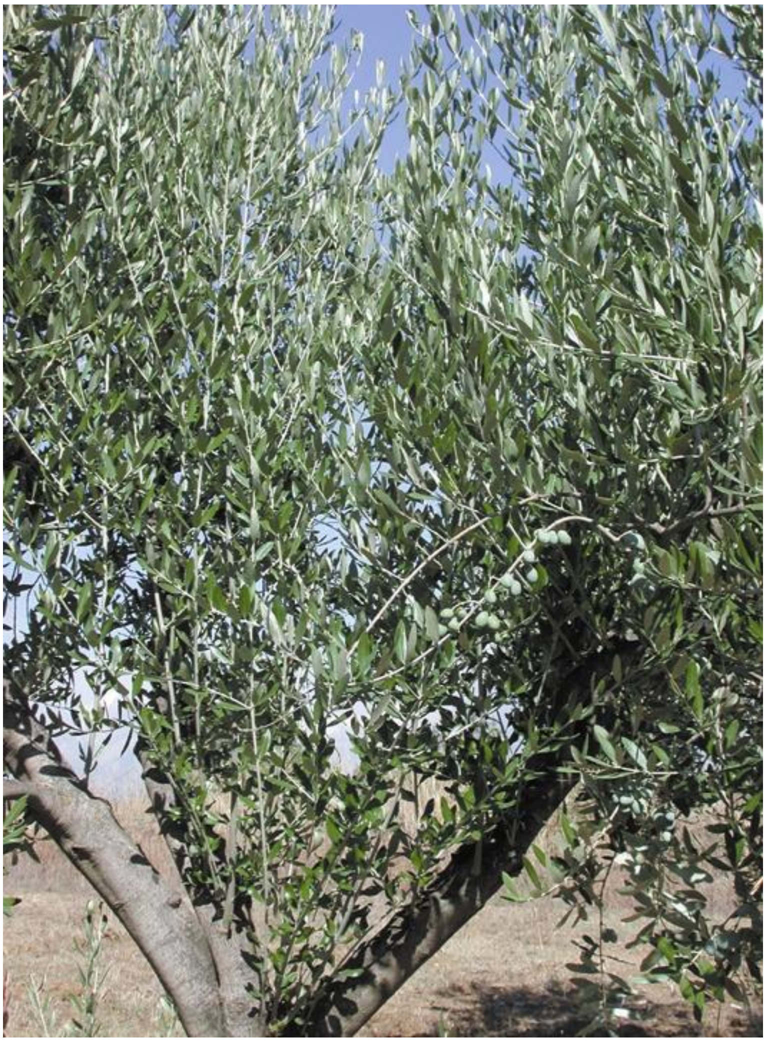

Figure 84: **when there are many suckers, it can be convenient to remove them in the summer**

7.3.6 Turning of pruning

Pruning can be carried out annually (annual round), every two years (biennial shift) or every three or more years (multi-year shift):

- the annual round allows a timely elimination of branches and exhausted or poorly positioned shoots, ensures a good airing of the crown and counteracts the alternate bearing, increasing the longevity of the tree (since it involves smaller cuts); on the other hand, it implies higher labor costs;
- the two-year round favors alternate bearing, it involves a rather energic pruning to be carried out after the year of charge with return cuts on the branches, thinning of secondary branches, elimination of exhausted shoots, and thinning of the inner part of the crown; eventually, in the following year, a fast pruning can be performed to eliminate any suckers and sick parts; the two-year pruning involves lower costs, but also a lower average annual production given the alternation; good results can be obtained where the olive trees grow well even in the year in which it is not pruned, since in this case the biennial shift does not cause significant production decrease or problems for mechanical harvesting and can therefore represent the best compromise between technical results and costs; to reduce alternate bearing, the two-year pruning can be alternatively performed on half of the trees of the entire orchard, pruning half of the trees one year and the other half the following year and so on;
- the multi-year round involves a very intense pruning, which consists in lowering the crown and in shortening or eliminating the old branches; the drawbacks described for the two-year pruning are accentuated; moreover, it causes a premature aging of the fruiting vegetation and reductions in production; it is practicable in conditions of scarce water and environmental resources, where the skilled labor is lacking and where the expected average production would be rather low even with annual or biennial pruning.

7.3.7 Performing pruning

In general, at first it should be made an intervention on the main structure of the tree, with the biggest cuts, then gradually moving to the smaller ones on the branches and finally on single shoots, in order to maintain a better control of the final result of pruning, regulate the vegetation density and avoid unnecessary repetitions of cuts.

To reduce the time of pruning, either manual or facilitated with pneumatic or electric tools, it is advisable to avoid interventions on individual small shoots, instead cutting portions of greater size (branches), using mainly loppers and saws instead of shears.
The following is the order in which operations should be carried out.

1. Control of size and shape of the crown

   a. Reshaping the crown, laterally, in relation to the planting distances, and in height, by means of return cuts, i.e. cuts made to shorten the branches, to perform above a branch or on a side branch, suitable to replace the function of the removed part. This intervention is aimed at avoiding mutual shading between contiguous plants, removing protruding branches that hinder crop operations, avoiding excessive accumulation of wood and ensuring solidity and rigidity of the tree structure, necessary for mechanical harvesting. Typically, downsizing should be done every 2-3 years.

   b. Correction of any differences in the height of the main branches through return cuts to shorten the longer ones.

   c. Removal or shortening secondary and tertiary branches not well spaced and/or superimposed on others, reminding that they should be spirally arranged to limit the mutual shade.

Figure 85: primary branches after pruning

2. Elimination of basal suckers

a. Suckers that grow at the base of the trunk must be completely eliminated by cutting them at the point of insertion to the tree using shears or loppers.

Figure 86: sucker removal

3. Removal of internal suckers

a. Suckers inside the canopy that do not serve to reconstitute structural parts of the crown (primary or secondary branches dried, sick or weak) or to form new branches, must be removed.

b. Suckers intended to replace branches should be chosen well in advance of substitution. At the beginning it should not be shortened but rather freed from the lateral ramifications that go towards the inside of the canopy, topping the others; only when it will be well grown, it could be slightly shortened. The sucker should then be bent in the direction of the branch to be replaced, then the weight of ramifications should cause its further inclination.

c. In the bare portions of the canopy (i.e. basal areas of main branches) some low-vigor suckers can be raised (inserted laterally or below the branches), which must be bent or shortened, leaving 2-3 pairs of buds, to prepare them to form coating branches.

4. <u>Thinning and rejuvenation</u>

a. Tree canopy should be thinned out, starting from the top of the main branches and proceeding towards their base, both to ensure adequate light penetration and to proportion the production load to the potential of the tree.

b. Each branch top should be set on shoots of medium vigor and must always be evident but should be lightened (lightened) if too dense, to avoid shading and competition with the underlying parts of the branch; when the top is set on vigorous and unbranched branches, with an excessive lengthening and the formation of a vegetation tuft in the terminal part, it will be better to completely remove the portion. It is necessary to take into account that the top of the main branches plays an important role because it promotes the balanced development of the entire branch and limits the development of suckers.

c. After having set the top, small branches and producing shoots must be thinned along the branch to avoid an excessive load of fruits and the aging of vegetation (see below "Removal of exhausted branches"); small branches oriented towards the inside of the canopy and those intertwining with each other must also be eliminated.

5. <u>Prevent the formation of bifurcations</u>

a. To avoid the formation of bifurcations (dichotomies), i.e. the formation of two branches or opposite branches with the same strength, which reduce efficiency and accelerate the aging of the canopy, it is necessary to promptly remove one of the two, leaving the one that favors a balanced distribution of vegetation.

6. Removal of exhausted fruiting branches

   a. Depleted fruiting branches, easily recognized because they are defoliated and with few short shoots (less than 10-20 cm in length), as previously mentioned, must be renewed using one of the suckers usually formed at the base of old fruiting branches when the weight of fruits causes their bowing (rising cultivars may escape from this rule). After the elimination of the exhausted fruiting branch with a cut immediately above the chosen shoot, this will emit strong new fruiting twigs whose weight will favor their inclination and stimulate their production. In the next two or three years, the weight of fruits will determine a further inclination of the branch which, for this reason, will abundantly produce and, therefore, it will be exhausted and will have to be renewed with a new basal shoot.

   b. With the progress of the years, following successive rejuvenation cuts on the same small branch, structures formed by a series of small arches will be formed, bringing the fruiting portion to the extremity; when the series of small arches is excessively lengthened, the vegetation must be brought back cutting at the base of the structure; if there are no suitable shoots, their formation could be induced by ramming a basal bow. This cyclic pruning, besides the periodic rejuvenation, avoids the excessive removal of the fruiting branches from the main branch and, therefore, it contrasts the accumulation of excessive quantity of wood.

In cultivars with an upright habit, in which the fruiting branches are rising, the central axis must be trimmed to widen the branches and lateral shoots must be ramified to replace the exhausted branches afterwards. Also, in this case, it must be avoided that fruiting branches become excessively lengthened.

It is important to remind that, to reduce pruning costs, it is advisable to make a few cuts on wood with more than two years (i.e. on fruiting branches) rather than numerous cuts on younger wood (shoots). In fact, if the tree is in a vegetative-productive equilibrium, the cuts can be limited to return cuts on a few branches and to the complete elimination of the exhausted branches.

Figure 87: operator using a pneumatic shear mounted on a rod and wearing personal protective equipment

Figure 88: electronic scissors with battery

Figure 89: electronic chainsaw mounted on a telescopic pole with a battery carried by a vest

Figure 90: operators who are using the slider canopy and the lopper

7.3.8 Pruning and health of the plant

Pruning increases the risk of fungi infections responsible for the wood decay (especially *Fomes fulvus*) and the bacteria responsible for the olive knot (*Pseudomonas savastanoi*), which can penetrate into the tree through pruning wounds. On the other hand, pruning can contrast the development of parasites, both allowing the removal of the attacked portions and therefore sources of infection and favoring the air circulation and the penetration of light into the canopy, which hinder the development of many parasites. A light crown density after pruning also allows a good penetration of pesticide treatments.

To reduce the risk of pathogen and pest attacks and accelerate cicatrization of cuts, it is worthwhile to observe some rules when making cuts:

- better use two-blade scissors; if you use scissors with a single blade and counter blade, the latter may damage the bark by compression, thus it must be positioned on the part of the branch to be removed;
- if it is necessary to use a saw for cutting, it is preferable to use a double-row type of teeth that, unlike traditional blades, produces a very clean cut, in order to facilitate the healing and the quick draining of rainwater, otherwise it would favor the attack of pathogens;
- to remove the suckers, do not use the hoe, but the scissors;
- when shortening the branches, perform back cuttings, i.e. cut just above a bud able to assume the function of the eliminated part;
- when branches are removed, never leave stumps because they would dissolve or could be attacked by parasites, which would then also extend to healthy wood;
- on the other hand, it is not necessary to make cuts too close to the insertion point, since the conducting system present in the swelling, called "collar", at the base of the branch, would be damaged and consequently the cicatrization would slow down with risks of parasitic attacks; the cut must therefore be done without leaving stumps, but leaving the collar intact;
- to facilitate cicatrization, the cutting surfaces should not be horizontal but inclined, to facilitate the draining of rainwater;
- to eliminate large and heavy branches, in order to prevent the branch from tearing the bark and falling down before the cut is finished, it is advisable to first make a shallow cut under the branch and then complete the cut from above, making sure that the two cuts are on the same level;
- Pruning wounds generally need no curative treatments; however, if the diameter of the cut is greater than 5-10 cm and if the environment is favorable to attacks of olive knot or other wound pathogens, it is advisable to spread on the cut surface a scarring substance or at least a copper product;
- In the presence of sick plants with wound pathogens (e.g. olive knot), after their pruning and before moving on to other healthy plants, it is necessary to disinfect cutting tools (with

flame or alcohol or copper products, leaving them to soak for a few minutes), to avoid the spread of pathogens.

Figure 91: pruning cuts can promote parasitic attacks

7.3.9 Effects of no pruning

If pruning of adult olive trees is stopped, suckers take over the upper parts of the canopy and vegetation moves upwards, where there is lighter, while in the lower part branches gradually strip off the leaves, due to the shadowing and the pathogen attacks favored by the shading and by the poor aeration. In the early years, unpruned trees can continue to produce, but the strong competition exerted by the load of fruits will reduce the vegetative development, triggering a strong alternate bearing, more accentuated in difficult pedo-climatic conditions. After a few years of non-pruning, the vegetative-productive balance of trees will be definitively compromised, which could be partially restored only through drastic pruning reforms.

8 HARVESTING

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Harvesting is the last part of the annual olive production cycle; this practice is one of the more significant aspects in the production of olive oil because it can affect:

- quality and quantity of final product;
- future fruits production of olive trees;
- the economy of harvesting itself.

The harvesting timing is defined considering physiological processes which take in the olive plants and into the fruits during the ripening, in particular the processes influencing quality and quantity of oil production.

The most frequent problems occurring during the harvesting are:

- Low production caused by early harvesting (mechanical harvesting further reduces the yields) or late harvesting (strong olives falling into the ground);
- Quality reduction or low organoleptic profiles of olive oil due to anticipate or late harvesting;
- Fruits damaging during harvesting and transportation processes;
- Operators' safety threatened by the use of equipment as ladder (hand harvesting), or by the use of equipment and machinery for harvesting (trunk or twigs shakers, etc.).

➢ *Harvesting operations*

The harvesting operation can be optimized as described below:

- The ripening process is monitored by a ripening index to identify the optimal ripeness period.
- Oil mill and olive treatment have to be conducted rapidly after the harvesting;
- Harvesting operations have to avoid fruit damages which reduce oil quality;
- Mandatory law has to be applied during all the harvesting processes taking care of safety and healthcare of workers (professional training courses and adoption of personal security equipment)

The most frequently problems occurring during fruits transportation and storage are:

- damages of fruits;
- long storage of fruits, phenols and minor component of oil were lost, and aromas and flavours were reduced (fruitiness, spiciness and bitterness)
- wrong storage room conditions, as high humidity and high temperatures which would expose olives to mould and pathogens compromising the qualities of the product. (acidity increased, peroxide, perception of defects as “mould”, “winey” and “riscaldo” characteristics).

