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Cultivation Techniques

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1. Introduction

In an agricultural context, olive growing is emerging as a dynamic and interesting topic. The majority of Italian olive growing still requires organic renewal interventions such as farm restructuring and tree planting, varietal conversion, mechanization, technical assistance for the implementation of technological innovations, better organization and contractual weight in product marketing. Therefore, the main objective in this area can be obtained with a more economical management of olive orchards in order to achieve a high production per unit area at lower costs and while respecting the environment. Therefore, current olive growing must be based on two pillars such as the reduction of management costs and the use of cultivation techniques with a low environmental impact. More and more attention is being paid, by the EU, and also by Italy, to environmental sustainability, biodiversity and compliance requirements in agriculture. Indeed, in recent years the EU has issued a set of regulations aimed at environmental protection and enhancement of rural areas by improving the competitiveness of the agricultural sector in order to obtain high-quality products aimed at enhancing the peculiarities of the different territories of origin (PGI, PDO) and protecting agricultural and natural resources. Quality must always be considered a key resource for agriculture, which will enable farms to survive and compete in both Italian and International markets. The cultivation techniques used in olive orchards are directed to preserve and improve the physical and chemical characteristics of the soil (soil preparation and tillage, irrigation, fertilization) and to enhance plant production (training, pruning, fruiting, production and pesticide treatments). The knowledge of olive morphology and biology is a prerequisite for the rationalization of cultivation techniques to improve the quantity and quality of production.

Although the olive tree can be considered a hardy plant and is cultivated in marginal areas, it requires specific cultivation techniques coordinated and integrated with each other in order to exalt their productive potentialities. This is why the wise use of tools such as pruning, irrigation, nutrition and soil management plays an important role in achieving a

greater vegetative and reproductive plant balance, and cost containment should be the main goal that guides management decisions.

2. Soil

Soil is defined as the top layer of the earth's crust. It is formed by mineral particles, organic matter, water, air and living organisms. It is in fact an extremely complex, variable and living medium, and represents a non-renewable resource which performs many vital functions: food and other biomass production, storage, filtration and transformation of many substances including water, carbon, nitrogen. As long as 100 years ago, Wollny (1898) described the positive effect of soil structure on root growth, water availability, gas transport in soils as well as the positive effects of soil structure on soil strength. He mentioned that the mechanisms involved in the interaction between soil structure and plant growth and yield needed to be investigated. Since then, the positive effects of a favorable soil structure and the negative effects of, for example, soil compaction on crop growth and/or yield have been repeatedly described (e.g. Blank, 1932-1939; Dexter, 1988; Hakansson et al., 1988; Kay, 1990). The anthropogenic activities such as tillage, mineral fertilization, waste disposal and industrial pollution, affect both chemical and physical natural soil properties (Kabata-Pendias & Mukherjee, 2007).

Recent improvements and new methods in analytical chemistry and increasing areas of environmental investigation have substantially added to our knowledge of agricultural soil science. For example, the soil characteristics of an olive plantation are especially important in terms of vulnerability to erosion and, to a lesser extent, to leaching of potentially contaminating elements contained in fertilisers and pesticides. The root system of the olive is concentrated in the top 50-70 cm of soil although it may send out roots to a depth of more than one meter to satisfy its water needs. Therefore, the soil must have an optimal texture, structure and composition to a depth of at least one meter. The management of a cropping system requires periodic evaluation that includes systematic testing, with the aim of determining the nutritional status of soils in order to assess the existence of any nutritional deficiency, excess or imbalance and form a basis for planning the nutrient supply as well as other practices (tillage, amendment, correction). The following is a brief description of the main chemical and physical soil properties.

2.1. Soil texture, porosity and density

The textural class is the first parameter that defines soil properties, and is determined by the relative percentage of the three major soil compounds: sand, silt and clay, defined by the respective particle diameter size.

Clayey grounds are characterized by particles of a diameter of less than 0.002 mm, constituted by flinty minerals with different capacities to inflate in the presence of water and to contract in dry conditions, forming cracks which are typical of vertisols. Clayey soils show a low water permeability and high plasticity, which can induce stagnation phenomena and root asphyxia in wet conditions; while in the dry state it has notable tenacity and cohesion.

Silty soils have elementary particles of greater dimensions than the clayey ones and, unlike these, they have greater difficulty in reaching a glomerular structure. The lower structural stability of silty soils causes a low macroporosity and a great bulk density, that determine conditions of low aeration, low permeability and water stagnation in the profile. This type of soil is subject to loosening conditions with greater facility in comparison to clayey soils. However, they have a greater tendency to pulverization in the dry state, and the formation of mud in the wet state.

Sandy soils have particles of a diameter between 2 and 0.02 mm; they are characterized by high permeability of rainwater, and fast mineralization of organic matter.

The Olive tree responds best to soil textures with balanced proportions of sand, silt and clay. Soils that are primarily sandy do not have good nutrient or water-holding capacities, but they do provide good aeration and olives do well, especially when water is available and the crop is properly fertilized to satisfy its mineral requirements. The soil should not contain too much clay to avoid limiting air circulation and to prevent soil management problems. The soil particles should aggregate in granules or crumbs to make the soil porous; this is ensured by sufficient quantities of organic matter and rational soil management to prevent compacting and erosion. Soil is composed of solid particles (mineral and organic matter) of different sizes, usually bound together into aggregates by organic matter, mineral oxides, and charged clay particles. The number and size of pores vary considerably among soils exhibiting different organic matter content, texture and structure and cultivation techniques have a great effect on bulk density and porosity: any management practice that increases organic matter will increase the granular structure of the soil, increase the pore space, and decrease the bulk density (Gisotti, 1988; Giordano, 1999; Hao et al., 2008).

2.2. Organic Matter and nitrogen ratio

The Organic Matter (OM) is a complex mixture of organic compounds deriving from metabolic wastes and decaying residuals of plants, animals and microorganisms, at different stages of decomposition. The OM percentage directly influences the structure and chemical-physic properties of soil in terms of water infiltration and retention, element absorption, particle aggregations, Cation Exchange Capacity (Al^{3+} , Fe^{3+} , Ca^{2+} , Mg^{2+} , NH_4^+), buffering power, over the nutrient source for the plant. The quantity and nature of OM is highly dependent upon farming practices and climatic conditions and is found as both chemically stable humus (or passive OM) and partially decomposed plants, microbes and animal residues (or active OM).

Measures to increase the organic content are a very important part of good soil management in Mediterranean regions, especially in order to reduce vulnerability to erosion (European Soil Bureau, 1999). Practical measures are based on the incorporation of organic matter such as farm-yard manure, cover crops, pruning and processing residues, and soil tillage.

Plant availability of organic N is dependent on OM breakdown, which is difficult to estimate. The ratio of total organic carbon and total nitrogen (C/N) is the traditional guide to the nature of the organic matter present in the soil.

The basic premise behind this ratio is that organic carbon is the primary source of energy for soil microbes, but these also require nitrogen to multiply and utilise this energy. The microbes utilise soil carbon via respiration, with the consequent loss of carbon dioxide from the soil. As the active fraction of the OM is thus degraded, the C/N ratio drops until a steady state (the passive fraction) is finally attained. Interpreting this ratio is complicated, as it also depends on the nature of the OM. The passive fraction of the OM can have a C/N ratio that is 'medium'. Consequently, medium C/N ratio soils can have a wide variation in mineralisable N status, and this is a limitation when considering the C/N ratio in isolation.

