Production techniques in olive growing

INTERNATIONAL OLIVE COUNCIL

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PRODUCTION TECHNIQUES IN OLIVE GROWING

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The scientific team designated to compile this publication under the guidance of the IOC Executive Secretariat is made up of internationally renowned researchers whose hard work has made this book materialize.

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Foreword

Foreword

Throughout the world, farmers are adapting to the new circumstances brought about by the profound changes underway in the technological, economic and social spheres. Olive growers are no exception to this process. To help them in their move towards modernization, the International Olive Council (IOC) has brought out this publication entitled *Production techniques in olive growing,* which is the culmination of lengthy work carried out by a group of specialists from IOC member countries.

It has been written for technical and extension officers and producers with the chief aim of helping the sector to increase productivity and meet the growing consumer demand for quality produce while respecting the environment.

The subjects covered range from production techniques, notably orchard planning – including for super-intensive cultivation – pruning and soil management to herbicide use, fertilization, irrigation systems, plant health protection and harvesting.

I hope it will give readers clear, precise solutions to deal with all the difficulties they may encounter in their day-to-day jobs.

Executive Director
International Olive Council

Habib Essid

1

Orchard planning and planting

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Orchard planning and planting

1. Orchard planning and planting

1.1. INTRODUCTION

In a number of situations it is necessary to plan establishing a new orchard (Fig. 1):

1) When the orchard is obsolete and responds poorly to cultural practices because the trees are aged and large areas of the base and trunk have died from decay.
2) When root expansion and functionality are jeopardized by poor soil fertility, which reduces the availability of oxygen, fertilizers/nutrients and water.
3) When planting density is no longer optimal because it has decreased owing to the death of trees from frost or pest damage.

Figure 1. Renewal of olive orchards to make them more efficient.

Figure 2. Rational management of bearing trees makes olive growing more competitive.

4) When the orchard has to be replaced because it is sited on excessively steep terrain or in areas at risk from frost, drought or waterlogging.
5) When the orchard has to be adapted for mechanization (harvesting) (Fig. 2).
6) When orchard varieties have to comply with the regulations for designations of origin (PDO, PGI), or to be adapted to pollination requirements or harvest machinery.
7) When crop production has to be increased to meet growing product demand.

Several circumstances are conducive to setting up new olive orchards:

1) The financial outlook for olive growing is bright in many individual countries as well as on a world scale.
2) Effective, relatively cheap options are available for preparing orchard sites.

3) It is easy to find olives for planting out (Fig. 3).

4) The trees grow quickly and start bearing early.

Consequently, one of the foremost demands in the near future will be for the creation of new olive orchards, which will be the chief, most effective option for raising and mechanizing crop production.

The fundamental goal of orchard planning is to achieve cost-effective management through high yields and economical cultural practices. High productive efficiency is obtained in orchards where the factors which have a bearing on the underlying physiological processes of crop production are optimized and where crop production costs are lowered through intense use of machinery, particularly for harvesting.

Another important objective of orchards is to produce quality olives and oil.

Figure 3. Well developed, rationally shaped trees ready for planting out.

The choices made in terms of orchard planning, training shapes and orchard management techniques must therefore respond to the physiological and economic fundaments of olive growing.

1.2. PHYSIOLOGICAL FUNDAMENTS

Root system activity, carbohydrate synthesis, flower bud differentiation and fruit development (Fig. 4) are the most important processes in the productive cycle of the olive tree.