The above-mentioned defects can be avoided by:

- use of appropriate harvest crate (opened and strict) where olive fruits don’t reach more than 30 cm of thickness;
- the thickness of the ground stratification of olives cannot exceed more than 10-12 cm of high;
- select appropriate storage rooms (closed, ventilated, cleaned, odourless and temperatures over to 15 °C)
- short term-storage (between few hours and 48 hours up to 48 hours, depending on temperatures and fruits damages).

Figure 92: use appropriate containers to store the olives

8.1 Olive fruits ripening

Fruit compositions like chemicals, physical and sensorial constituent change during the ripening and they have to be monitored to define the optimal period to harvest the fruits.

Oil accumulation in the fruits

Oil accumulation starts in august, it increases between mid-September and mid-October than it slows down in the last periods of ripening. This process can be also influenced by climate conditions. During the last phase of ripening the fresh weight of fruits decrease cause of the loss of water content. As consequence, the percentage of oil content increases into the fruits, even if there were not an effective accumulation of oil.

The oil production per tree depends on the amount of fruits production in particular it is affected both to the increase of olives weight and to the oil accumulation into the drupes. During the ripening period the oil content per tree reaches a maximum level and then it decreases as a consequence of fruits falling. Indeed, olive fruits are characterized by a scaling ripening and then the fruits have different degree of ripening. The maximum oil reachable per plant corresponds to the initial fruits drop. The quantity of oil into the fruits starts to decrease when the oil accumulation into the olives doesn't balance the oil lost with the olive drop. On the other hands, the quality of oil improves with its accumulation into the drupes, but then it decreases before the maximum oil accumulation point. So that, the priority of the production has to be defined between quality or quantity of oil.

Change in olives weight during ripening

The olive development follows a double sigmoid curve characterized by a latent period at the beginning of the process and another one at the end. At final stage of ripening, the fresh weight of drupes can be reduced by the loss of water even if it can increase again in rainy condition. The olives dry matter quickly enhances until the end of October then it decreases till the final value.

Colour change during ripening

When the ripening starts the colour of the olives epicarps changes. The initial green colour decreases, and the pigmentation starts initially red-violet at the apex and then the red-violet colour is extended over the surface of the drupe with darker shades of black. In the final stages of ripening, pigmentation may also affect the pulp (mesocarp) from the exterior part to the endocarp. The pigmentation, which starts at approx. 130 days from full bloom, is influenced by several factors, such as season, fruit load, and cultivar. For example, Frantoio drupes remains green even near maturation, while Leccino drupes changes colour early in the time and in Moraiolo only at the final stage of ripening. But an abundant production of fruits also provokes a delay of fruit colouring.

Change in fruit hardness during ripening

During the fruits ripening, mesocarp occurs several processes which makes fruits even more soft and sensitivity to wounds during the harvesting and storage processes.

Change in fruit attachment force during ripening

Separation of the fruit from the tree depends on how strongly fruit is attached to the shoot. At the beginning of ripening it correspond to about 6 N (1 kg = 9,81 N), then in the intermediate phase it is about 4-4.5 N and in the advanced ripening phase it is less than 3 N. Values around 3 N indicate an imminent fruit drop (about 10 days later). Fruits drop starts below 2.5 N values. The reduction of detachment strength is not uniform then each cultivar has a characteristic fruit attachment force.

For example: in Moraiolo, it is very high around 6 N in the first decade of November, then it decreases regularly until mid-December. In Leccino, it stays constant close to 5 N for a long time. In Frantoio, it has values of 4.5 N in November and it begins to decrease towards the end of the month only. In San Felice, it is about 4 N, and the fruit drop occurs since the second decade of November. Fruit resistance in detachment is a fundamental value when harvesting is carried out by trunk vibrators.

Oil quality changes during fruit ripening

Oil sensory profile is massively influenced by the harvesting processes. The ripening stage influences quality and composition of fundamental compounds of oil, these substances are:

- compounds responsible for the note of fruity in the oil, those called "head space";
- Phenols and other antioxidants like as tocopherols and carotenoids, which preserve olive oil from oxidative processes (rancidity) and reduce inflammatory processes, tumour development, cardio-vascular problems, aging, etc. in human body. Moreover, they are responsible for the bitter and spicy flavours in olive oil;
- Fatty acids interested in human nutritional intake.

Often, the pigmentation and consistency of the fruit are parameters related to the quality of the olive oil and they can be assumed as important index of ripening. The quality of the olive oil decreases when the pigmentation affects the pulp and the hardness of the mesocarp becomes very low.

8.2 Ripening and olive oil quality

During ripening processes:

- the oleic and linoleic acids increase (unsaturated fatty acids);
- the palmitic and stearic oils decrease (saturated fatty acids);
- the phenol content increases and it tends to decrease in some cv, while in others cultivar decreases progressively only;
- the stability of the oil decreases (the antioxidants decreases and linoleic acid increases). e.g. If phenol content is low and the harvesting is late there were a reduction in oil stability;
- green colour (due to chlorophyll) decreases;
- the fruity feeling evolves
  - starting from the green fruits where there's a predominance of herbal scents,
  - until mature fruits with prevalence of floral and / or fruit flavours.
  - after, the fruity feeling decreases strongly (sensory flattening) due to the decrease of aldehydes and other volatile compounds.

However, late harvesting can give good quality oils ("sweet" oils) if it is accompanied by adequate phytosanitary defence and by correct olives storage techniques.

Figure 93: nets for olive conservation

In conclusion, oils obtained from unripe olives have a strong green colour due to carotenoids and chlorophylls and they are characterized by strong and unbalanced herbs, bitter and spicy flavour. Oils obtained from olives harvested at the right degree of ripeness have fruity, harmonious and balanced sensations. Oils derived from late harvesting are light with fruity sensation tending to be "sweet", often they take on hints of dried fruit (almond, hazelnut, pine nuts, etc.). The acidity flavour is not directly influenced by ripening, but late harvesting increases the risk of mechanical or parasitic degenerations of pulp, which would result in an increase in acidity.

Optimal harvesting time

The optimal harvesting period occurs when:

- the fruits have accumulated the maximum quantity and quality of oil
- The harvesting machines provide the best results.

The best harvesting time varies from year to year, it can change in the order of 1-2 weeks because it is affected by climate change, irrigation and load of fruit. Usually, harvesting time is concentrated from late October to December. Cultivars characterized by an average-high size of fruit (2-4 g) have high yields in that period. Other cultivars with small olives size have a gradual increase in yields with the season's progress, which is due to the reduction of fruit attachment force (ie below 4 N, while it is considered high above 6 N). Harvesting should be carried out when the strength/weight of fruits ratio (N / g) is around 2.

How determine the optimal harvesting time

The optimal harvesting time could be determined monitoring:

- The trend of fruits drops, the fresh and dry weight of fruits, the oil accumulation, the pigmentation, the fruit attachment force and the hardness of the drupes;
- the amount of oil yields from plants;
- the change of the acid composition, the phenols content, the substances responsible for the fruity flavour, etc.

The most important ripening indexes are:

- Colour of fruits;
- Fruit attachment force;
- Fruits drop;
- Fruits hardness;
- Oil content.

8.3 Colour index

The colour index is obtained by a visual evaluation of the fruit pigmentation. Method based on olive skin and pulp colour: The colour of each fruit is evaluated by first observing the skin colour of the whole fruit and then by observing the colour migration inside the pulp after cutting a portion of the pulp with a sharp knife. Maturity values of each fruit are classified in eight categories (Table 6).

Table 6: The eight categories of skin and pulp colour of olives during the ripening process

Maturity value	Colour description
0	Skin colour deep green – fruit hard
1	Skin colour yellow-green – fruit starting to soften
2	Skin colour with less than half the fruit surface turning red, purple or black
3	Skin colour with more than half the fruit surface turning red, purple or black
4	Skin colour all purple or black with all white or green pulp
5	Skin colour all purple or black with less than half the pulp turning purple
6	Skin colour all purple or black with more than half the pulp turning purple
7	Skin colour all purple or black with all the pulp purple to the pit

The steps of the evaluation procedure are:

1. Start the Maturity Index evaluation before the beginning of harvest (for example, mid-September) and repeat it twice a week until the harvesting decision is made.
2. Randomly select 100 fruits out of the same sampling bucket and evaluate the colour characteristics.
3. The maturity value of each of the one hundred olives is determined according to Table 6 and the fruits in each category are counted.
4. The Maturity Index (MI) is obtained by multiplying the number of fruits in each colour category by the number of the corresponding maturity value, adding all the numbers together and dividing by 100 as follows:

$$MI = [(0 * n_0) + (1 * n_1) + (2 * n_2) + (3 * n_3) + (4 * n_4) + (5 * n_5) + (6 * n_6) + (7 * n_7)]/100$$

Where: n_0,n_1,n_2,. . . , n_7 = number of olives in each of the eight categories of the maturity value.

The MI based on the evaluation of colour increases with the ripening process.

8.4 Fruit detachment force

This index is determined using a dynamometer measuring the traction force required to pick up a fruit from the branch. This data is very useful when the olives are mechanically harvested. The dynamometer returns values in grams, which has to be multiplied by 9.8 to obtain the Newton (N). Trunk shakers obtain optimal yield when the detachment force is lower than 4-5 N (<4 N with small fruits ie <2 g), or when the ratio of strength / weight (N / g) is low than 3.

Figure 94: the resistance to detachment decreases with advancing maturation

8.5 Fruits drop

The harvesting must be completed before fruit drop is greater than 5-10% so that loss of product is avoided, and a good oil quality is obtained. For example, the optimum timing for the most varieties cultivated in Central Italy can be identified when 15-20% of fruits have an attachment force less than 3 N. Usually, the optimum harvesting time coincides with the fruits drop. This parameter can be easily monitored by applying tissue bags to some branches and then controlling weekly the percentage of felled olives compared to the total one's present. Alternatively, it can be determined by placing nets under the crown and making periodic surveys to quantify the percentage of dropped olive fruits.

Figure 95: early drop of olives can constitute an index of maturation

8.6 Hardness of the pulp

Hardness of the pulp index measures the degree of fruit pulp interpretation evaluating the resistance to the penetration of the epicarp (peel) and mesocarp (pulp). The epicarp resistance doesn't vary during ripening while the mesocarp resistance decreases. This parameter is calculated using a penetrometer, with a tip of 1.5 mm in diameter, to a sample of 50 drupes.

Figure 96: pulp consistency is reduced with advancing maturation

8.7 Fruit oil content

The oil content is a parameter used to determine the maximum yield (quantity). In general, the oil content is considered in relation to the dry weight of the fruit (since it is not affected by rain or irrigation). The index is obtained dividing the fresh weight of fruits (generally between 15 and 22%) by the dry matter (calculated by drying the fruits in a ventilated hoven at 90 ° C for a few days). The fruits oil content can be also determined by pressure (Rambotti method), by solvent extraction (Soxelet method), by evaluating the different density of the oil-solvent mixture respect to the pure solvent (Foss-let method), or by using a spectroscopy technique of "Near Infrared" (InfraAlyzer 2.000 Olive). These instruments measure the total oil content in the fruits; this level is higher than that obtained in olive mills where a small quantity of the oil inevitably remains in shrubs and in vegetable water.

The optimal harvesting time is determined considering the ripening indices. The optimal values are not defined for all the olive cultivar, for these reasons the ripening indices corresponding to its own cultivar have to be in order to use it all over the years. Obviously, the definition of reference values for ripening indexes should be carried out in several years of observations (at least 3-4) in order to take into account, the effect of seasons and fruit load.

Special cases- late and early harvesting using the trunk vibrators

When may be convenient to anticipate the harvesting:

- In the presence of fly attacks to limit damage;
- If it is hailing during the harvesting time to contain the oil deterioration;
- When herbaceous, bitter or spicy oils are desired.

Harvesting times should not be delayed excessively over the optimal period since accidental product losses may occur due to the increase in wind, thunderstorm and snow. In particular frostbite can cause the increase of acidity and the appearance of unpleasant dry or wood tastes. Then, it is better to anticipate or widen the harvesting period if necessary.

When may be convenient to delay harvesting:

- when "sweet" oils must be produced; to safeguard the integrity of the fruits;
- Using mechanical harvesting with trunk vibrators on "difficult" cultivars. High yield (olives harvested compared to the total present on the tree) can be obtained identifying the period

when the weight of the fruits is high, the detachment strength is low and the quantity and quality of the oil are at good levels.