2.3. Cation Exchange Capacity (CEC), pH, electrical and hydraulic conductivity, water content

Plant nutrients usually exist as ions which carry an electrostatic charge. This electrostatic charge is a result of atomic substitution in the lattices of soil minerals and because of hydrolysis reactions on the broken edges of the lattices and the surface of oxides, hydroxides, hydrous oxides and organic matter (Hendershot et al., 2008a). These charges attract counterions (exchangeable ions) and form the exchange complex. Ions can be bound to the soil in varying degrees. At one extreme, they may be an integral part of the soil, strongly bound to silica and essentially unavailable to growing plants. At the other extreme, they may be fully soluble and not interact with the soil to any significant extent. Exchangeable ions are between these two extremes, and are weakly bound to soil particles. The bonds between soil particles and exchangeable ions are not permanent, and are continually broken reformed, as the ions move within the water surrounding soil particles. The bonding of these ions largely prevents their loss by leaching, but is not so strong that plants cannot extract them from the soil. In fact, plant roots absorb exchangeable ions by 'swapping' them for hydrogen cations (H^+).

The cation exchange capacity is often estimated by summing the major exchangeable cations (K, Ca, Mg, and Na) using units of $cmol\ kg^{-1}$, even if the common expression for CEC is in terms of milliequivalents per 100 grams (meq/100g) of soil. The CEC of soil can range from less than 5 to 35 meq/100g for agricultural type soils, and is related to clay and organic matter content.

CEC is important for maintaining adequate quantities of plant available calcium, magnesium, sodium and potassium in soils. For many crops the magnesium level should ideally be twice as much as that of potassium. When magnesium is lower than potassium, suppression of magnesium uptake can occur. Sodium is only of secondary importance in the soil test as its uptake by plants is largely dependent on the plant species involved and the potassium status of the soil, rather than the level of sodium extractable from the soil.

The Total Base Saturation is related to CEC, which represents the proportion of the soil's total capacity for cations that is actually occupied by these nutrients. It is calculated by summing together the levels of calcium, magnesium, potassium and sodium found in the soil and expressing this sum as a percentage of the CEC value.

Soil pH is one of the most common and important measurements in standard soil analyses (Hendershot et al., 2008b). The pH value expresses degree of acidity or alkalinity of the soil. It is important because it influences the chemical and physiological processes in the soil, and the availability of nutrients. Availability changes differently with pH levels: aluminium, copper, iron, manganese and zinc increase when the pH decreases; unlike magnesium that decreases when the pH decreases (Belsito et al., 1988; AA.VV., 1989; Jones, 2003).

Electrical conductivity (EC) is the ability of a material to conduct an electrical current and is commonly expressed in units of microSiemens per meter ($\mu\text{S cm}^{-1}$). It is used to estimate the level of soluble salts. The measurement of EC in the soil water extracted from the field-water content is theoretically the best measure of salinity as it indicates the actual salinity level experienced by the plant root (Miller & Curtin, 2008). However, this measurement has not been widely used because it varies as soil-water content changes over time and so it is not a single-valued parameter. A soil is considered saline if the EC of the saturation extract exceeds $4000 \mu\text{S cm}^{-1}$ at 25°C . The soil EC varies depending on the amount of moisture held by soil particles. Consequently, the EC correlates strongly to soil particle size and texture and affects crop productivity.

Soil water analyses can be organized into two main groups: analysis of storage properties and analysis of hydraulic properties. The water content of soil is part of the analysis of storage properties which refer to the soil's ability to absorb and hold water. Instead hydraulic conductivity is a hydraulic property which refers to the soil's ability to transmit or conduct water. It is more difficult for plants to absorb nutrient elements at low soil moisture levels, so nutrient element contents will be lower.

3. Soil management

In order for plants to live, two key functions can be attributed to soil: habitability and nutrition. The function of habitability mainly depends on the physico-chemical characteristics of the soil. The function of nutrition depends on the factors that make nutrients bio-available to the plants, described above, determining the fertility of the soil as productive attitude. Biological soil functions depend on the micro-organic pattern, responsible for processes on the organic matter such as: mineralization, humification, nitrification, nitrogen fixation, symbioses, and parasitism. The agricultural management systems of soils, such as crop rotation, nutrient application, plant species, kind of tillage, and use of pesticides may have a strong impact on the composition of the soil microbial community. Maintenance of sustainable soil fertility depends greatly on the ability to harness the benefits of rhizosphere microorganisms such as arbuscular mycorrhizal fungi (AMF), which form a symbiotic association with the roots of most plant families. Olive plants are known to form arbuscular mycorrhiza (Roldán-Fajardo & Barea, 1985; Briccoli Bati et al., 1992; Calvente et al., 2004), the most common mycorrhizal type involved in normal cropping systems, being considered as a key component in environmentally friendly agro-biotechnologies (Jeffries & Barea, 2001).

Mycorrhizae act as biofertilizers, bioregulators, and biocontrol agents (Lovato et al., 1996; Von, 1997). Arbuscular mycorrhizal fungi allow the plant to absorb greater quantities of

water and nutrients, particularly those less mobile in the soil such as phosphorus. In addition to phosphorus, other elements such as nitrogen, zinc, calcium and sulfur are involved in the mechanisms of mobilization and uptake by mycorrhizal fungi.

Mycorrhizal symbiosis also acts as a bio-regulator, able to influence some physiological processes, growth regulators and the development of the plant, to modify the morphology of the roots, the roots/foilage ratio and sometimes branching foliage and flowering. These soil fungi improve the agronomic fertility of the soil through the formation and stabilization of particle aggregates, in particular in land lacking structure.

3.1. Tillage

Tillage consists of some mechanical operations, performed with different tools, which modify soil structure, according to the management needs, that can be summarized as: increase of the soil mass (active layer); increase in soil permeability, runoff and erosive phenomena; accumulation of water reserves; reduction of evaporation due to interruption of superficial capillarity; destruction or containment of weeds; burial of fertilizers, corrective, amendants, and crops residual.

Usually, for olive groves a deeper autumnal tillage is carried out, to increase the water reserve and to bury the phospho-potassic fertilizers; while during the spring-summer period, some harrowing is performed to reduce evaporation and to eliminate weeds. Soil tillage was classified according to the epoch and the type of performance, distinguishing into preparatory practices, performed before the plantation, to constitute suitable conditions to sustain the crop after the implant, and subsequent practices, performed during crop culture.

Soil tillage can be performed with different tools classified into three main groups: mouldboards, rippers and scramblers. Mouldboards cut and upset the soil; rippers cut the profile producing clods but without modifying soil stratigraphy; and scramblers break up and remix the worked layer.

The choice of the best tillage technique must be performed in order to: reduce costs, in terms of working times and fuel needs; increase the timeliness of intervention; maintain a suitable productive level of crops and soil fertility; contain erosive phenomena.

The soil water content strongly influences the choice of the epoch and the type of intervention performance. Dependent on this, there are different physical soil states: i) cohesive, when the soil is dry; in this state the soil does not stick to utensils, it has maximum tenacity, it is crushproof and resistant to breakup; ii) plastic, characterized by a progressive warping and stickiness, that increases with an increase in damp; iii) liquid, when the soil behaves like a suspension. Tillage is difficult and harmful to the soil when the soil is sticky; over this limit, the passing of machines provokes undoing of the structural aggregates. With dry soils the work needs higher powers, and forms compact clods of varying dimensions, according to the type of performance: plowing causes large clods, while with rotary hoeing a notable pulverization and formation of small clods occurs.

A soil is considered as loosening when it has an optimal damp for the execution of tillage, approximately corresponding to half of their field capacity, with a more or less ampler range depending on the soil type and intervention (Bonciarelli, 1981; Giardini, 1986).

Plowing is the most known and commonly used form of soil tillage in agricultural practice and is performed with three type of tools: the ploughshare plow and the disk plow, that work by traction; and the rollover plow, that acts by the tractor power take-off (PTO).