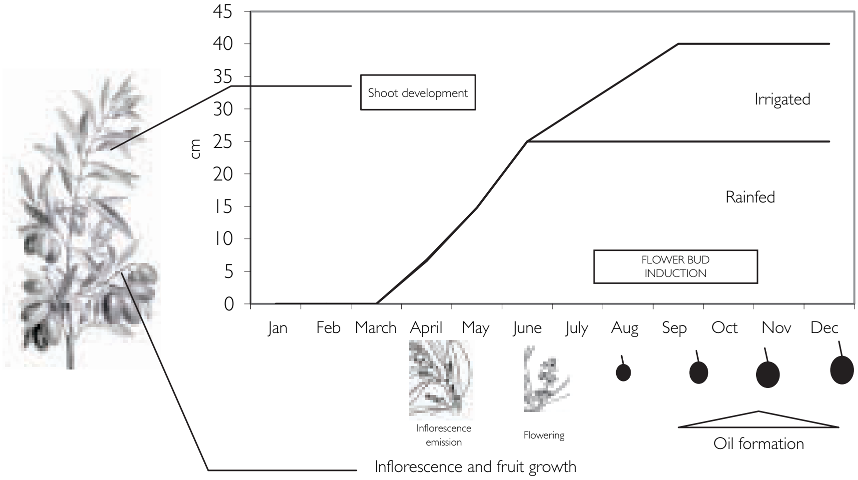


Figure 4. Biennial fruiting cycle of the olive showing the periods of shoot, flower and fruit growth.

Besides carrying out its functions in a large volume of soil where oxygen, water and nutrients are available, the root system develops by absorbing water and metabolizing the nutrients provided by the canopy.

Carbohydrate synthesis occurs in the leaves at optimal temperatures of 20-30 °C and at light intensity values ranging between the compensation point, equal to 20-30 µmole photons $m^{-2}s^{-1}$, and 600-1,000 µmoles. Above this last value, photosynthesis remains constant (Figs. 5 and 6).

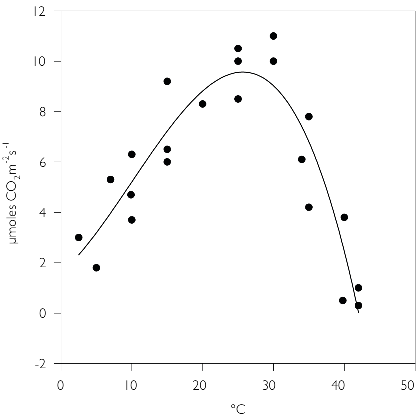


Figure 5. Changes in photosynthesis of cv. Maurino leaves according to temperature.

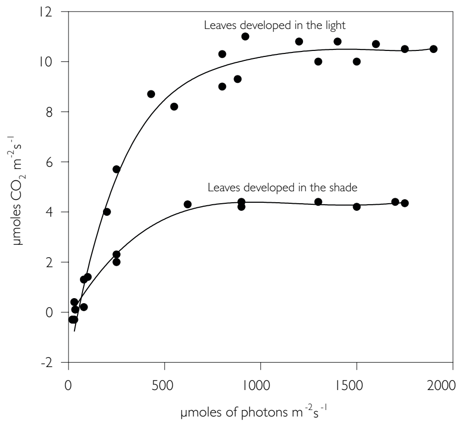


Figure 6. Influence of leaf development conditions and light intensity on photosynthesis.

However, only the leaves on shoots exposed to sunlight (1,600 µmole photons $m^{-2}s^{-1}$), receive a mean light intensity equal to saturation levels (Fig. 7), owing to the effect of the angle and orientation. The photosynthetic balance of leaves shaded inside the canopy and by the canopies of adjacent trees may be negative for a good part of the day.

Photosynthesis is limited by water and temperature stress and by attacks from pests and diseases (Fig. 8).

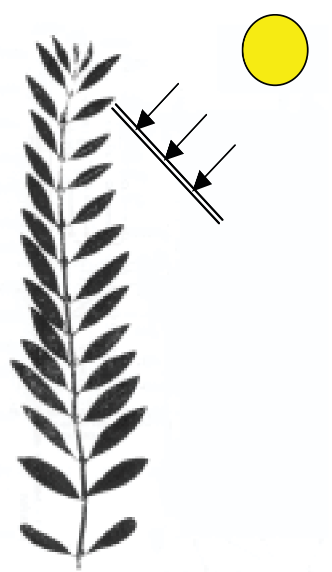


Figure 7. Owing to their position, the leaves on a well-lit shoot (1,600 µmoles of photons $m^{-2} s^{-1}$) receive an average light exposure of 900-1,000 µmole photons $m^{-2} s^{-1}$.