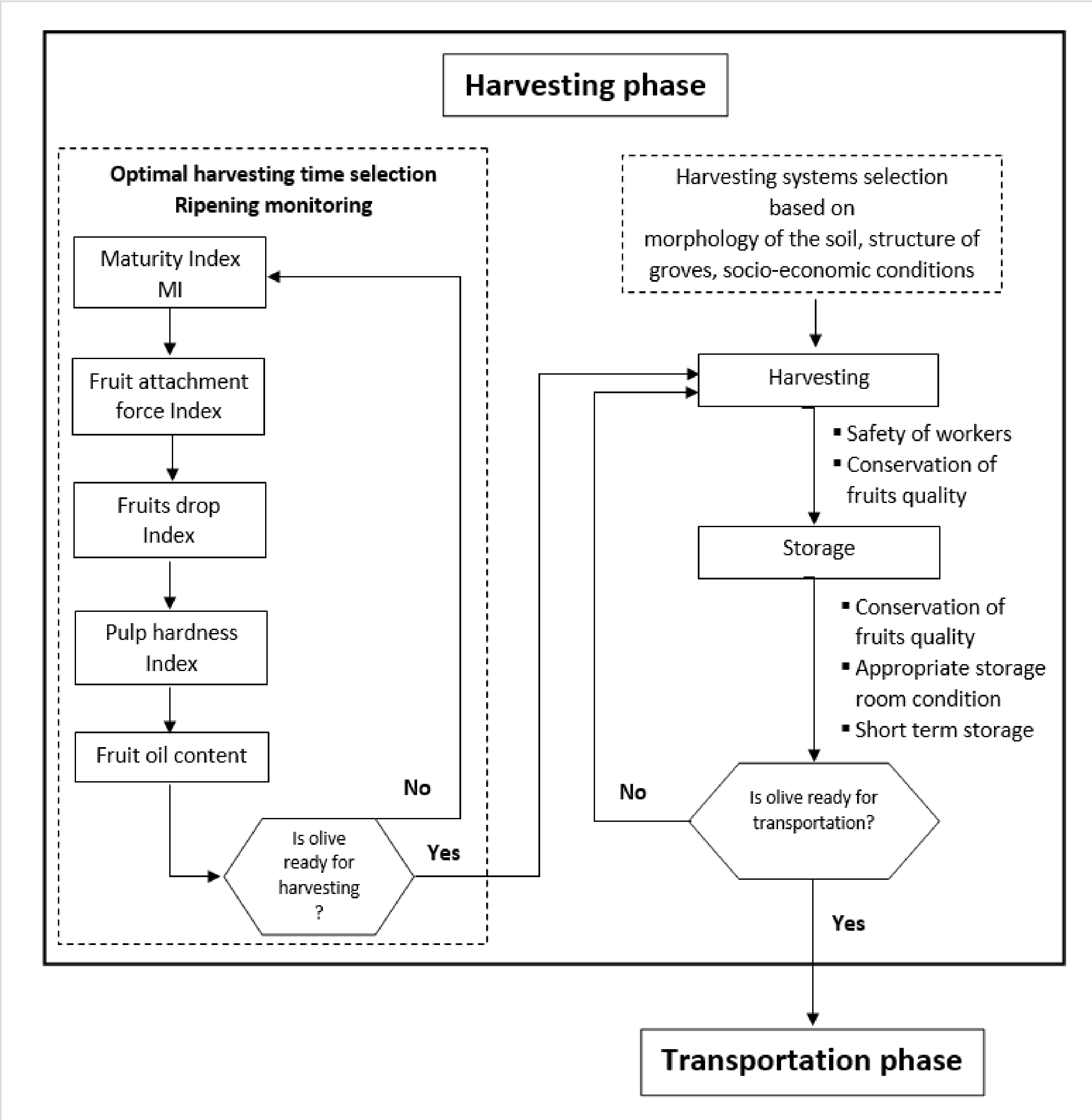

Figure 97: harvesting guidelines

8.8 Harvesting systems

The harvesting method has to be selected according to several factors such as layering and morphology of soil, development and conformation of trees, business size and socio-economic conditions where crops are cultivated. Possible collection systems are:

- Collecting from the ground
- Beating or hand harvest
- Electric olive harvester
- Trunk shaker
- Continuous mechanical harvesting
- Straddle harvesters with beaters

Figure 98: manual harvesting of olives

8.8.1 Olive Harvesting using electric olive harvester

Harvesting can be facilitated by hand held mechanical tool carried by the operator and applied directly onto the branches. These machines work thanks to small electric motors or electric batteries. The separation occurs both by direct action and by the induced vibration. The harvesting is realized of 1/2 operators each plant and grounded nets managed by other operators. The operators have to change place each other every 2 hours to improve the process. Long rectangular nets extended on more plants are useful to improve the harvest efficiency.

These tools can be distinguished on the base of their operating mode:

a) *Branch shakers*

Combs consisting of teeth, varying in number and length, depending on the model considered. These devices cause the fall of the fruits both by direct action on and by indirect vibrations induced on branches and branches. The combs made up of longest and shaving teeth (usually a variable number from 3 to 5) are more suitable for plants with high and / or dense crown (eg cultivars characterized by high and unpruned crown). While larger and thick teeth are particularly useful with early harvesting (high detachment resistance) and in the presence of little fruits.

b) *Combing machines*

These tools consist of aluminium rods carried at the top a rotating titanium metallic rake which provokes the olive separation from branches. The "rake" detached from the rod can be used in the lower branches. The swivel joint allows to adjust the harvesting work depending on the characteristics of the crown. Various measurements of "rake" are available, the choice depends on the type of olive fruits, the degree of ripening and the training system.

Figure 99: pneumatic combs

Figure 100: electric combs

c) Hook Shaker

These machines consist of a rod at the end of which is mounted a hook. This tool hooked to the branches transmits vibrations to detach the fruits (up to 1,000-1,500 strokes / min.). The rod can be telescopic and generally does not exceed 3 m in length, however some models can collect fruits up to 8 m high (e.g. Hill Solution). They are driven by their own burst which is supported by the operator. Usually, the diameter of the branches on which the hooks are applied must not be <5-6 cm for the efficient use of it. These machines are equipped with anti-vibration grip systems to minimize vibrations transmitted to the operator.

The hooks are mounted on rods of variable length, made of light but durable materials, such as aluminium, fiberglass, nylon, carbon fibre. The weight of tool depending on the length of the rod and on the materials varies from 2 kg to 3 kg.

Generally, they work at a variable operating pressure of 6 to 8 bar and they consume about 200 l of air / min each. The use of high length pipes minimizes the handling of the tractor or the engine compressor; However, it is advisable not to exceed 100 m in length to ensure optimum amount of air and lubricant.

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Figure 101: shaker hook

Electric branch shakers are generally provided by 12 or 24 V batteries and the autonomy is about 7 hours. These machines have very limited noise and are generally equipped with an electronic device to prevent engine damage in the event of blockage. Electric powered equipment is particularly interesting to small companies, which do not have the availability of a tractor and do not intend to purchase a motorized compressor.

Grove training system and efficiency of the electric harvesting equipment's

Harvesting tools can work on every training system adopted but the height of the trees should not exceed 4-4.5 m. The cultivar, the harvest time, the production effect speed and efficiency / productivity of harvesting. Good results occur when the value of the ratio of resistance to fruit ripening / fresh fruit weight is under 3. The harvesting productivity indicates the amount of olives harvested per unit of time by an operator.

Figure 102: harvesting with electric comb

Pruning and electric harvesting equipment's

The harvesting with electric tools requests short-crown height. As consequence, crown development has to be led in width by pruning. Best results are obtained with varieties with medium/high fresh fruits weight and low attachment force. Branch shakers and combing machines can harvest almost all the production, while hook shaker can reach 60-75% in early stages (end of October to early November), and 90-95% in late stage. This equipment helps to increase the productivity of the harvesting, expressed as the number of plants harvested per operator per hour and as kg of olive per hour per operator.

Advantages of electric harvesting equipment's

Electric harvesting tools increase the harvest productivity of 2-4 times more than hand harvest. The cost is relatively low cost and the use is poorly influenced by soil conditions. They can reduce the cost of maintaining traditional olive groves because they are very useful in small-scale olive groves and in difficult-to-access areas such as hilly marginal areas where mechanical means can't work. (such as terrace located in an area with slopes of more than 25%).

Disadvantages of electric harvesting equipment’s

Electric tools tend to cause more damage to plants than manual harvesting, especially in early harvesting when the fruit attached force is higher. Usually if compared to manual harvesting, mechanical tools don’t greatly increase the level of damage to fruits. They have optimal results in small olive groves since the need for manpower is only partially reduced. Electric tools result in a greater operator fatigue, especially hooks shaker characterized by higher weight, highest noise and the production of combustion gases.

8.8.2 Straddle harvesters with beaters

Straddle harvesters are machines made up a standing support panel fitted on a movable arm mounted on a tractor (1-1.5 m long). The oscillating or vibrating support panel causes the drop of the olives from the plant by the beating of the branches. It reaches 7.5 to 8.5 m in height. The action is carried out only around canopy directly involved (discontinues way), so the tractor must make several moves to collect the whole production.

Figure 103: straddle harvester with beaters

The timing is streaky connected to the canopy size and it depends on the quantity of fruits. The harvesting, intended as kg of olive / h per operator, is also strictly linked to the productivity of the olive grove. Straddle harvesters are designed to be used on irregularly trunk structure tree, on which the traditional tools cannot be used. They are versatile, as they have no special requirements regarding the cultivar, the training system and the structure of the plant. They can also be used in olive groves with old large irregular-stems plants or policaules.

They reach beast results in case of high height and low attachment force of fruit. Considering the structure and dimensions of the machines, they have to be used with:

- large space over-the-row, so that the crowns are not in contact each other.
- low Slopes.
- higher unitary plant production.

Efficiency of Straddle harvesters

The yield efficiency can be very high about 90-100%; the increase in yield is generally correlated to the duration of the mechanical actions on the branches. The straddles productivity is 3-4 times higher (40-50 kg / h per operator) than those of hand harvesting, but it’s lower if compared to the trunk shaker instead.

Damage caused by the straddle

Compared with other collection systems, the straddle causes more damage to branch, canopy, and fruits. In susceptible cultivars, it may be useful to treat with Bordeaux mousse immediately after harvesting. Damage to fruits is similar of those caused by combs. It is therefore advisable to perform a rapid olive milling.

Economic convenience of straddle

Trunk shaker has high cost-effectiveness, a high purchase price, between 15,000 and 30,000 euros depending on the model, and very high operational capacity (time / plant). These tools are useful only in the presence of plants with good production (> 15 kg) and a minimum grove area of 4-5 ha (with 250-300 plants / ha).

8.8.3 Mechanical harvesting with trunk shaker

Olives are harvested by means of a vibrating grip head attached to the trunk or, in the case of very large trunks, to the main branches. Trunk shakers can be self-propelled or mounted on tractors. The cost of self-propelled shakers is higher than that of tractor-mounted shakers and therefore they are mainly used by large olive groves or service companies. For trunk shakers a tractor with power greater than 60-80 CV is required, depending on the size of the grip head and the combination of the collecting frame for the olives. The vibrating grip head consists of a jaw with a cushioned system to avoid damage to the bark of the trunk or branches. Vibrations are generated by two eccentric rotating masses turning in opposite directions or by one mass in an orbital movement. The arm supporting the vibrating grip head may be telescopic, thus allowing greater versatility in movements, especially when it is necessary to apply the grip head to the main branches. The vibration time is 10–15 s, depending on the olive cultivar, the ripening stage and the tree shape, but most of the olives drop in the first few seconds. In general, to avoid tree damage, it is preferable to apply two short vibrations than only one longer one. The falling olives are intercepted by nets manually spread on the ground or by upside-down umbrella-shaped mechanical looms (diameter from 5 to 10 m), which close below the crown When trunk shakers operate in combination with mechanical looms for fruit collection, labour productivity may reach a value of 200–400 kg per hour per operator. As an average, in one month 20–25 hectares of olive trees can be harvested. Service companies may offer trunk-shaking service to small olive growers. The productivity of trunk shakers decreases greatly when it is necessary to attach the shaker to the branches and when nets have to be moved manually.

Figure 104: harvest with trunk shaker and umbrella

<u>Advantage of trunk shaker</u>

Harvesting needs only few seconds per plant (5-20) determining a high productivity of harvesting work. Trunk shelter equipped with a reverse umbrella interceptor were reach 200-400 kg / h person. The productivity of harvesting reaches 4-5 to 20 times higher than those of manual harvesting. The percentage of fruit ripening (harvesting yield) varies from 70 to 95% depending on various agronomic factors, usually is over than 85%. Trunk shakers increase the amount of product harvested per unit of time, reducing the storage time (the minimum quantities need to be milled is reached faster). Moreover, trunk shaker selects fruits collecting those already ripened, leaving those less ripe and grown in shaded areas of the hair (so less rich in phenols and aromas). They considerably limit the man fatigue and injuries by avoiding the use of stepladders and reducing the man work. These machines also reduce the harvesting costs.

Figure 105: shaker without and with interceptor frame

Disadvantage of trunk shaker: trunk and branches damages

Trunk bark is the most frequently damaged plant portion, it well tolerates radial forces up to 37 kg cm^{-2} but it suffers tangential forces (10 kg cm^{-2}). Bark can be also damaged during the harvest period in case of particular favourable climate conditions and / or application of abundant irrigation. Excessive oscillations may cause branches breakups, especially if the stumpage has health problems (e.g. attacks of caries). The most vulnerable areas are the grafting point. Prolonged shaking may cause the leaves to fall on the higher parts of the plant; with no significant increasing in harvest yield. Damages may increase with the application of improper vibrations, inadequate tightening of the vibrating head, uneven orthogonality between trunk and shaking area, shaking point close to the main branches or close to collar. Harvesting machines can also cause soil compacting when they were used on wet soil and/or on bare soil.

Characteristics of olive groves for mechanical harvesting with trunk shaker

Agronomic factors affecting shaker effectiveness on yield:

- Olive grove productivity

High plant production is required to obtain high harvest yield, since harvesting times per plant don’t depend on plant charge. High production gives higher amount of harvested olives per unit of time and thus higher harvesting efficiency. Then, olive tree productivity directly influences the reduction of production costs and indicates a minimum level in olive yield per plant (equal to 15 kg) to make convenient mechanical harvesting with trunk shaker. Trunk shakers are highly cost effective when plant productions approach or exceed 20 kg of olive.

- Application point of trunk shaker

The shakers can be applied to the trunks or, if they are too large (diameter greater than 50 - 60 cm) or irregular, to the branches of the tree. Trunk application makes harvesting faster respect to the branches application, moreover it also makes difficult to intercept fruits with the reverse umbrella.