The plow operates by cutting and overthrowing a slice of soil, with an angle varying with the type of plough, the operating velocity and the operation goal: the complete overthrow of slices is necessary in green manuring and in weed control; while vertical slices improve airing and rainwater infiltration. Using a cylindrical bending breast a greater crumbling action is achieved; while a helical breast favours the slice overthrow with smaller production of thin soil. The speed of ploughing acts on both the slice overthrow and crumbling: a fast ploughing enhances the inversion of layers and the pulverization of clods. The ploughshare action can cause compaction of the deep soil, called tillage pan. Such a drawback can be enhanced using tractors working "within furrow", and in conditions of high damp. The tillage pan hinders the vertical movement of rainwater and the gaseous exchanges in the soil and the growth of the roots.

The drawbacks of the ploughshare plow are: excessive clod level, that requires other refining tillage, with further passages of machinery that stamp on the soil and degrade its structure; formation of tillage pan; high requirement of traction power. Such negative aspects can be mitigated using the disk plow, in which the ploughshare and the breast are replaced by a spherical cap, free rotating on an axle angled in respect of the operating direction. The disk limits attrition and needs of traction power. During rotation the cap lifts a slice of soil that is then crumbled and remixed. In comparison to the classical plow it better prepares the bed for seeding; it is proper for light ploughing in loose or medium textured soil rich of skeleton and in groves.

There are other tillage techniques that can be carried out, using different types of machinery which can be complementary or alternatives to ploughing. Among these the most common are:

- Ripping technique is characterized by the vertical breakup of the soil without inversion of the layers. The tools used in this type of tillage are constituted by a varying number of anchors (from 1 to 5) that practice a different action on the soil depending on their shape and interaxle. Some machineries are endowed with vibrating tools that enhance shattering of the soil, and can be joined to rolls or harrows to finish up and to level the surface in a single pass.
- Rotary Hoeing consists in the shattering and remixing of the soil performed by machinery moved with a tractor PTO., with tools that work on a horizontal axle (millers) or vertical axle (rototiller). Their drawback is the excessive shattering of soil, that worsens its structure, with compaction, formation of superficial crust and tillage pan, fast tool usury; while requiring high working power. They are unsuitable in heavy and/or skeleton soils.

- Weeding is a tillage practice complementary to ploughing, carried out to reduce the clod of the soil, and to bring up weed roots. This machinery is formed by bent rigid or elastic rippers and with different types of feet.
- Harrowing is performed to refine clods, eliminate weeds, bury fertilizers and break the superficial crust. The tools for this operation are of different shapes and dimensions, according to soil types, soil conditions and the needs of soil refining.

All tillage up to 15 cm of depth is included in the minimum tillage group, , with the aim of energy saving, preserving soil structure and timeliness of work. Among the different operative options, various types of machinery are available that can perform tillage, fertilization, seeding and chemical weeding of the soil in a single pass (Toscano, 1998).

3.2. Tillage: Soil characteristics and erosion

The usable kind of tillage depends on the soil texture. In clayey soils, the minimum tillage can have positive effects on the containment of erosive phenomena, due to the residual crop on the soil surface, and on compaction, in order to reduce passing of the machinery.

In silty soils all the tilling techniques that do not involve the inversion of layers favour soil structuring, and the presence of residual crop, and avoids the destructuring caused by the beating action of rain water.

In sandy soils, the choice of tillage techniques should exclude deep intervention, while all the minimum tillage techniques generally guarantee best results.

The different handling of the soil can determine a different availability of the nutrient elements, as well as a different biological activity. The techniques that do not involve the inversion of layers, allow maintaining or increasing the organic matter in the soil. With regards to the availability of the principal nutrient elements, the effects produced by the different tilling techniques vary according to the different movement of each element in the soil.

Nitrogen results mostly available for plants in a worked soil, due to the high aeration of the mass and for the velocity whereby the residual and organic fertilizers are degraded into mineral elements which can be assimilated.

For the phosphorus, a low mobile element, there are strong differences in its stratification along the profile according to the type of tillage. With a plow this element has the tendency to distribute itself in a more homogeneous way in the soil in comparison to how it is distributed in soil that has not been worked, or only cracked soil, in which phosphorus remains in the most superficial layers.

The common good supply of natural Italian agricultural land, particularly clayey ones, leads to a substantial independence of availability of potassium from the plowing technique adopted.

All tilling techniques that improve soil permeability, and allow maintenance of a vegetable coverage, are very useful in the control of erosive phenomena (Stein et al., 1986; Rasiah &

Kay, 1995; Raglione et al., 2000; Toscano, 2000; Toscano et al., 2004a). Erosion consists in the removal of the most fertile soil layers by wind and/or rainwater action. The eroded amount is proportional to the intensity of the rainfall, to the slope and type of the soil.

3.3. Soil grassing

To protect the soil profile, structure and edaphic biocenosis, it is useful to apply less expensive cultivation techniques which have a lower environmental impact than traditional tillage. The minimum tillage or controlled soil grassing, generally determine a great activity of the soil biota, due to the greater presence of organic matter and the low trouble of soil.

It is possible to implement soil grassing, which can be either natural or artificial, and to partially or wholly cover the orchard surface. The benefits of controlled grassing in olive orchards are: improvement of the soil structure, increase of soil organic matter and water absorption, reduction of runoff and erosion, improvement of carrying capacity and reduction of compactness, enhancement of microbial activity and nutritional balance; simplified management at lower operating costs. The possible competition of turf for water and nutrients with regards to the olive plants (Pastor, 1989), can be prevented with proper grass management, such as cutting, or additional fertilization (Toscano et al., 2004b).

The simpler type of soil grassing is “permanent”, whereby the soil is constantly covered by spontaneous vegetation that is periodically mowed or shredded.

Alternatively, in dry summer conditions, temporary grassing can be adopted, eliminating grass, when competition for water competition begins, with superficial tillage or using contact herbicides; the coverage naturally reestablishes itself with the resumption of the rainy season, retaining its beneficial effects up to the following spring.

For artificial grassing the choice of the essences is very important, these must have fast growth following planting and to be resistant to pounding and to mulching. However, the artificial grassing presents some economic and managerial limits such as the difficult choice of the essences and the seeding costs.

The machinery for grass management consists in the rotary mower, and the shredder. They are of great working capacity and have low power needs, compared to the tools that operate on the soil; the shredder has the advantage that it grinds the mown grass, thus reducing degradation times, and it can also be used for pruning residues. Both these machines can be equipped with intercept rotary mower, which allows cutting of the grass along the row, avoiding damage to the tree trunks. Long-time experiences of controlled grassing in different non-irrigated olive orchard soils have confirmed the effectiveness of this technique in improving soil properties, in the drainage system, in the control of soil erosion and on olive tree productivity (Briccoli Bati et al., 2002; Toscano et al., 1999, 2006). On the contrary other tests, comparing different application methods of grassing, have evidenced better agronomic and productive results with green manure in summer, to avoid the increased competition for soil water occurred by permanent grassing in this environment (Toscano, 2009). Therefore, the choice of the best soil management system must be made according to

the specific soils and crop characteristics. In olive groves the replacement of tillage with other techniques is possible, according to water availability, in order to obtain the best maintenance of soil fertility, a reduction of the erosion in slopes, a timeliness of intervention, a reduction of the costs and, therefore, the attainment of greater incomes.

4. Nutrition

The olive tree is still often considered a rustic plant, having little nutritional requirements and capable to survive even in rough environments, with minimal care and management. The olive plant grows in most soil types as long as they are well drained. These plants, could also vegetate in the absence of fertilization, but require suitable nutrition to express their productive and qualitative potentialities.

In the traditional olive-grove plant nutrition is mainly based on systematic and massive inputs of chemical nutrients distributed to the soil, not always correctly and often unnecessarily (if not harmful) for plants and the environment (groundwater pollution). In many cases olive tree fertilization is often empirically approached and farmers apply much more fertiliser than the crop really needs (Tombesi et al., 1996).