- Canopy volumes

Plant canopy must be adjusted to mechanical harvesting. The trunk shaker returns good results with canopy volume up to 40-50 m3; while higher volumes give less harvesting yields. When the canopies are very large, with trunk diameter greater than 50-60 cm and / or the canopy volume exceeds 50-60 m3, adequate harvest (>85%) can be obtained only using the shaker on the branches. Branches shaking increases harvesting times, with negative effects on the operation's economy.

Figure 106: for the application of the shaker the trunk must be at least one meter high and the main branches in the vase must be raised

- Plant Characteristics

Plants must have single and regular trunk at least of 100 cm height characterized by vase training system or central leader training system. The canopy should not be in contact to the interceptor frame. The canopy volume should remain constant after pruning to avoid yield reduction; in that case, canopy volume of median and apical part must be increase. The branches angle (respect the trunk) should be relatively close (35-40 °). The secondary branches must be short and linear to guaranty the best transmission of vibration.

- Training system

Single-stem and vase training systems return high harvesting yields. Even if, operating times tend to be higher (+ 10%) for single-stem training system due to the difficulties in the engagement/deactivation of the shaker to the plants. On the other hand, vase training system has the difficulty of catching shaker and to the higher time requested for the greater number of connecting point. The trunk shaker on the open vase training system allow to obtain similar yield to the single-stem training system, if applicable, but the harvesting times are considerably higher.

- Planting distance

In order to use trunk shaker, the olive groves must have:

- soil slope less than 15-25%, using crawler tracts and lightweight headstocks for higher slopes.
- regular planting distance between lines (at least 5 m).

The optimal planting distance is 6 x 6 m. The distance between plants along the row is relevant in case of trunk shaker with no interception systems, because of the machine movement which is essentially into the interlines in presence of interceptor frame. In that case the requested distance along the row is at least one meter.

- Appearance and attachment force of fruits and trunk shaker

To obtain a high yield, the fruits should have medium-high dimension (> 2g) and a high attachment force (about 4 N or less); the resistance to detachment is considered high when it exceeds 6 N. The harvesting yield is good when the ratio between attachment force and weight of fruits is equal to 2, while it can be difficult with ratio values of 3.

- Cultivar and trunk shaker

Cultivars particularly vocated to mechanical harvesting have medium or large (up to 1.5-2.0 g) fruits and medium/low attachment force of fruits that allow the highest yields. The most difficult crops to be harvested have small fruits and high attachment force of fruits, such as Canino, Carboncella and Moraiolo.

- Age of plants and trunk shaker

Trunk shaker can be applied in the harvesting of young plants when the trunks reach a diameter of 8-10 cm. Vibrations are transmitted with less efficiency in older plant; In this case the risk of trunk or branch breaks are increased. Usually, old plants do not allow to achieve good harvest yields, because of the high volume of canopy.

Olive-harvesting yards

<u>Harvesting net</u>

Yards site use trunk shakers and nets on the ground to intercept olives. The nets are variable in number, generally from 4 to 7, and require a large number of workers to move and drain them. Generally, "net-yard sites" times exceed 20-60% of the corresponding "shaker-catcher yard sites" times, where post-detaching operations limit harvesting productivity (it can go down to 10-12 plants / h).

Figure 107: interceptor umbrella

Inverted umbrella catcher

It consists of parts arranged to form a reverse cone with a centre wrapped around the tree trunk and a hopper for temporary storage of the olives (average capacity of 200 kg or more). Inverted umbrella catcher has a diameter varying between 5 and 10 m. Fruits from the umbrella goes into a box set at the base of the structure. The metallic box mean loading capacity reaches 400kg, it was emptied by tilting in the trailer. The umbrella, in the resting position, remain closed near the shaker. One operator is required to control the machine while a second operator is responsible for the tilting of olive into the trailer and assists the first operators in the various manoeuvres. Mechanization of harvesting and the use of inverted umbrella allow a substantial increase in productivity (20 times compared to manual harvesting and 7 times if compared to collection with pneumatic combs).

Figure 108: unloading the olives harvested with a shake

Trunk shaker with interceptor mounted on a tractor

The trunk shaker is equipped with interceptor towels mechanically stretched and folded. The yards harvesting site consists of 6-7 operators. Olives felled on towels are conveyed in a box when the tower is rewound; these machines can be equipped with a fan removing leaves, when the fruits pass from the tower to the crates. The interceptor consists of a rectangular towed equipped with 2 or 4 wheels, mounted on a medium power tractor; it is laterally provided with two longitudinal rollers with two grids. The interceptor act on 2 trees per time.

Figure 109: trunk shaker with trailed interceptor frame

For the use of mechanized interceptors, olive groves must have the following characteristics:

- ✓ regular plantation distances;
- ✓ small trees;
- ✓ flat lay.

The use of trunk shaker with towed interceptor can be problematic in olive groves characterized by short plantation distances and in high speed land because of the large size of these machines.

8.8.4 Continuous harvesting

Continuous harvesting performed using 3-4 hours / ha (speeds of 0.3-1 km / h) is carried out with straddle harvester (modified grape harvesters) which work along the row in superintensive olive groves. In superintensive groves it is very effective, and the productivity is about 90-95% (if the attachment force of fruit is under 600g).

Figure 110: continuous mechanical harvester

Grape harvesters are modified increasing the number of shaker bars from 4 up to 10-15 or more and adding free beaters up to increase the harvesting efficiency. The beaters in the top vary their curvature cyclically and alternately with a frequency of 400-500 cycles per minute. The machines are equipped with levelling and anti-slip systems to ensure stability even in sloping land.

There are two systems for the olives harvesting: straddle harvesters with beaters and Straddle harvesters with conveyor belt. The first has beaters very flexible material and tied to an arc. The ends of the beaters are fixed both sides and are maintained at a constant distance from the centre of the machine. It has also a unique bucket collection system that consists of two conveyors, each with soft baskets.

The system runs directly on rails at a rate inversely proportional to the machine's travel speed. It has beating bars that hit the trees from both sides simultaneously and knock the olives onto a moving conveyor belt that transports them to holding bins which are emptied periodically at the end of the rows. The Straddle harvesters with conveyor belt has beating bars that hit the trees from both sides simultaneously and knock the olives onto a moving conveyor belt that transports them to holding bins which are emptied periodically at the end of the rows.

The harvested olives are then cleaned from the leaves and branches by an aspirating apparatus placed above the collection crates. Finally, the product falls into 2 crates of about 1660 litres each, which are dumped by tipping over a trailer.

Table 7: results of straddle harvester and trunk shaker harvesting

Type of machines	Hourly cost (euro)	Hour / ha
Trunk shaker	70	11
Straddle harvester	157	3.7

The estimated total costs are about 1.5-2 euro per kg of oil. The harvesting efficiency also depend to the length of the rows, the area's morphology and the duration of machine movement between groves.

Superintensive olive groves

The super intensive groves have about 1600 plants per hectare, with hedgerow system and distances between the rows of 4 m and distances between the rows of 1.5 m.

Management of superintensive olive grove

Pruning is done manually and by mechanical tools. The elimination of vigorous branches is performed manually, using mechanical or electric hacksaws. Mowing bars are generally used to reduce the plant height and to remove the branches too close to the ground. Irrigation is indispensable for an adequate plant productivity; the volumes normally used are in the order of 2000-2500 m^3 per hectare per year. Fertilization is done by fertigation (5-6 interventions per year). Foliar fertilization may be joined to anti-dandruff treatments and anti-cryptogamic diseases treatments (5-7 annual interventions). Soil is not plowed, covered with cover crop between rows, while glyphosate treatments are required in the row. The expected theoretical economic life of the superintensive grove is around 15 years and the expected production is around 6-10 tonnes per year. To date only a few varieties (Arbequina, Arbosana and partly Koroneiki) have been shown to be responsive to this pattern. Other promising varieties (Oliana, Don Carlo, FS-17, Uranus, Tosca, Askal and Sikitita) are under evaluation.

Figure 111: super-intensive planting

Continuous harvesting in superintensive grove

Areas with slope higher than 5-10% can create operational problems to machine movements. The size of the headlands must be greater than 6-7 m in order to facilitate harvesting and to reduce damage to the plant structure and to the machines. The passage of the machine on the plowed ground can result in compacting of ground which damages the roots and the proper functioning of the machines self-levelling sensors.

The size of the vegetation must be compatible with the machine's structure, with a height less than 3 m and a width less than 1,5 m.

Figure 112: continuous harvesting in superintensive grove

9 TRANSFORMATION

Nicola Evangelisti, Francesco Castellani, Fabiola Filippa, Edvige Pucci

The olives transformation process within the oil mill, normally includes the following phases and environmental impacts (figure 117):

1. **Delivering of the olives to the oil mill**. After an initial storage phase, which should be very short to reduce the water losses, the olives are **defoliated** and **washed**. Normally, about 0.08 m^3 of water is consumed each quintal of worked olives. The water is partly reintegrated because of some losses that occur during the process (about 10% of the total amount of the olives processed).

Figure 113: washing and defoliation of the olives

2. In the most common cases, where olives are not previously pitted, the process continues with the **crushing machine** and then the **kneading or malaxation**. In the kneading phase the olive paste needs to be heated, even if at low temperature, using hot water. This process, therefore, produces an energy requirement (electric or thermal) that varies based on the technology used (traditional boiler, biomass boiler, electrical resistance, etc.).

Figure 114: crushing and kneading machine

3. The **extraction**. It is the "core" of the process and it is realized using a decanter (horizontal, 3 or 2 phases or 2 and a half phases). Regardless of the type of machine used, at the end of the process there will be, in addition to the olive oil, some wastes and/or co-products such as pomace (dry or wet) and, in the 3 and 2 and a half phases, vegetation waters. The pomace amount is normally equal to 40-50% by weight of the olives processed. The vegetation water (or wastewater), rich in organic substances, is composed by the water contained in the olives and the water added to the process to fluidify the olive pastes and therefore make it easier to extract the oil (about 20-30% by weight of the olives processed).

Figure 115: centrifugal extractor

4. After the extraction, a further **centrifugation** allows to remove all water residues. This water is the added to the vegetation and washing water produced during the previous phases.

Figure 116: vertical separator and column filter

Together with pomace and washing/vegetation waters, other aspects of the environmental impact associated to the olive oil production, are constituted by the emissions due to the electrical and thermal consumptions for the feeding of the machineries present along the production chain.

From what has just been reported, we understand how the impacts are strictly connected to the resources used and how the quantity of resources used depends, primarily, on the configuration of the oil mill.

The table 8 shows the average consumption that occurs in the oil mill.

Table 8: Electrical and thermal costs of pitting machines

Electric energy	**Without olive pitting machine**	**3.00**	**kWh/q_{olives}**
	With olive pitting machine	**3.75**	**kWh/q_{olives}**
Thermal energy		**5.00**	**kWh/q_{olives}**

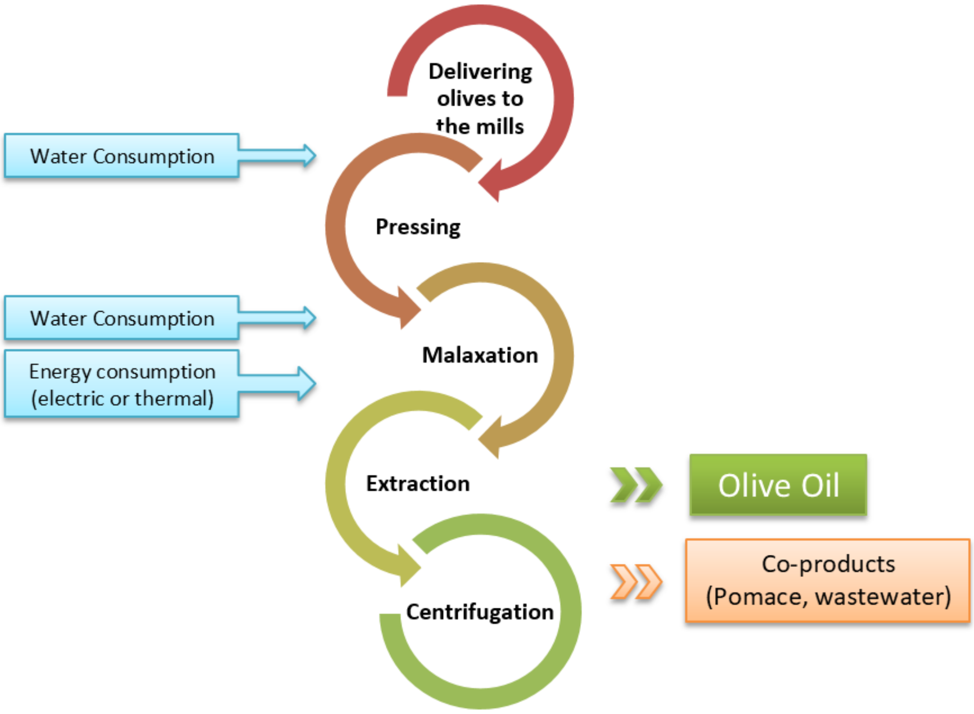


Figure 117: olives transformation process phases and environmental impacts

9.1 Olive pitting machine

Olive kernels (or stones) are usually considered a waste. In recent years, however, it is increasingly considered as a co-product obtained during the transformation process of the olive fruits through an olive pitting machine. In particular, kernels can be reintroduced into the life cycle of olive oil, or other products, with important environmental benefits.

Figure 118: olive pitting machine

Even if the introduction of a new machine along the production cycle can lead apparently to a worse condition, the use of the stones as "fuel" for the heating of the water used in the process constitutes a greater benefit by balancing the higher electrical consumptions.

Figure 119: olive pits

To understand the impact of the olive pitting machine it is possible to observe the result obtained in a study conducted in some Umbrian companies (Italy). The study shows that the machine has an average consumption of about 0.12 kWh per kilogram of kernel produced or, reporting the consumption to 1 liter of EVO oil, about 0.05 kWh per liter. This amount corresponds, on average, to an overall increase in energy consumption of approximately 25%.

Reporting this value in terms of primary energy, to remove 1kg of stones are necessary 1.1 MJ. This conversion it is necessary to highlight the benefits of this process. Considering the Lower Calorific Value (LCV), i.e. the amount of heat evolved when a unit weight of the fuel is completely burnt, the kernels have a LCV of about 16.5 MJ per kg of product.

By comparing these values, it is evident that the energy released through the combustion process of the material is much greater than the one required for its extraction. The process is therefore energetically very convenient. By using the stones as a biomass for boiler feed and therefore for thermal energy production, it is possible to cancel the natural gas, or other conventional fuels, consumption with a significant reduction of the climate change gases emission and the energy demands of the production process.

Potential Benefits

The potential environmental benefits deriving from the use of an olive pitting machine, i.e. the reduction of the CO2e emitted during the life cycle, has been estimated using SimaPro software. The software allows to convert the energy consumption (thermal, electric, diesel, petrol, etc.), the total amount of raw materials, etc. in an equivalent amount of greenhouse gasses. All the gasses identified by the Kyoto protocol were then converted in CO2e through specific normalization factors.

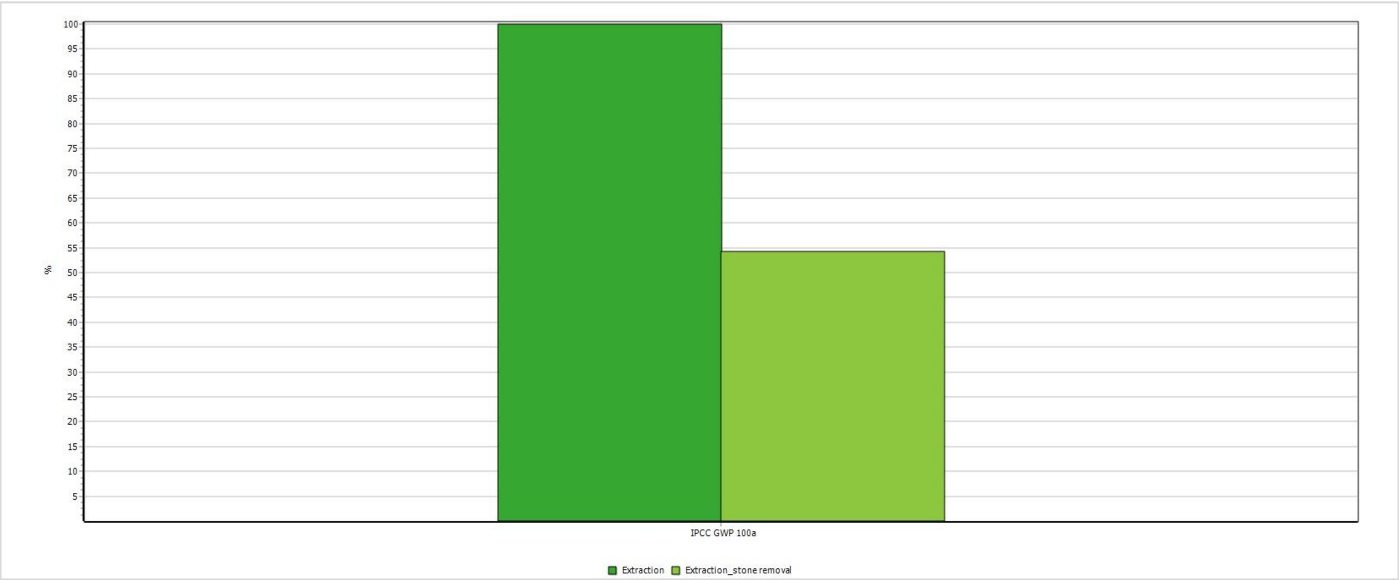


Figure 120: comparison of CO_2 emission without and with the olive pitting machine

The CO_{2eq} has been estimated using two different models. In the first model, without the olive pitting machine, the thermal energy requirements have been covered entirely through a traditional boiler using natural gas as fuel. In the second model, the thermal energy requirements have been covered by burning the olive kernels in a biomass boiler. All the other processes were not changed.

Comparing the results obtained, the percentage reduction of CO_{2e} emissions per year in the extraction phase is about 45%.

9.2 Power factor correction

POWER FACTOR is the ratio between the Active Power (kW) and the Total Power (kVA) consumed by an electrical equipment or a complete electrical installation. It is a measure of how efficiently electrical power is converted into useful output work. The ideal power factor is unity, or one. Anything less than one means that extra power is required to achieve the actual task at hand.

More specifically:

- Active Power [kW, kilowatt]: also known as Useful Power, it is the energy absorbed by the system and converted in useful work.
- Total Power [kVA, kilovolt ampere]: Maximum value of Active Power that could be obtained with a Power Factor equal to one.
- Reactive Power: when the Active Power is lower than the Total Power there are some losses within the electrical circuit and the Power Factor is lower than one, i.e. the waveform of the current no longer coincides with the waveform of the voltage. In this case the circuit is characterized by a power value called Reactive Power, i.e. a power absorbed by the system that is not converted in useful work.

Higher is the value of the Reactive Power, higher are the energy losses and, therefore, the current that must flow in the circuit to cover these losses. These conditions can determine:

- Higher operating costs of the electrical system also due to possible penalties in the electric bills defined by the electrical energy operator.
- A more rapid deterioration of the electric cables. A higher value of the current that flows in the circuit causes, in fact, a higher overheating of the electric cables.

The power factor can be increased by installing some capacitors in the electrical system according two different configurations:

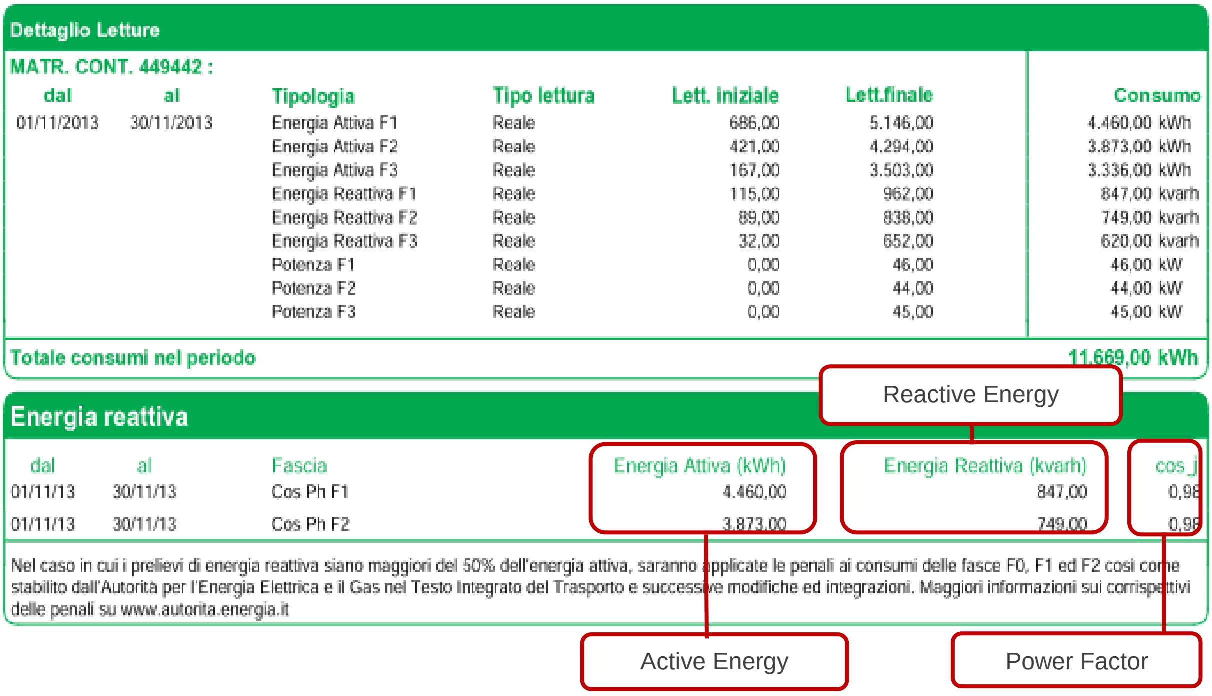
- One (or more) capacitor for each machinery.
- One (or more) common capacitor for all the electric circuit.

The choice between these solutions depends from several factor, for example the costs, the connected machineries type in the circuit, etc. Only after a in-depth analysis it is possible to evaluate the most appropriate solution.

Figure 121: capacitors installed in the electrical panel

With Power Factor correction it is possible to:

- Reduce the Current-dependent network losses, and therefore no compensation by increased power generation are required with corresponding reduction of CO_2 emissions.
- Increase the availability of additional transmission capacities, for instance for the transmission of renewable energy.



Dettaglio Letture

MATR. CONT. 449442 :

dal	al	Tipologia	Tipo lettura	Lett. iniziale	Lett.finale	Consumo
01/11/2013	30/11/2013	Energia Attiva F1	Reale	686,00	5.146,00	4.460,00 kWh
		Energia Attiva F2	Reale	421,00	4.294,00	3.873,00 kWh
		Energia Attiva F3	Reale	167,00	3.503,00	3.336,00 kWh
		Energia Reattiva F1	Reale	115,00	962,00	847,00 kvarh
		Energia Reattiva F2	Reale	89,00	838,00	749,00 kvarh
		Energia Reattiva F3	Reale	32,00	652,00	620,00 kvarh
		Potenza F1	Reale	0,00	46,00	46,00 kW
		Potenza F2	Reale	0,00	44,00	44,00 kW
		Potenza F3	Reale	0,00	45,00	45,00 kW
Totale consumi nel periodo						11.669,00 kWh

Energia reattiva

dal	al	Fascia	Energia Attiva (kWh)	Energia Reattiva (kvarh)	cos_j
01/11/13	30/11/13	Cos Ph F1	4.460,00	847,00	0,98
01/11/13	30/11/13	Cos Ph F2	3.873,00	749,00	0,9

Nel caso in cui i prelievi di energia reattiva siano maggiori del 50% dell'energia attiva, saranno applicate le penali ai consumi delle fasce F0, F1 ed F2 così come stabilito dall'Autorità per l'Energia Elettrica e il Gas nel Testo Integrato del Trasporto e successive modifiche ed integrazioni. Maggiori informazioni sui corrispettivi delle penali su www.autorita.energia.it

Figure 122: example of detailed analysis of an electric bill

The power factor, operatively, can be determined through:

- Measurements made with appropriate instrumentation, i.e. through a network analyzer that allows to monitor continuously the values of Voltage, Frequency, Current intensity, Active power and Reactive power;
- Detailed analysis of the electric bills (in the Figure 122 an example for the Italian service). In the electric bills, instead of the power value, can be specified the energy value.

Potential Benefits

The reduction of the CO_2 emitted by the power factor correction has been estimated considering the following criteria:

- Olive oil production line with a pic power of 70kW, low voltage 380V.
- Power factor range between 0.7 and 0.95.

The pic power has been define considering an olive oil mil composed as follow: olive storage system, washing and leaves removal machine, crusher, malaxation, decanter and oil polisher.

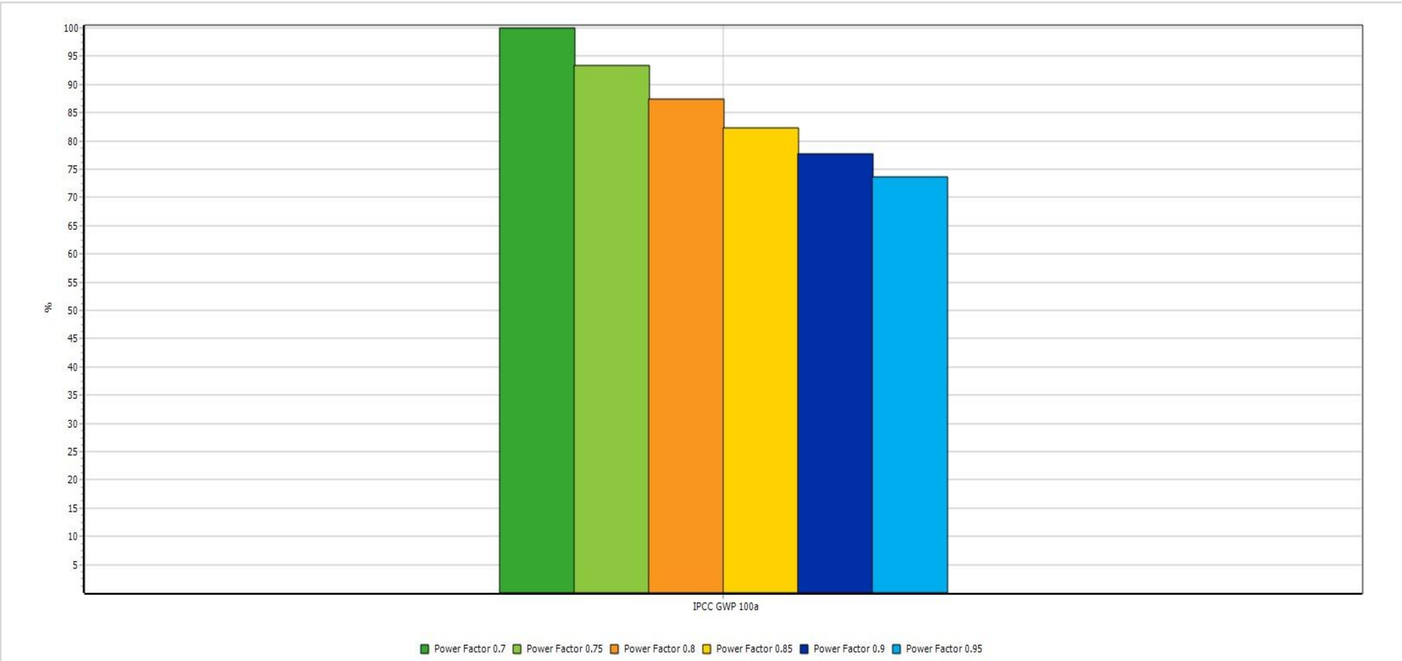


Figure 123: reduction of CO2 emissions (in %)

Comparing the results obtained, the percentage reduction of CO_{2e} emissions per year, passing from a power factor of 0.7 (green) to 0.95 (light blue), vary from 5% to 25%. In each step the power factor has been increased by 0.5.