The compilation of adequate fertilization programs, in terms of type, doses, epochs and disposal of the nourishing elements, are not of simple generalization and depend on local environmental and climatic factors, as well as on the effectiveness of the fertilizer composition and its application method.

It is indispensable to carry out a prior analysis of soil chemistry and of the nutrient contents of the plant by plant tissue analysis (usually leaves are used). These analyses will give significant data on the status of both soil and plant, indicating the most useful typology and doses of nutrients to apply in the fertilization plans.

Leaf analysis, is a reliable method for assessing the nutritional status of the crop (Bouat, 1968; Freeman et al., 1994). The content of the major nutrients in the leaves differs not only according to the cultivars, the soil and climatic conditions of the cultivation area, the time of sampling for the analysis but also in relation to the pruning and irrigation applied to olive orchard (Briccoli Bati et al., 1995). Some research on a regional scale has defined certain relationships between the time of leaf sampling, the foliar nutrient content and the quality of production (Failla et al., 1997; Soyergin et al., 2000). In fact, it was found that the leaf diagnostic at flowering is conclusive for the less mobile elements (Ca, Mg, Fe and Zn) while during the winter rest foliar analysis better shows the nutritional potential of the soil for nutrients with increased mobility as N, P and K (Failla et al., 1997). The level of global nutrition, generalizing, expressed as percentage amount on the leaf dry matter for nitrogen, phosphorus and potassium, results as 3,5% divided, respectively, in 2,1 - 0,35 - 1,05 with a physiological relationship of 6:1:3.

In profitable olive growing, the nutritional needs also vary in relation to the phenological phases, to the climate, to the cultivar, to the trees' productive potentiality, and to the olive orchard management, i.e. presence of soil grassing and irrigation. For these reasons,

fertilization planning cannot be approached as a standard procedure and many authors report different evaluations about the nourishment needs of olive trees (Natali, 1993; Petruccioli & Parlati, 1983).

Fertilisation systems include: chemical fertilisers (NPK applied beneath the tree canopy projection, usually in the form of combined fertilisers), organic fertilisation (green and animal manures, leaves, compost, manufactured organic fertilisers), and fertilisation through watering systems and through foliage.

During the first three years of the olive plantation, when vegetative activity prevails on fructification, it is important to stimulate, with fertilization, rapid canopy and root growth of the tree to predispose the plants quickly to flowering and fruiting (Palese et al., 1997). In this phase, Nitrogen is the essential element, while phospho-potassic fertilizers at this time are less important, provided that during the preparatory work of the soil for planting, such fertilizers were distributed over the entire surface and buried with deep tillage.

When the plant completed the first phase of growth (5th - 6th year) and during the entire life of the orchard, the scope of fertilization is to induce and support the yield and, simultaneously, also to ensure the renewal of fruiting shoots and roots.

In order to calculate the amount of nutrient supply to plants it is helpful to adopt the returning criteria of nutrients removed with fruit harvesting, with pruned wood and abscised leaves: for 100 kg of drupes produced the olive tree needs around 900 g nitrogen, 200 g of phosphorus and 1.000 g of potassium. In fertilization planning, such doses must be triplicate, due to the losses leaching, volatilization, fixation, etc.

Traditionally nitrogen is supplied annually and divided in at least two doses. Most of the quantity to be given (2/3) at the end of winter before flower bud differentiation and before the growth of new lateral shoots, and the second during the flowering period (from the pre-flowering stage till fruit set). Usually the recommended nitrogen application ranges between 500-1500g for bearing tree, according to canopy volume.

Throughout the life of the olive-grove, phosphorus and potassium supply must be repeated every 5-6 years, with the doses defined by the results of soil and leaf analysis. These fertilizers are usually supplied in autumn, and burying with shallow tillage, on alternate inter-rows to limit damage to the roots, with doses of 200-400 units of potassium and 100-200 of phosphorus per hectare integrated with suitable doses of organic matter (manure, green manure or compost).

During the annual cycle, nitrogen absorption is more intense from the flowering up to the pit hardening, while the contents of N and P decrease in the leaves up to the pit hardening and at the same time they increase in the drupes. Subsequently, both in the leaves and fruits nitrogen and phosphorus decrease after veraison. Instead, potassium, constantly decreases in the leaves, while increasing in the fruits.

Biennial or triennial interventions for phosphorus and potassium, in the poor soils are useful, applied after harvesting in concomitance with deep tillage for rainwater storage, in

old or dry-condition raised olive orchard; or at the end of winter, with lighter tillage in a young and intensive olive grove.

4.1. Nutrients typology and effects

The use of the appropriate fertilizer at the right time increases the efficiency and reduces the cost of fertilization, with a positive impact on the produced olive fruit and oil content.

Fertilization can be distinguished into organic and mineral. The first one has the purpose to improve the physical characteristics of the soil, such as the structure, the porosity, the permeability, the tackiness, the consistency, the water retention, and the pH. The second one is destined to feed the plants.

Nitrogen is fundamental in plant growth, it participates in the formation of amino acids and in the formation of proteins, therefore, it is crucial in the growing processes when the plant is young. In adult trees nitrogen supports the formation of shoots, a necessary condition to ensure constant productivity and positively influence flower formation, fruit setting and fruit development, especially during the early stages, up to the pit hardening. Nitrogen fertilization consistently increases the olive yield but only when leaf N is below the sufficiency threshold (Hartmann, 1958). It is usually applied to the soil using urea, ammonium sulphate, or ammonium nitrate. Nitrogen can also be supplied with either organic materials such as feathers or blood meal, compost, or a leguminous cover crop. Its deficiency is manifested by decreased growth activity, leaf yellowing, high ovary abortion, low yield and alternate bearing (Cimato et al., 1990; 1995).

Phosphorus also has a role in growth, being essential for cell division and the development of the meristematic tissues, fruit set, fruit growth and maturation, and in lignification of the shoots. Even if absorbed by the olive tree in a relatively high quantity, the effects of phosphatic fertilization are nevertheless manifested with extreme slowness. The most used phosphate fertilizers are soluble phosphates and in particular superphosphates with 35-45% of phosphorus pentoxide, which is the form absorbed by the plant. A content of 50-100 ppm of phosphorus pentoxide in the soil detected by soil analysis, can be considered to be satisfactory. The symptoms of deficiency of this element, which is very rare, occur with a reddish or purplish coloration of the green parts of the plant, and it causes metabolic problems for growth and fructification, with delays in drupe maturation.

Potassium promotes the accumulation of carbon hydrates such as starch, an energetic reserve for metabolic processes. This element, regulates the water consumption of the plant through an increase in water retention in the tissues and it also controls transpiration. Potassium is an enzymatic activator, it increases the plants resistance to thermal extremes and to some fungal diseases, and it promotes oil accumulation in the fruits. This element is, usually, applied to the soil during winter in order to gradually reach the rooting zone with the rain. Regular potassium fertilization is necessary in order to maximize both yield and quality, especially in heavy yield years.

After nitrogen, phosphorus and potassium, other very important nourishing elements are magnesium and calcium. Magnesium is an essential component of chlorophyll and generally it is not considered in fertilization plans because it is already contained in many fertilizers. Occasionally, magnesium deficiency can be revealed in orchards growing on sandy, neutral soil. Fertilization based on magnesium sulfate corrects this deficiency.

Calcium is vital to olive plant growth, because it is an essential constituent of cell walls and contributes to the mechanical resistance of tissues, it also acts as an activator of some enzymes. Deficiencies of calcium due to soil acidity, can be corrected with an adequate lime supply as calcium carbonate.

Sulphur is present in plant amino-acids such as cystine, cysteine and methionine and is located in the soil in the organic matter. Fertilizers containing sulphur as ammonium or potassium sulphate, etc. are distributed against possible deficiencies of this element.