9.3 Photovoltaic system

A photovoltaic system, also known as PV system or solar power system, is a power system designed to transform solar power in usable energy.

Figure 124: photovoltaic system

It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity. Farm buildings often have significant surface areas. Where there is exposition to solar radiation, photovoltaic panels could be installed to produce renewable electricity. Sometimes, electricity consumed from the grid could be replaced by the local renewable electricity produced (balance between the activity of the farm and the size of the installation). The advantages associated with this technology are:

- Absence of polluting emissions during operation (avoided emissions: 0.5 ÷ 0.7 kg CO_2 per kWh product).
- Saves fossil fuels.
- Reliability of the systems since they have no moving parts.
- Minimized operating and maintenance costs.

The principal disadvantages are:

- Solar energy has intermittency issues.

- Solar energy panels require additional equipment (inverters) to convert direct electricity (DC) to alternating electricity (AC) in order to be used on the power network.
- Solar panels efficiency levels are relatively low (between 14%-25%).

9.3.1 Technology and types of PV cells

Currently, the following photovoltaic cells[1] type, or solar cell, are used:

- Monocrystalline solar cell: made of silicon, each cell consists in a wafer whose crystalline structure is homogeneous.
- Polycrystalline solar cell: made of silicon, each cell consists in a wafer whose crystalline structure is not homogeneous but organized in locally ordered grains;
- Thin film: is made by depositing one or more thin layers of photovoltaic material on a substrate.

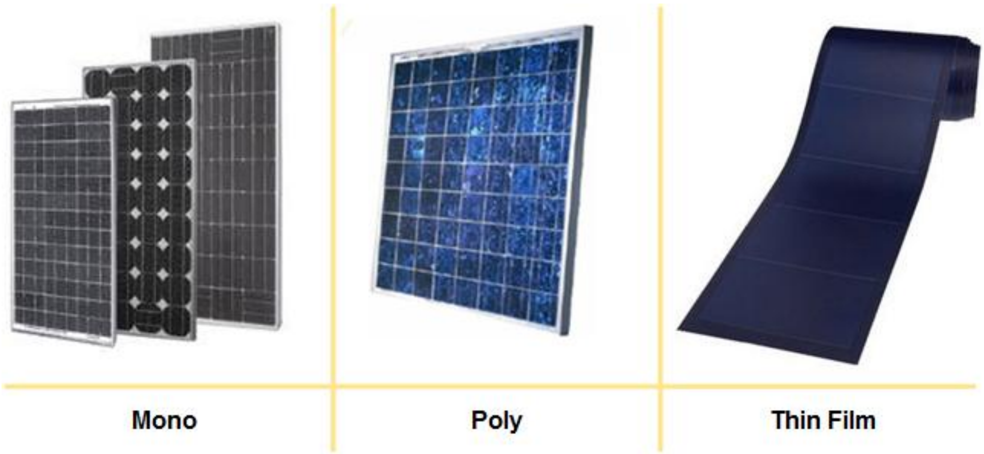


Figure 125: photovoltaic cells type

As stated in the previous point, solar cells are mainly made of silicon semiconductors. This condition derives from the following reasons:

- Almost unlimited availability (resources of the planet).
- Wide use in the electronic industry.

[1] Electrical device used to convert sunlight into electricity.

- Possibility of recycling the waste of the electronics industry as the photovoltaic industry tolerates impurity concentrations typically of $10^{-5} \div 10^{-6}$ (compared to the values of $10^{-8} \div 10^{-9}$ related to the electronics industry).

9.3.2 Main components of a PV system

The main element of a photovoltaic technology is the silicon cell, capable to convert the light energy into electrical energy. The DC-DC converter[2] is then used to modify the voltage of the direct current produced by the plant. The inverter finally converts direct current into alternating current, possibly at a different voltage, to make it usable by the machines connected to the system.

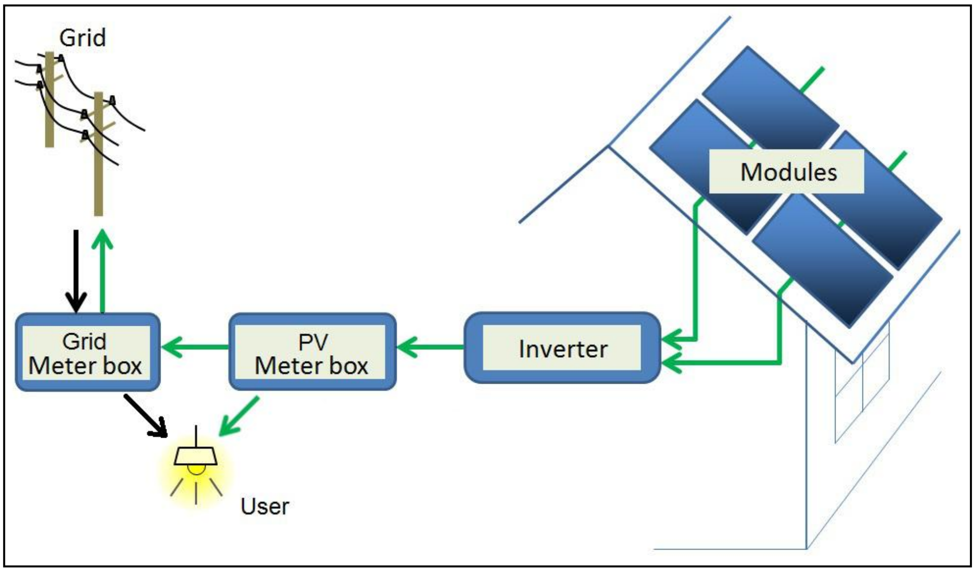


Figure 126: main components of a PV system

9.3.3 Minimum installation conditions and possible limiting factors

The photovoltaic system must be calibrated on the real consumption of the company. The first step is therefore the analysis, as thoroughly as possible, of the real consumption of the site where the system will be installed. At least the detailed bills for one year are required. This information will be used to determine the economic feasibility of the PV system by comparing the kWh consumed by the company with the plant production.

[2] It is an electronic circuit that converts a source of direct current (DC) from one voltage level to another.

After this first step, it is possible to proceed with the sizing of the plant. However, many other factors must be taken into account that for the evaluation of the PV system efficiency. Following the main factors that should be considered:

(https://www.rethink.srl/caso-studio-fotovoltaico-2017-conviene-ancora-alle-aziende-ecco-il-business-plan/)

- The useful surface available, i.e. the surface characterized by a good exposure.
- The installation site information, i.e. latitude, available solar radiation, temperature, reflectance of the surfaces around the modules.
- The layout of the modules: inclination angle (or Tilt angle) and orientation angle (or Azimuth angle).
- Any potential shading obstacle around the installation site.
- Technical characteristics of the modules: nominal power, temperature coefficient, losses due to decoupling or mismatch.
- Technical characteristics of the BOS[3] (Balance Of System).
- Type of existing connection.

An efficient photovoltaic system must be also kept cleaned and constantly monitored. The most common causes of malfunction are:

- Shading: it is possible to change the strings of the modules, thus ensuring a better efficiency.
- Not accurate cleaning of the modules.
- Excessive voltage losses in wiring.
- Inverter problems: usually an error code clearly defines the anomaly and, therefore, the consequent resolution.

Sometimes it is also necessary to replace the main components of the photovoltaic system, i.e. modules and inverters.

[3] Components and equipment that move DC energy produced by solar panels through the conversion system which produces AC electricity.

For the replacement of modules, it is recommended to keep the same module type; if this is not possible it would be a good habit to replace one module with another that has similar characteristics both in voltage and current. This condition avoids the creation of excessive imbalances in the power component.

The replacement of the inverter is an increasingly common practice for those systems that are out of warranty or need revamping. The inverter must be certified and prepared for the requirements of network services; it is also necessary that it has a high efficiency and it should be technologically advanced giving the chance to modify the point of maximum and therefore increase the daily producibility in a "dynamic" way.

9.3.4 PV system costs

The analysis of the graph shows that the cost of a photovoltaic system has decreased significantly in recent years thanks to:

- a progressive spread of technology;
- a lower production costs of the plant main components.

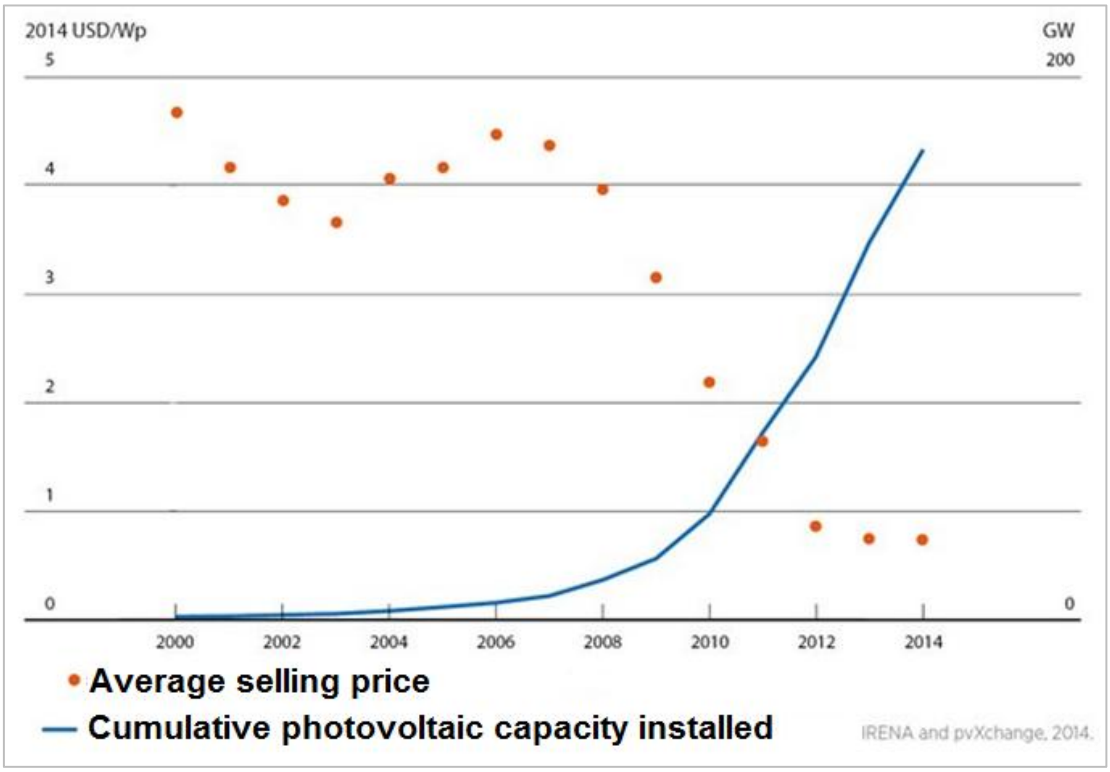


Figure 127: panels prices in relation to installed capacity

In figure 128 it is possible to observe the contribution of the different components in the total cost of the system.

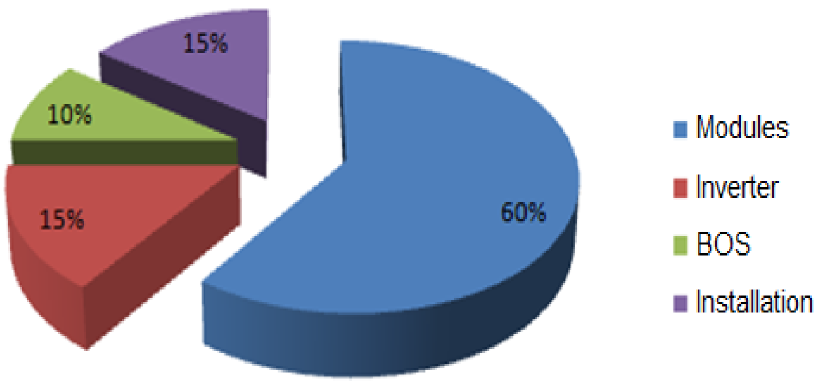


Figure 128: contribution of the different components in the total cost of the system

The current price of the photovoltaic module is about 0.6 - 1.0 €/Wp. considering therefore a typical average installed power of 3kWp we have a total price between 1,800 - 3,000 €.

9.3.5 Types of photovoltaic systems

➢ *Stand-Alone or Off-Grid system*

The main characteristics and components of this system are:

- It works independently of the public electricity grid.
- The accumulator supplies electricity when the modules are not able to produce electric energy.
- The charge controller is an electronic device that regulates the recharge and discharge of the accumulators and therefore it controls the energy flux between the modules and the accumulator.

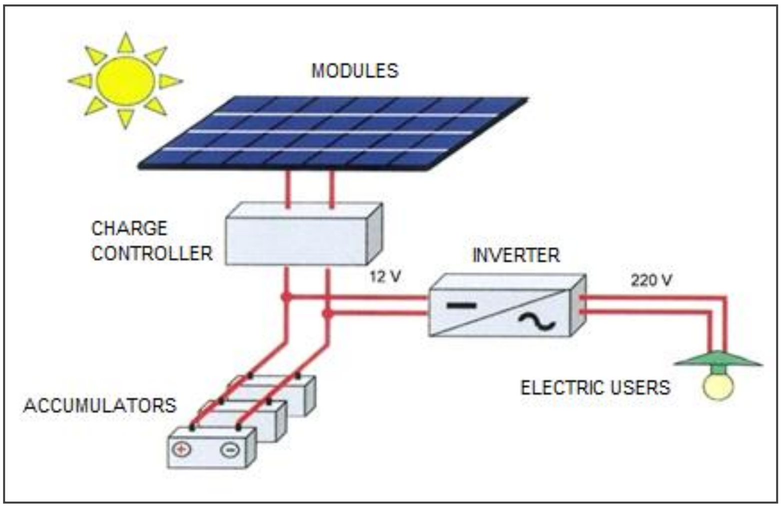


Figure 129: stand-un Alone or Off-Grid system

- The inverter which converts direct current into alternating current.
- Utilities: electrical devices powered by the photovoltaic system.

➢ *Grid-Connected system*

The main characteristics and components of this system are:

- It is connected to the distribution network.
- A bidirectional counter (electric meter) that allows to determine the electric energy consumption, i.e. the amount of electric energy coming from the network and from the PV plant.
- The inverter which converts direct current into alternating current.

This is the most commonly used solution. Thanks to its design, in this solution the energy produced by the PV system can be shared with the national utility (if the energy produced is greater than the one consumed) and the user become a producer. Vice versa, if the consumption is greater than the production, the user can always cover the needs through the utility grid.

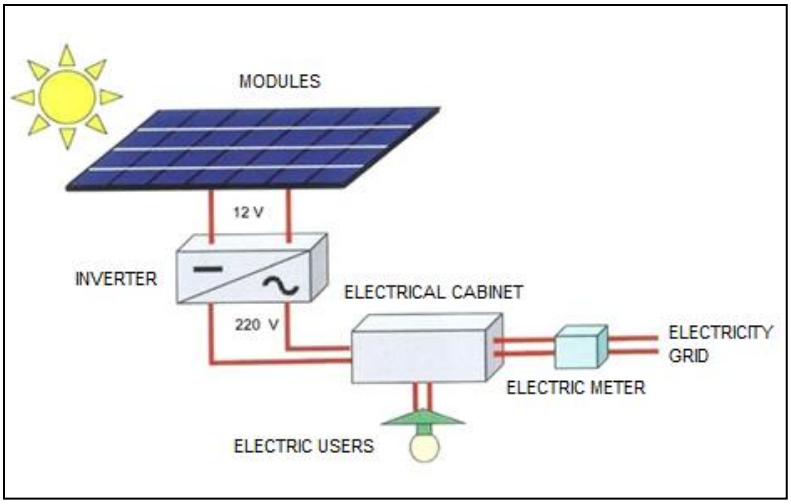


Figure 130: grid-connected system

Potential Benefits

The potential environmental benefits deriving from the installation of Multi-Si slanted roof panels, i.e. the reduction of the CO2e emitted during the life cycle, has been estimated using two different models. In the first model, without the electricity consumption during the extraction phase has been covered using a PV system installed on the roof of the oil mill. In the second model, instead, the energy requirements have been covered by the national grid. All the other processes were not changed.

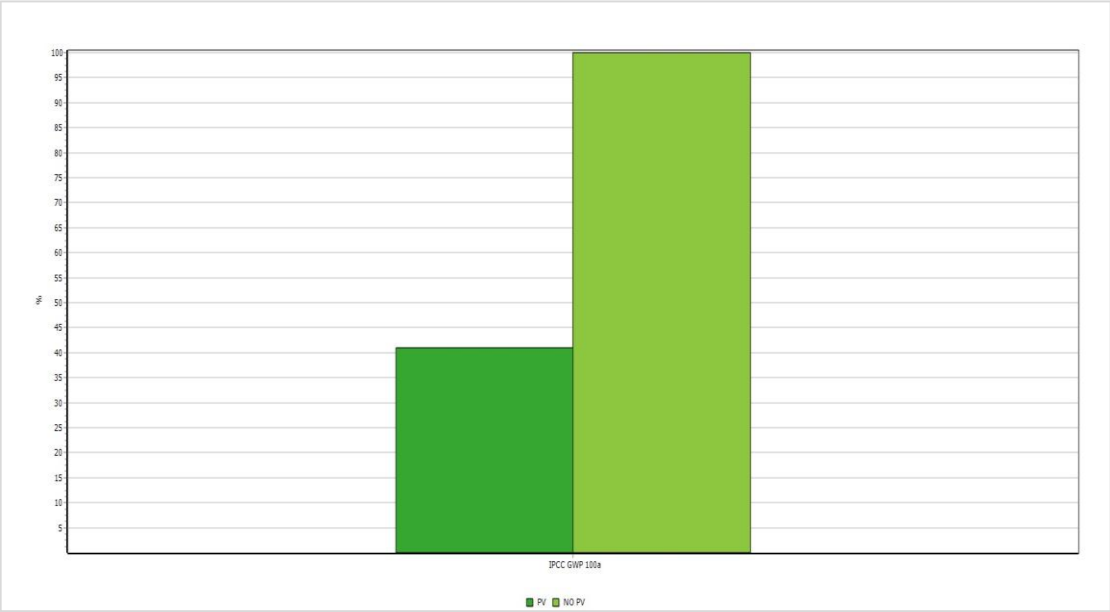


Figure 131: comparison between CO2 emission with and without PV system

Comparing the results obtained, the percentage reduction of CO_{2e} emissions per year in the extraction phase is about 60%.

10 BY-PRODUCTS OF OIL CHAIN

Luca Regni, Hanene Mairech, Primo Proietti

The environmental impact of olive oil production is important as oil extraction can require a considerable amount of water and generates huge quantities of oil mill wastes (OMW). The final by-products are generated in a limited period of 3-4 months of olive harvesting.

By applying pressure (traditional method) or 3-phase centrifugation oil extraction system effluents are olive/pomace and olive mill wastewater (OMWW). On the other hand, by applying a 2-phase centrifugation oil extraction system the effluent is wet olive/pomace. In many olive-growing countries (e.g. Italy) OMW could be legally spread directly in the field under specific requirements. Such application has raised interest not only because of its low cost, but also due to its potential to enhance soil properties increasing organic matter content*. This is very important since intensive farming leads to a gradual soil organic matter depletion* deteriorating its physicochemical and biological properties and leading to degenerative phenomena such as erosion and loss of fertility.

However, the direct spreading in the field of OMWW and pomace should be implemented with rationality since the little *stabilized organic materials may inhibit or reduce the development of crops, due to:* the presence of *tannins, fatty acids and phenols,* the *competition for the nitrogen* between the microorganisms of the soil and the trees due to a high C/N ratio, the high content of salts, the acidic reaction, etc. On the other hand, large quantities of phosphorous and potassium and organic matter can give a significant contribution to the fertilization of cultivated soil.

- *Carbon sequestration*

It should not be underestimated that the increase in organic matter in the soil, following to the administration of matrices such OMWW and pomace, besides the soil amendment and fertilizing effects, immobilizes considerable amount of carbon (C) in the soil, thus allowing to reduce the anhydride carbon dioxide (CO_2) content in atmosphere, with a significant environmental benefit.

The predictive models indicate that the potential of subtracting C by the soil in the coming years could be an essential measure to stabilize CO_2 emissions. Thus, the importance and the interest of the techniques of agricultural land management that maximize the accumulation of C in the soil are increasing, also for the provisions of art. 3.4 of the Kyoto Protocol, according to which countries that joined to it have pledged to reduce levels of CO2 emissions. Once acquired adequate knowledge on the potential for accumulation of C in production systems, it will be possible to quantify the "amounts of C per ha" to assign a remunerable value to absorption of C ("C credits") for the territorial budget that every country is obliged to respect. In fact, the production of C credits, which can be purchased on the voluntary market for the purposes of compensation, can be obtained from subjects adopting new agricultural techniques that increase the absorption / storage of CO_2 (as obtained with the increase in soil organic C).

10.1 Fertilization effect

The *OMW are very interesting for their fertilizing properties, due to the organic matter and nutrients supply (especially NPK) and to the soil porosity and soil water retention capability improvement*. This is of particular interest for soil poor in organic matter and nutrients, such as those of most Mediterranean agricultural regions.

However, an incorrect OMW management, may cause temporary immobilisation of soil mineral nitrogen and, consequently, crop yield reduction, due to the deficiency of N uptake by the plants. To avoid these effects, a proper amendment method and a rational use of OMW.

10.2 Olive Mill Waste Water (OMWW)

10.2.1 The agronomic properties of the OMWW

From the agronomic point of view the most important properties of the OMWW are

- The low pH
- The presence of nitrogen (almost exclusively in organic form)
- The high concentration, although with considerable fluctuations, in potassium and in phenols
- The presence of yeasts, fungi and especially cellulolytic bacteria, while there aren't nitrifying bacteria
- The beneficial effect of phenols is due to their antioxidant and bacteriostatic effect, which can affect the oxidative cycles of soil's oxidative cycles of organic and mineral nutrients present in the soil, such as oxidation of ammonium compounds to nitrite and nitrate.

The odour release following OMWW spreading is very low and less offensive than normal manuring.

Most of the experiments carried out on the fertigation with OMWW showed no real risks of irreversible degradation in soil or toxic effects on crops, except in the case of excessive doses or irrational distributions, while the results obtained lead to consider OMWW as a slow effect fertilizer. Consequently, the controlled spreading of OMWW on agricultural soil (fertigation) can be considered a technique of great interest, since it allows to give to soil some fertilizing substances, allowing to reduce the use of chemical fertilizers, and avoid OMWW treatments which, in addition to destroying useful substances, can cause a consumption of energy.

10.2.2 Fertigation with OMWW

In many countries most of the olive oil mills solve the problem of OMWW disposal by spreading them on the soil (fertigation), respecting the national laws which, recognizing some fertilizing properties to the OMWW, define the criteria and the general technical rules for the agronomic use of OMWW and pomace.

For example, in Italy OMWW and pomace, according to Law 152/2006, are considered natural soil improvers and can be used as amendments without any preventive treatment.

Clay-loam soils, with a high percentage of clay and high cation-exchange capacity (C.E.C.), seem to be the best choice for fertigation applications of OMWW. In addition, the carbonate content of the soil is important in order to exert efficient buffer power and avoid drastic changes in the soil pH values. The latest could cause the immobilization of different macro- and micro-nutrients and accelerate changes in the microbiological activity of the soil.

10.2.3 Spreading load

In order to avoid unwanted side effects of OMWW spreading, it is necessary to follow the correct spreading techniques according to the corresponding legislation. For instance, in Italy the producer who intends to fertigate with OMWW (or even to amend soil with pomace) **must submit annually a technical report to the mayor, at least 30 days before starting the OMWW spreading**.

The technical report must contain information on geo-morphological, hydrologic and other characteristics of the receiver, spreading time planned, as well as on systems used to ensure a suitable distribution. In some countries, the national or local laws establish the maximum spreading load allowed.

In Italy the agronomic use of OMWW (as well as pomace) derived from extraction system by pressure (traditional method) is allowed ***up to 50 m3 ha-1 annually*****,** whereas the use of those derived from the extraction system by centrifugation of the paste (modern method) are allowed up to **80 m3 ha-1 annually**.

To determine the spreading load, it is **necessary to take account of water infiltration of the soil**. If it is low (<5 mm h-1), low spreading load should be applied to prevent surface runoff or phenomena of waterlogging in the plains. Spreading load **have to be reduced even for soils**

with high water infiltration (> 150 mm h-1) since excessive percolation of OMWW organic fraction can cause pollution of groundwater.

Spreading load can be substantially increased when a physical or physical-chemical pre-treatment of OMWW occurs. The latest can partially remove suspended solids, dispersed macromolecules and emulsified oil.

10.2.4 Time of spreading

Time of OMWW spreading should comply with regional laws (if any). For tree crops (especially olive) the major limit is represented by the slope of treated soils that in rainy periods can cause runoff or accessibility problems for machineries.

To prevent leaching, **OMWW must not be applied on days when there is rain or frozen soil**.

10.2.5 Spreading methods

The spreading must be done ensuring a *homogeneous distribution of OMWW on the whole surface of the soil*, for example by a modified sewage spreader that allows the distribution of OMWW by sprinkler or furrow on the surface of the cultivated land or incorporated in soil surface layer by small spades or other tools installed on the same spreader.

For olive trees, OMWW **can be spread between the rows at a distance of 0.5 to 1 m from the tree trunks.**

OMWW incorporation in the soil accelerates oxidative degradation of phenols and facilitate interaction between organic material and soil, thus preventing it from being dragged off by runoff or percolation. So, when possible (i.e. if there is not green cover) it is preferable to incorporate OMWW in the surface layer of soil (e.g. with a vibrating tine cultivator) after spreading, with benefits also to soil porosity and also to avoid potential visual nuisances and/or unpleasant smells.

Considering the load capacity of a sewage spreader (about 5-6 m^3), it follows that it is necessary a working day for the spreading of 80 m^3 of OMWW on a surface of 1 ha. This, of course, represents a non-negligible cost, albeit offset by the fertilizer value of OMWW. To simplify the distribution of OMWW on cropland also an automated irrigation system was successfully tested, connecting directly the oil mill to area of spreading, consisting of I) a storage tank of waste water, II) an electric pump automatically activated depending on the level of the OMWW in the tank and III) a self-propelled machine to irrigate.

Figure 132: distribution of vegetation water on the ground

OMWW spreading for the Italian law cannot be applied in soils not used for agricultural purposes or less than 10 meters from water courses or the beginning of the sandy shore or located less than 200 meters from the towns or 300 meters from the protected areas of uptake of water for human consumption or with horticultural crops or where groundwater is located less than 10 meters deep or on frozen soil, snow covered, waterlogged or flooded or with slope more than to 15% (this limit, according to some regional laws, can be increased to 25% in the presence of soils covered with grass or if there are drainage systems or in the case in which are used systems which simultaneously distribute and incorporate the OMWW in the soil). Also, forests, gardens areas of public use and quarries are excluded from spreading.