The most important microelements are iron, copper, zinc, manganese, molybdenum and especially boron, all developing a specific and exclusive role as enzymatic activators in the biochemical processes of the plants. These elements, present in small amounts in olive tissues, have a very narrow range between a sufficiency and toxicity level. Leaf tissue analyses provide excellent information in order to directly diagnose the toxicity or the lack of these microelements.

Above all it is very important to know the boron content of the leaves because it plays a major role in pollen growth, fruit set and plant productivity. Visible symptoms of boron deficiency are manifested with leaves with apical chlorosis, followed by necrosis and leaf drop. In the cases of a slight boron deficiency, the fertility of the flowers is reduced due to increased ovary abortion (Perica et al., 2001). Boron deficiency is nevertheless removable with extreme rapidity and effectiveness through leaf treatments during the pre-flowering stages. Foliar applications have had statistically significant effects on the yield and leaf B contents, therefore, the most economic dose was found to be 0.4% foliar application of sodium tetraborate.

The organic matter in soil plays a central role in controlling the availability of N, P and K and it can also act as a chelate, making certain micronutrients more available for the roots in the form of complexes.

4.2. Fertilization techniques

Plant nutrition is physiologically dependent on the absorption of nourishing elements through the roots; it is therefore necessary to ensure that in the active soil layer there is a suitable endowment of available nourishing elements for the plants. Normally fertilizers are spread on the soil. Nitrogenous fertilizers, nitric, ureic or ammoniacal, are used annually according to requirements and the time of intervention, the first one being easily soluble with a fast effect, while ureic and ammoniacal products have a longer acting time and greater persistence. The nitrogen amount usually provided is of 1kg N equal to, approximately, 5kg of ammonium sulfate, 3kg of ammonium nitrate, 4kg of calcium nitrate

or 2kg of urea. The principal provisions of phosphorus and potassium, due to their low mobility in the soil, are provided before the plantation of the orchard establishment, further applications are made every 4 to 5 years in the autumn on the ground.

Fertilizers can also be supplied by the foliage, and in olive trees this characteristic can be effectively exploited in order to satisfy the needs of the plants in situations of particular demands (lacks of microelements), or as integration of soil fertilization in the different phenological phases. This technique is considered to be a valid support to increase the nutrient levels and the crop yield, reducing competition among metabolic sinks (shoots, inflorescences and fruits) and increasing the absorption of nutrients through the roots (Cimato et al., 1990, 1991, 1994, 1995; Toscano et al., 2000; Toscano, 2008). It provides nutrients quickly, uses low amounts of fertilizer, can be combined with pesticide applications, is well suited to rain-fed olive trees or when ground fertilizations would be useless due to a lack of soil humidity. The advantages of this technique are manifold: timely intervention, nutrients are given at the moment of greatest necessity, and is effective in a short time, and allows an integral use of the administered element. If only a foliage solution is applied, several applications take place (Fernández-Escobar, 1999; Ben Mimoun et al., 2004). Some results demonstrate, however, that foliar fertilization cannot entirely replace nutrition through the roots, even though it permits a reduction of the fertilizer required to be applied to the soil (Fontanazza, 1988; Toscano et al., 2000).

Many authors have studied the efficiency of olive foliar nourishment and for specific nutrients good results have been achieved using urea solution (Cimato et al., 1991; 1994).

Potassium is easily absorbed and distributed through leaf tissues (California Fertilizer Association, 1998) and foliar application is helpful to satisfy plant requirement having a high efficiency (Inglese et al., 2002). Phosphorous is given during summer fruit growth, in order to be readily absorbed and translocated to the fruits for quality purposes, therefore its application is better in the form of a foliar fertilizer.

In addition, recent studies have assessed the effectiveness of some commercial products on different olive cultivars, which behave differently. A helpful example of this efficiency is shown using NutriVant (NV) foliar fertilizers in addition to soil fertilization and showed that better results are obtained on the 'Carolea', than on 'Nocellara del Belice' cultivar. This difference is more clear in the "off year" orchards, during which an increase in the vegetative parameters and yield entity, in comparison to the control tests, was recorded. Conversely, in the "on year", the NV test had good results on both observed cultivars (Toscano et al., 2002b; Toscano, 2005; Toscano & Godino, 2010).

In irrigated orchards it is possible to supply nutrients to the plant by watering systems (fertigation) (Toscano et al., 2002a). The advantages of such practice consist in the easiness of application and in the efficiency of fertilizers, being able to reduce the needs of fertilizers by up to 30% in comparison to soil distribution. Fertigation implies a sensitive reduction of the management costs both in terms of purchase, transport and distribution of fertilizers, enhancing their efficacy in order to grant a better nutritional level to the trees, to maximize yield, oil production and profitability.

5. Irrigation

The efficient use of water resources in agriculture is extremely important in order to improve the economical and environmental sustainability of agricultural activity. Mediterranean regions of Italy are characterized by a high evaporative demand of the atmosphere, water scarcity and increasing negative consequences of climate change. In Italy the rainfall can vary annually from less than 400 to over 800 millimeters, and the lack of precipitation that is often manifested during the summer, involves the use of irrigation during dry periods to ensure the constant productivity of olive orchards.

In traditional olive cultivation areas, characterized by water scarcity, rainfall and underground water resources are the only supplies for the olive tree water requirements. Rainfed olive groves, therefore, are characterized by low plantation density which allows the exploitation of an adequate soil volume by the root system, minimizing competition for water among plants.

The olive, a sclerophyllous evergreen tree, is able to tolerate the low availability of water in the soil by means of morphological and physiological adaptations acquired in response to coping with drought stress (Connor & Fereres, 2005; Bacelar et al., 2007). Under semi-arid conditions olive trees were able to restrict water loss by modulating stomatal closure at different levels of soil moisture and evaporative demand and show a non-balanced allocation of dry matter among the different plant organs, resulting in a reduction of the vegetative growth and a significant decline in the productive performance (low yield and alternate bearing behaviour) in favour of development of the root system. Indeed, olive tree roots can extend and go deep into the soil to exploit a wider soil volume (Fernández et al., 1991; Dichio et al., 2002). Olive plants maintain a high rate of photosynthesis during long drought stress periods. The high efficiency of the olive is also due to its ability to continue to absorb carbon dioxide and to produce carbohydrates in water deficit conditions that determine the complete stomatal closure and threaten the survival of other species (Xiloyannis & Dichio, 2006). A higher photosynthetic rate under drought is a decisive factor for better drought tolerance in olive cultivars (Bacelar et al., 2007). Generally, when water is not restricting growth, plants invest a considerable fraction of photoassimilates in the expansion of photosynthetic tissues, maximising light interception and, as a consequence, growth (Dale, 1988). The capacity to withstand severe and prolonged drought periods, however, is negatively associated with olive tree growth and productivity, owing to the decrease of assimilates under water deficit conditions. Reductions in photosynthetic performance under water stress have also been observed by several authors (Inglese et al., 1999; Patumi et al., 1999; Tognetti et al., 2005; Bacelar et al., 2006; Lavee et al., 2007; Ben Ahmed et al., 2009).

Much research shows the productivity benefits of irrigation. Irrigation is highly effective in increasing yield and yield components such as fruit size, fruit number and oil content, moreover, irrigation affects the pulp-to-pit ratio, phenology and time of fruit maturation (Agabbio, 1978; Goldhamer et al., 1994; Michelakis et al., 1994; Inglese et al., 1996; Gómez-Rico et al., 2006, 2007; Dag et al., 2008; Servili et al., 2007).