The spreading of OMWW should not be carried out even in soils with high levels of salinity, since the high salt content of the OMWW can, albeit temporarily, to further increase the salinity of the soil and consequently cause a decrease in the stability of aggregates. In normal soils, respecting the doses envisaged by law, the OMWW does not cause harmful increases in soil salinity.

From a practical standpoint, the application of OMWW does not affect the chemical and biological quality of the soil when it is clayey and calcareous (avoid acid and sandy and stony soils). Similarly, OMWW can be spread on shallow (20 to 30 cm) finer textured soils, which have better water and fertilizer storage capacity. Chemical analysis of the soil is strongly recommended before OMWW spreading to determine two parameters: pH and electrical conductivity (salinity).

10.2.6 Composting of OMWW together solid matrices

An interesting perspective to enhance the benefits of composting, which is the natural process of biological transformation of the organic matrix to produce a stabilized material, rich in minerals, sanitized and not phytotoxic. In fact, the organic component of OMWW is essentially non-humified, while from the agronomic point of view the most efficient form of organic matter is the humified one. OMWW to be composted should be added to a solid substrate rich in cellulose and with adequate C/N ratio (25/30). Experiments have demonstrated that the imbibition with the OMWW of solid matrices having a high adsorbing power and suitable porosity (e.g. olive pomace, straw, wood chips) with the addition of urea, if necessary, to ensure an adequate C/N ratio, allows to mineralize and to humify the substrate, resulting in the formation of a final stable product and without phytotoxic effects.

10.2.7 Storage and transport

OMWW can be collected from the decanters in mobile tanks, spread directly on the field or stored in basins. The basin is the simplest and economic system of storage, but risks of soil and subsoil water contamination exist.

For this reason, storage of OMWW requires prior notice to the competent bodies and should be implemented in tanks or basins suitably waterproofed according to specific rules (size, shape, materials, coverage, etc.). It allows avoiding spreading until the rains persist and the soil is saturated with water. Storage tanks or basins should be large enough to contain OMWW during periods when spreading could be prevented by agronomic or climatic causes or regulations.

In general legislation **prohibits mixing OMWW** (or even pomace) **with other effluents and waste**.

During storage, the concentration of pollutants in the OMWW decreases by about 15% due to the fermentation of organic compounds (sugars) by microorganisms. Indeed, microorganisms belonging to the genus *Pseudomonas* are able to grow at the presence of phenols. Consequently, the BOD5, the amount of suspended solids and the nitrogen concentration tend to decrease, whereas pH increases.

Finally, yet importantly, the eventual transport of OMWW (as well as wet pomace) *should be conducted through suitable means of transport to prevent spills and hygienic-sanitary incidents*.

Figure 133: basin for the storage of vegetation water

10.3 Pomace

10.3.1 The agronomic properties of the pomace

Pomace has a similar composition to vegetal soil amendments and thus can be used for agronomic purposes.

As a soil amendment, olive pomace can be directly incorporated in the soil. This is obviously a very simple and direct utilization and hence a very frequent one.

Due to its consistency, compared to the OMWW, for the spreading of the pomace more attention is needed to obtain a good distribution uniformity; the problem is greater with pomace deriving from two-phase oil extraction system, since these pomaces tend to form lumps if it is not previously dried.

The use of pomaces as organic amendments could determine some problems due to their high organic load and mineral salt content, low pH and the presence of phytotoxic compounds.

Pomace **may also be composted, mixing them with other by products of food chains** such as stalks, orchard pruning residues, or straw, prior their agronomic use. These matrices increase the porosity of the mass and making it suitable for composting. To a greater degree than pomace, compost improves the physic-chemical characteristics of the soil, adding more stabilized organic matter and plant nutrients (especially potassium, nitrogen and phosphorous) in a consistent proportion.

Besides, the agronomic use of the pomaces allows to increase organic C content, and so C sequestration in the soil.

In general, according to the experimental results, the pomace can be spread on agricultural soils, even though, to enhance the obtainable benefits, it seems that it is more appropriate to use its compost.

Figure 134: olive pomace

10.3.2 Composting of pomace

Composting of pomace can enhance agronomic benefits. Indeed, compost can allow a further reduction of soil chemical fertilization, with positive effects on the environmental compatibility of crops by improving soil fertility, compared to the pomace. In addition, compost, compared to the pomace, allows to obtain a greater storage of C in the soil.

In fact, it is well known the role of stabilization processes to improve the quality of organic matter contained in the fertilizers. The results of some experimentations have shown a good attitude of the pomace to be composted with the olive tree pruning, leaves, grape stalks and straw. Composts obtained in these experimentations shows a high content of organic matter, especially humic-like substances, a balanced C/N ratio and high concentrations of plant nutrients. In relation to the latter, an aspect of particular agronomic and environmental interest is that almost all the nitrogen of the compost is in organic form, as this allows to provide to the soil slow release nitrogen, not susceptible to leaching.

Figure 135: leaves resulting from the cleaning of olives in the mill

Moreover, pomace composting allows to decrease water content, and shows a beneficial effect in the reduction of potential phytotoxicity of pomace. The compost derived from pomace can also represent a material to be used as an alternative, partial or total, to the peat in the production of nursery substrates for species with medium salt tolerance such as olive, without negative effects on production and with economic and environmental benefits. A great interest also assumes the possibility that the compost can develop in the substrate repressive effects against some plant pathogens.

Figure 136: preparation of a pile for composting pomace

10.3.3 Soil amendment

The use of pomace on soil surface in grass-covered soils or incorporated at a depth of 10-25 cm in tilled ones, is a practice widespread, mostly in olive groves, since, in addition being economical and easily practicable, it has positive effects on the characteristics of the soil and on crops and allows to increase C sequestration in the soil.

In Italy, spreading of the pomace on agricultural soils can be made in accordance with modalities set out in the law n. 574 of 1996. Various experimentations show that the spreading of pomace or derived compost on the soil greatly improves its physical-chemical characteristics.

10.3.4 Spreading load

The Italian law (n. 574 of 1996 and subsequent modification and integration) states that the volume of pomace allowed to be spread is 50 m^3 when it is produced by pressure (traditional method) olive mills and 80 m^3 when produced by centrifugation (modern method) olive mills.

10.3.5 Time of spreading

The best period for the pomace spreading, with respect to precipitation, is autumn-winter and in any case before vegetative growth resumes. Rainy days should be avoided. Moreover, spreading should be avoided on water saturated or frozen soil.

10.3.6 Spreading methods

The spread of pomace is done with the same machine used for spreading manure. When possible (i.e. there is not green cover) it is preferable to lightly plough the soil after pomace spreading. As with OMWW, this helps to improve the soil structure.

10.3.7 Storage and transport

As in the case of OMWW, the storage and transport of the olive pomace must be done in compliance with current legislations as well as in compliance with safety requirements. For instance, the containers for the storage of wet pomace must be properly waterproofed and covered with tarpaulins to avoid percolation and infiltration.

11 GUIDELINES FOR THE DATA COLLECTION AIMED TO THE CERTIFICATION OF THE CARBON CREDITS ORIGINATED FROM THE OLIVE GROVES

Antonio Brunori, Francesca Dini, Luca Regni, Primo Proietti

The possible activities that could be eligible for the C credit generated by a sustainable olive grove management are:

- Reduction of the use of fertilizers
- Management of pruning material
- Green cover
- Conservation tillage

11.1 Reduction of the use of fertilizers

Nitrogen fertilizers are the most commonly used fertilizers in Olive groves with a consequent greater impact on the environment. **To estimate Carbon credits for this activity, it is necessary to calculate the reduction of Nitrogen emissions (N2O) deriving from the use of fertilizers** (distinguished by direct and indirect emissions). The estimated emission will be then converted into equivalent CO2.

Direct emissions are calculated based on the quantities of nitrates fertilizers used. Indirect emissions are calculated by taking into account two processes:

1. the NH3 and NOx volatilization due to fertilizer application and the subsequent rendering of these gases such as NH4 + and NO3- in soils and waters
2. NO3-SO2 emissions following leaching and surface sliding.

The first data to be estimated is the quantity of fertilizers currently used by the farmers; called Business as Usual (BAU).

The second data to be collected is the reduction in the use of nitrogen fertilizers.

This reduction compared to the quantities currently used with respect to Business as Usual (BAU) will generate the quantity of CO2 equivalent (in ton) that will be calculated in C credit.

11.2 Management of pruning material

Agronomic practices commonly used in olive growing include annual or biennial pruning operations. Generally, the resulting wood residues are burnt on site or taken away. Some farmers chose to chip the residues to be scattered on the ground or buried.

To estimate Carbon credits for this activity, it is necessary to calculate gain from avoiding prunings burning or from using residues for energy and/or calculate the increase of C in the soil due to scattering on the ground or burying residues.

Figure 137: pruning material chipped and spread on the ground

The first data to estimate are the quantity of pruning currently burned by farmers or taken away from the groves; this is called Business as Usual (BAU).

The second data to collect is the quantity of pruning that is chipped or left in the ground.

The correspondent quantity of calculated C compared to the quantities released by burning pruning with respect to Business as Usual (BAU) will generate the quantity of ton CO2 equivalent that will be calculated in C credit.

11.3 Green cover

Soil working is a management practice that is currently adopted by many farmers in olive grove management and it is considered as BAU.

Figure 138: green cover

Green cover allows to maintain and increase the level of organic matter in soils. This results in a moderate increase in soil organic carbon (SOC), positively influencing the carbon balance in respect to BAU. A periodic or perennial green cover is an action applicable to the soil management when the olive grove area is not affected by water scarcity. Natural green cover has to be preferred because it reduces the emission due to soil working and seed transport. The practice of green cover in olive groves generates an increase in organic carbon in soils (SOC).

To estimate Carbon credits for this activity, it is necessary to calculate the increase of C in the soil due to the adoption of green cover.

The first data to estimate are the quantity of working hours by machines (listed by models); this is called Business as Usual (BAU).

The increase in CO_2 absorption due to the application of the natural green coverage is estimated based on organic carbon data in the soils (SOC) derived from literature.

11.4 Conservation tillage

Minimal and superficial processing (conservation tillage) are some actions that are applicable for an optimum soil management, where green cover cannot be applied due to poor rainfall.

Among the sustainable land management practices, with particular reference to the reduction of machining, the following activities is the minimum tillage.

To estimate Carbon credits for this activity, it is necessary to calculate the increase of C in the soil due to the adoption of conservation tillage.

The first step is to describe the common soil management practice adopted by farmers; this is called Business as Usual (BAU).

The second step is the selection of the proposed conservation practices:

- simple surface machining with disc harrow or deep milling 8-20 cm;
- milling or machining with disk harrow only on the row (strips from 5 to 10 to 20-30 cm) between rows there are not worked, the depth varies from 30 to 5 cm.

The adoption of conservative agronomic practices reduces the CO2 emissions by increasing the stock of organic matter in the soil. The increase in CO2 absorption generated by the application of this activity is measured based on the organic carbon data in the soils (SOC).

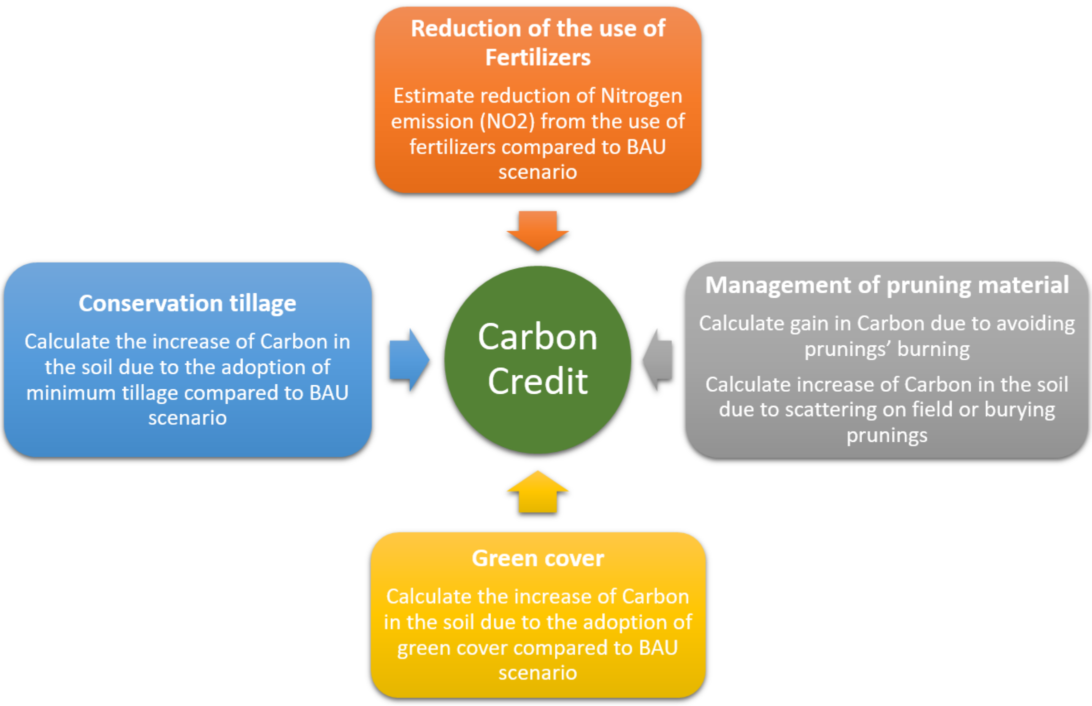


Figure 139: carbon credit management guidelines

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