A proper soil water availability enhances vegetative growth, such as shoot length, allowing the olive trees to produce a higher number of buds able to provide the opportune basis for the next year's production (Patumi et al., 2002; D'Andria et al., 2004; Gucci et al., 2007; Ben-Gal et al., 2008;). Stress levels and water requirements are highly dependent on fruit load and best irrigation management must account for biannual bearing effects. Although biennial bearing is basically genetically determined, the degree to which it occurs is greatly affected by environmental conditions, especially the weather and cultivation practices (Pandolfi et al., 2000). Alternate fruit bearing occurs under both extensive and intensive growing conditions (Pannelli et al., 1996; Lavee, 2006). With irrigation, olive production can increase up to five times that of olive groves in dry arid climates, in the Italian climate on average a double production must be expected (Bini et al., 1997). Obviously the scale of production will depend on soil conditions, average rainfall, evapo-transpiration and temperatures, cultivars, planting distances and other cultural practices (Nuzzo et al., 1997). Proper management of irrigation, especially during the summer drought, keeps leaves in activities promoting fruit growth and accumulation of reserves in the various plant organs (Xiloyannis & Palese, 2001), in any case, table olives cannot be cultivated without irrigation.

5.1. Olive tree water needs

The unitary water consumption of the olive tree, namely the quantity of water that must be transpired in order to synthesize a gram of dry substance or commercial product, have been estimated to be 1 liter of water by 1 m² of leaf, daily transpired in August. Such indexes, with opportune calculations, can be useful to help establish watering volumes. Best indications are drawn by the compilation of water budgets that, from the comparison among the entity of the rains and the losses of damp from the soil by evapo-transpiration, allow the determining of the water deficit or excess in the different periods of the year.

The criteria to be adopted in watering planning must be based on respect of the water requirement of the crop, and on the knowledge of the critical phases of the vegetative cycle of the plants, over that of the quantity of available water for irrigation, for the evaluation of the economic convenience of the intervention. As for all the other production factors, the economic principle of marginal productivity is in force also for water.

Olive tree water requirements are variable and depend upon factors such as soil type, climate, planting density, age of trees, cultural management (e.g. fertilizing, pruning) and the method of irrigation.

In the olive tree there are nevertheless some critical periods during the annual cycle, during which the plant mostly needs water. The first one extends from bud differentiation up to flowering and therefore to the fruit set: in these phases a water deficit can create trouble in flower development with a smaller number of flowers for inflorescence, increasing ovary abortion, and a lower fruit set. Generally during this period in Italy there are no deficiencies in soil water. Subsequently, at the second phase of fruit growth, corresponding to the pit hardening period, olive trees are most resistant to water deficit (Goldhamer et al., 1994; Moriana et al., 2007), on the contrary the third phase, when olive oil is accumulated, the olive tree again seems to be sensitive to water stress (Lavee & Wodner, 1991)

The inolition process starts around the pit hardening phase and reaches a maximum before ripening. The effects of irrigation on oil content are nevertheless quite controversial depending on different experimental conditions

Some authors did not find any difference in oil content between irrigated and non-irrigated trees (Michelakis et al., 1994; d'Andria et al., 2004), while Inglese et al. (1999) reported a lower oil content in the fruits of trees grown under high soil water deficit conditions. The literature suggests that the fruit and oil yield response to irrigation is highly cultivar specific (Lavee et al., 2007). Despite the increasing use of irrigation in olive groves, there is still a poor understanding of the effect of irrigation deficit on the qualitative parameters of olive oil.

Increasing irrigation leads to fruits with a greater water content (lower oil percentage), and irrigation has been found to decrease the polyphenol content (Patumi et al., 1999; Gómez-Rico et al., 2006; Ben-Gal et al., 2008; Dag et al., 2008), which then changes the oil bitterness and spicy tastes.

Several studies, which focused on the effect of irrigation on olive oil composition, report that irrigation increases free fatty acids in oil (Dag et al., 2008), can affect the fatty acid composition (Ranalli et al., 1997; Aparicio & Luna 2002; Servili et al., 2007) and the accumulation of secondary metabolites, that are fundamental in improving the organoleptic characteristics of the oil, is increased (Pannelli et al., 1996; Inglese et al., 1996).

For the calculation of the water needs in an olive-grove, some formulas are used that consider climatic environmental data, such as the rains and the potential evapo-transpiration (ETP), adopting different coefficients in relation to the spacing of trees, the age and shape of the plants, and season. The water deficit, will be given by the difference between the water used by the crop and the water availability in the soil: such a deficit will be therefore compensated for with irrigation to optimize the productive potentialities of the plants.

The calculated seasonal watering volumes, will be nevertheless reduced considering the threshold of convenience, in relation to the efficiency of the irrigation system, the cost and availability of water and the value of the product. For the intensive olive growing in South Italy, it increased from 1.500 up to 3.000 m³ hectare⁻¹ per year (Agabbio, 1978).

An evaluation of the water needs, such as the water consumed by the crop (evaporation and transpiration), can rationalize the irrigation technique. The evaporation potential (ET₀) must be determined through the compilation of the soil hydrological balance and the search for an empirical correlation between the potential evapo-transpiration and one of the climatic factors.

To satisfy the needs of an intensive olive-grove the results of different watering trials pointed out that for the olive tree it is enough to supply 30-50% of the evaporated water.

The beginning of the irrigation season should take place when the soil is still wet (60-70% of available water) to ensure the maintenance of adequate reserves even in deeper layers and at points not covered by providers in order, however, to maintain roots present in those areas.

Irrigation can be realized in different ways and the choice of the optimal method should be made according to each single olive-grove typology and environments. Sprinkling methods,

with giant irrigators or wings, have the advantage of adapting to any soil condition, the facility of moving and transfer, and the timeliness of intervention, but generally with high costs and low efficiency of water. On the contrary localized irrigation, that allows water distribution evenly in sloping land, is a technique which offers the possibility to intervene in certain biologically critical phases for the plants (flowering, fruit setting, pit hardening, etc.), allowing a significant reduction, of about 25-30%, in the consumption of water. Furthermore it allows a more uniform distribution of water over time, with shorter shifts and increases the efficiency of irrigation up to 90%, avoiding losses due evapo-transpiration, runoff, etc.

With sprinkling the volumes are calculated for the whole surface; with the localized irrigation on the wet surface equal to 10% with drip irrigation and to 25% with microjets. Microjets enable irrigation of a rather large surface to meet the different needs of the olive tree during its development, but also creates constraints for tillage and weeds removal by mechanical means and increase water loss by evapo-transpiration.

In the center-northern olive-grove environments of Italy, natural water availability is often such to allow satisfactory production, even without resorting to irrigation. In the South of Italy, generally the annual average rainfall is rather low, with rains concentrated in the autumn-winter season, that does not coincide with the needs of the plant, therefore it is necessary to apply irrigation during summer.

The irrigation intervals depend, more than from the evaporative demand of the environment, on the type of soil and therefore from the quantity of water that it can retain.

In the case of localized irrigation shifts are on average 2-4 days with about 30 m³ ha⁻¹ of water, the turns will progressively be shorter passing from slimy-sandy to sandy soil.

The most critical phases in which water stress should be avoided are at floraison, at fruit set, at fruit growth and at inolition. An effective watering season could start, according to watering water availability, at the end of flowering (May-June) and continuing until late September.

In recent years many studies have tried to apply deficit irrigation strategies to olive trees. These are based on the observation of Chalmers et al. (1981), who reported for peach trees that the maintenance of a slight plant water deficit can improve the partitioning of carbohydrate to reproductive structures, such as fruit, thus controlling excessive vegetative growth. The asynchronous growth of olive fruits and shoots reduces competition for assimilates at critical stages, providing a sound basis for the application of irrigation deficit.

The controlled irrigation deficit is a water management method that does not completely satisfy the tree's water requirements during the growing season. It causes a temporary and regulated water deficit in a specific phenological stage. When it is applied in the pit-hardening period, the olive oil yield is not affected while the water use efficiency (WUE) is improved. On the contrary when the controlled irrigation deficit is applied from fruit set to harvest, the oil yield decreases but the WUE and certain olive oil quality parameters improve. As the productive tree responses are not affected by moderate levels of water stress, irrigation deficit strategies are recommended in arid and semi-arid areas to save the scarce conventional water resources (Angelakis et al., 1999; Massoud et al., 2003).

Finally it is interesting to note that the olive is quite resistant to salinity. This plant tolerates brackish water (up to a salty residue of 4 g/liter), and therefore can allow the realization of irrigated olive-groves, valorizing waters which are not usable for other crops (Basta et al., 2002; Perica et al., 2008).

6. Pruning

Pruning is a very expensive practice in olive grove management, reaching up to 40% of total cultivation costs, but it is also essential for olive grove profitability. It is finalized to modify the natural shape and structure of the trees, to reduce to the least one skeletal structures, to balance the vegetative and productive activity, and to maximize fructification. To reach the best results, pruning must be rationally managed, and based on the harvesting system. A modern approach to this practice allows to form and maintain the tree structure at a relatively low cost, reducing and simplifying pruning operations without negatively affecting yield, oil quality, or orchard sustainability.

Strategies of “minimum pruning” can be developed at a farm level independently of the type and size of the orchard. Managing the canopy according to the criteria of “minimum pruning” is suitable both for traditional olive groves and modern, high-density orchards.

The growing habit of the cultivar, the natural tendency for high vegetative activity, the type of buds and branches, and alternate bearing are all important biological features of the olive tree that it is important to consider for pruning.

In practice, pruning is distinguished into a formation and a production pruning: formation pruning has the purpose to give the selected form to the olive tree; while the production pruning is finalized to preserve the form and the size of the canopy, to eliminate inefficient or unproductive structures, to facilitate the functional positioning of fruiting shoots to enhance harvest efficiency, to maintain the trees’ vegetative and productive balance. Olive trees bear fruits on the previous year’s shoots, so to have fruit every year an adequate vegetative growth must be achieved. Annual interventions should be faster, smaller and easier cuts using small tools such as shears and saws.

The execution of pruning should avoid the accumulation of too much wood caused by an excess of primary branches and an excessive overlapping of secondary branches. To stimulate olive production pruning must be reduced to strictly necessary interventions, leaving the most possible greater number of leaves. Periodically some return cuts made on the branches return the plants to their assigned volume to maintain the volume and the shape of olive trees.

Extraordinary kinds of pruning are practiced when it is necessary to restructure the canopy in another form held to be more convenient. Pruning old trees requires drastic cuts to rejuvenate or to restore the health of the plants so as to stimulate their growth and renew fruit-bearing shoots and branches.

Pruning also contributes to reducing the occurrence of pest and disease. Dense canopies encourage the presence of parasites due to high relative humidity, whilst well-aerated

canopies considerably decrease the attack of pest and disease such as the 'olive knot' which appears on branches and is otherwise very difficult to control.

6.1. Training system

Around the Mediterranean basin, a traditional area of olive tree cultivation, there are many different training systems for olive trees, but now in modern orchards the most common shapes are:

- The "vase" with several different variants is by far the most popular shape and the most practical for hand or semi-mechanical harvesting. Usually the vase has a single trunk varying in height from 50 cm to 120 cm, branching into some primary branches, in adult plants generally three, equally spaced so as to intercept as much sunlight as possible. These branches, tilted about 45-50 degrees, support the scaffolding of the tree.

The only pruning required is in the centre of the canopy to allow enough sunlight to come through and removing cross branches leaving the greatest possible number of leaves on the plants, because productivity and the oil quantity in the drupes is dependent on them.

- The "single-trunk" is constituted by a central axis of the tree that raises a series of primary branches chosen amongst those that grow vigorously inserted in a spiral, alternated by 50-60 cm between them. To achieve this form few thinning cuts are made during the training phase. When the plants are in production the primary branches are periodically pruned by cutting or heads back, or eliminating them in order to renew the fruit-bearing surface. This shape is good for the intensive olive growing systems where the canopy cone reduces distances between the plants and for the mechanical harvest with shakers, but it is difficult to manage.
- The "bush" shape is the result of natural basal sprouting of the olive tree with numerous branches and those that arise from the bottom. This system is suitable for intensive cultivation models to be collected by hand or with tool facilitators it requires very little pruning during the training phase, but it is unsuitable for mechanical harvests with shakers due to lateral branches shooting from the proximal part of the trunk.
- The hedgerow is a training system in which trees grow freely, so that the canopy forms a productive wall along the row, usually managed with mechanical pruners to maintain the trees with an available volume.

Lately the training system suitable for olive orchards with over 1000 trees per hectare, is a single axis, obtained by thinning out the side branches in the apical part and by also removing those located below 0.5 m from soil during the first year of planting the to allow the passage of the machine. Once full production has been reached, plants are pruned so as to contain vegetation within 2.2 m in height and prevent the development of little branches of a diameter greater than 3 cm. In these groves mechanical pruning alternating with manual interventions is used to contain the development of foliage.

The training system is the result of the growing habit of the tree and pruning practices and it must be chosen before the planting as a function of the harvesting method and mainly of the

area climate. Indeed, experimental tests of comparison between the "vase" and the "single-trunk" conducted over several years in the experimental field of CRA-OIL, located in Mirto Crosia (CS-Italy), showed the extreme difficulty in maintaining the last shape due to the climatic characteristics which are strongly favorable to olive plant development.

6.2. Pruning scopes and effects

A first objective of pruning is to provide a shape and structure to the tree which guarantees proper illumination of the canopy to enhance photosynthesis, good circulation of air, avoidance of pest disease, and a better disposition of fruiting shoots to facilitate and maximize the harvest.

At plantation, the first cuts are executed to plan the scaffold and the principal branches are chosen according to the selected shape. In the following years, pruning will be limited to the elimination of unfit shoots, favoring correct skeletal development. After the third-fourth year, with the beginning of the yield, annual pruning will have to balance volumetric growth with the vegetative-productive equilibrium of the trees.

Pruning intensity increases with the age of the tree. Pruning is light on young trees to allow the shaping and to grow and build energy reserves.

As general guidelines, for adult trees, given the light need of this species to perform photosynthesis, it is necessary to reduce the density of the foliage, allow sunlight to penetrate into every part of the olive canopy and promote air circulation. All the suckers around base of the trunk and branches that have already produced should be removed. It is also important to keep the upper parts of the tree open to allow the lower parts to remain productive.

In adult olive-groves, in full production, annual pruning allows better regulating of the balance between vegetative and reproductive activities and so contributes to reduce alternate bearing. This phenomenon is more dramatic the wider the pruning shift. The shift of pruning cycles should be chosen based on factors such as the growth of branches, the fruit-laden, the training system, soil fertility and climate and structural aspects of the farm. The execution of pruning every 2 or more years allows a reduction of the cost of such practice but favors the occurrence of alternate bearing.

Tests for several years showed that it is necessary to maintain a large leafy area of the plant, and pruning of medium intensity in shifts of two - three years, depending on the cultivar, gives the best results (Tombesi et al., 2002; Tombesi et al., 2007). These pruning cycles, compared with annual pruning, allow an increase in the production efficiency of the plant, and also a net saving of human work, since the execution times are not very different, and the number of cuts per plant is almost similar.

According to whether the mechanical harvest are adopted, with shakers or mechanization, in the first instance it is necessary to build the canopy towards erect forms, with shoots which are relatively short and rigid, to favor the transmission of vibrations up to the drupes in the whole

volume of the canopy, while in the second case, the pruning will have the aim of bringing up the external wall of the canopy longer and pending fruiting shoots, to facilitate harvesting with pneumatic combs (De Simone & Tombesi, 2006; Tombesi et al., 2008).

Pruning must be carried out at the end of winter, before the restart of vegetative growth. It must be avoided after the harvest, because it reduces the cold resistance of the plants and does not allow wounds to heal, favoring diseases from fungi or other parasites. Traditionally in late summer a second pruning is performed on adult plants to eliminate suckers inside the plants, with special reference to the vase shape, where the formation of shoots within the canopy becomes a rule.

In profitable olive orchards pruning mechanization is essential to reduce management costs and regain timeliness in working, even though it penalizes the productive efficiency of trees. To balance the economic needs of management there are several ways to carry out mechanical pruning that should not be performed simultaneously on the entire plant. To ensure a good production of fruiting branches the canopy that remains after pruning should not excessively be reduced. Mechanical pruning can be applied alternately in different years and/or rows by carrying out topping and hedging, reserving annual hand pruning to eliminate shoots and suckers.

Several experiments have been performed in different types of olive orchards in order to study the feasibility of mechanical pruning (Giametta & Zimbalatti, 1997; Ferguson et al., 1999; Ferguson et al., 2002; Peça et al., 2002; Tombesi et al., 2008; Dias et al., 2008; Farinelli et al., 2009). In our experience, the technical-economical convenience of pruning mechanization, also considering equipment integrated with pneumatic combs for olive harvesting, was evaluated. The results showed the good effectiveness of the pruning equipment in terms of cutting quality and working capacity (Pascuzzi et al., 2007; Toscano 2010a). Other trials have been carried out to assess the performances and the effects of mechanical pruning, that was performed both with toothed disks and scissor blades pruning machines. Both resulted in great efficacy and work productivity; nevertheless, the first ones are more efficient for woody vegetation, up to 10 cm diameter, while the second ones work better on thin branches, even though it can cut woody branches up to 5 cm diameter (unpublished data).

7. Harvesting

In olive grove management, the harvest is the other most expensive practice, together with pruning. Harvesting systems, can be considered rational only when they can reconcile the operation costs with the necessity to pick up the maximum yield in respect of the product quality. In the past, the availability of low cost manpower with a manual harvest allowed the satisfaction of these two demands, but the low availability and increase of the cost of labor, have made such operations excessively onerous, and applicable only to table olives.

Manual harvest can be improved using hand-held pneumatic combs to detach the olives from the plant that assuage the work, and give maximum flexibility in terms of harvesting time, and increase the operators productivity, but it is time-consuming and costly.

Mechanical harvesting is executed with shaker, also equipped with a reverse umbrella as an olive interceptor, that has considerable economic advantages compared with traditional manual picking procedures (Tombesi & Tombesi, 2007). In this way a great reduction in labour costs, harvesting timeliness and good performance, is achieved. Nevertheless it is difficult to apply in the majority of traditional olive groves due to the presence of malformed, voluminous plants, or those of an unsuitable cultivar.

In the new intensive olive groves, with trees optimized for cultivar and structure, mechanical harvest is instead applicable with positive results, usually in a step, getting up to 80-90% of yield (Hartmann & Reed, 1975; Ferguson et al., 1999; Giametta & Pipitone, 2004; Toscano & Casaccia, 2006). In these orchards with well pruned trees it is possible to harvest up to 50 trees/hour with a suitable shaker and collecting system (Lavee, 2010).

Using shakers, the more efficient harvesting yard is constituted by 5 or 7 operators, of which one operates the shaker, and the others the nets and the moving of olives, reaching a productivity up to 0,4 tons/man by hour (Briccoli et al., 2006; Tombesi, 2006; Toscano, 2007).

In super intensive olive orchard, or intensive olive orchard with trees structured in a productive wall, continuous harvesters, derived from grape pickers that work on both walls of a row (Bellomo et al., 2003; Arrivo et al., 2006) can be used. Wall pickers, that work on a single side of tree walls, also reach a working productivity up to 1 hectare by hour, with yield percentages similar to the shakers (Toscano, 2010b).

7.1. Ripening physiology of drupes

The olive tree fruits (*Olea europaea* L.) are oval or round drupes, of variable weight according to the cultivar, the yield, the nutritional and health state of the tree. The drupe is constituted by the external exocarp (peel), by the fleshy mesocarp (pulp) and by the internal stone (pit). Fruit development and ripening are a combination of biochemical and physiological changes that occurred during maturity of fruit. The development process is characterized by changes in size, weight, composition, color, flavor and physical properties of the fruit (Connor & Fereres, 2005) and is critical for final yield and oil quality. Oil accumulation, which occurs from pit hardening to harvesting may be early or late depending on the variety, generally it starts in the northern hemisphere from the month of August and continues up to November-December, subsequently the increase of oil content in the drupes is apparent being due to water reduction.

The maturation of olives also varies depending on the crop load, environmental conditions, which are subject to strong annual variations, soil moisture, and cultural practices. At harvest, within a tree, not all the fruit are at the same ripening stage, in fact this parameter also depends on the position of the fruits.

For the olives to be used for the oil extraction, the harvest must have been carried out at the beginning of the ripening phase of fruits, at veraison, when the pulp changes its color from green to purplish red. This stadium corresponds to the maximum oil yield per hectare, since, even if subsequently a slight increase in the oil content of the drupes is had, the loss

for natural fruit drop undoes the advantage. In many instances the oil quality also decreases. An early harvest allows the production a good oil, rich in antioxidants and aromatic flavors, that confers resistance to oxidation, and a "fruited" taste. Instead, oils obtained from olives harvested at an advanced ripening stage are less intense, less bitter with a lower percentage of mono-unsaturated and saturated fatty acids and a higher percentage of poly-unsaturated fatty acids, that penalize its stability.

With regards to the harvesting method, oils with excellent quality can be produced with both manual and mechanical harvesting, as long as the drupes are intact and healthy.

For table olives harvesting is carried out manually from the plant, to avoid damage to the fruits that would consequently depreciate their market value. In some cases harvesting in the olive-grove is done in different steps as a consequence of the ripening scale, or performed at the same time and the sub-size fruits are sent to the crusher for oil extraction. To facilitate the harvest it is necessary that the plants are of a contained dimension, and with suitable forms that assemble the fruits on the outside of the canopy and on lean shoots.

In table cultivars for green fruit processing the harvest is done when the peel color changes to light green, that corresponds to the beginning of pulp softening and the maximum content of sugars, fundamental during tanning, for the fermentation process that follows sweetening, with lye or brine. For the olives destined for tanning to black, the harvest must be effected when the pulp is also colored, based on the physiological maturation of the fruits.

The most important parameters to determine the stage of maturation of the drupes are the fruit separation force and the development of natural fruit drop. Before the natural fall of olives there is an attenuation of the force with which they are attached to branches and shoots. These physiological changes do not occur simultaneously on all the drupes of the same tree but occur with a certain scaling. Therefore, the decrease of the attachment strength of the fruit and the drop of the first fruits are the most important indices of the final stage of ripening. These indices are easily determined and able to predict with sufficient reliability the time to start harvesting.

The optimal time of harvest can be, further, defined as one in which there is a high amount of fruit on the plant capable of being detached by the machines in considerable percentages and with a high content in good quality oil when ripening the pulp becomes less consistent (Farinelli et al., 2006).

8. Conclusions

The information contained in this paper highlights that it is possible to achieve some improvements in olive tree productivity (in terms of quantity and quality) and a reduction in costs, spreading more rational agronomic practices. Increasing the olive groves income can be achieved through updated cultivation techniques. All these must be coordinated and integrated with each other to obtain a rapid formation of the tree production structures that allow the maximum expression of their productive potential and provide a high level of

mechanization. Soil management, plant structure, fertilizer, irrigation, pruning and mechanical harvesting must be chosen according to variety and environmental features. The paper provides useful indications on the introducing of the cover crop to better soil management in order to control erosion and maintain soil fertility.

Moreover, olive trees respond very strongly to irrigation and take advantage of very low volume of water also with regulated irrigation deficit. With regards to olive pruning, this cultural practice must be managed rationally based on the harvesting system and both these techniques (pruning and harvesting) must be done mechanically to reduce the running costs for better crop competitiveness.

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