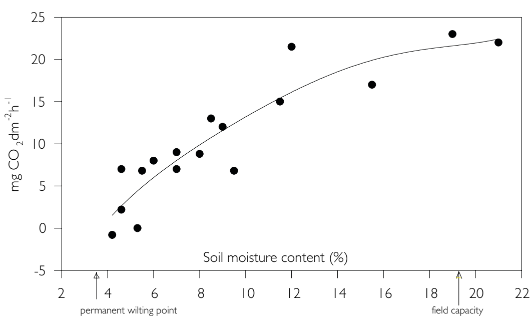


Figure 8. Influence of soil moisture content on olive leaf photosynthesis.

The plant tissues use part of the assimilates for annual growth and respiration while the rest go straight to organs like the fruits or the reserve tissues.

Flower bud differentiation, fruit set and fruit growth are stimulated by the photosynthetic activity of the canopy whereas they are inhibited by leaf shading (Fig. 9).

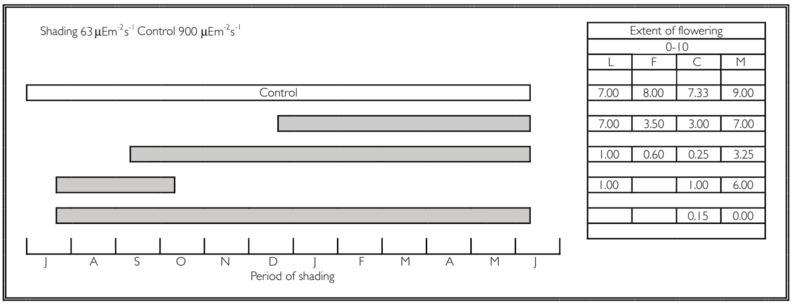


Figure 9. Extent of flower formation in cv. Leccino (L), Frantoio (F), Coratina (C) and Maurino (M) in differing light conditions.

1.3. ECONOMIC FUNDAMENTS

For a number of reasons, olive growing has to aim for quality product and a drastic reduction of labour. Viewed from this angle, it is essential to mechanize cultural care, especially harvesting (Fig. 10). At present, shakers are the reference markers for harvest mechanization. Trees need to be medium-sized for shaker harvesting, with a trunk at least one metre high and a canopy without drooping branches where the crop is concentrated in the middle-upper area. The orchards have to be planted at a suitable density on land that does not slope steeply. Soil cultural care such as tillage, fertilization and irrigation must also be easy, and pruning, which accounts for 10-20% of cultural care, must be cost-effective, i.e. it must be simple, quick and cheap.

Figure 10. Harvest mechanization is a must in new orchards.

1.4. ORCHARD OBJECTIVES AND CHARACTERISTICS

When setting the objectives to be met by olive orchards, it is necessary to tap available scientific and technical expertise to define the characteristics of an orchard that is efficient, competitive in terms of management costs and reliable in applying tried-and-tested methods (Fig. 11).

Figure 11. Olive orchard growing in a suitable area and competitive in terms of crop production and management costs.

Harvesting is a critical aspect of production because, if done by hand, the costs are heavy. One alternative is mechanization. Trunk shakers have demonstrated they are capable of harvesting olive fruits efficiently and at low cost, but they do have specific requirements. The one fundamental condition is that the trees must have the right canopy volume (1).

(1) $V = \pi/4 \cdot d^2 \cdot h$ where V = canopy volume; d = canopy diameter; h = canopy height; $\pi = 3.14$.

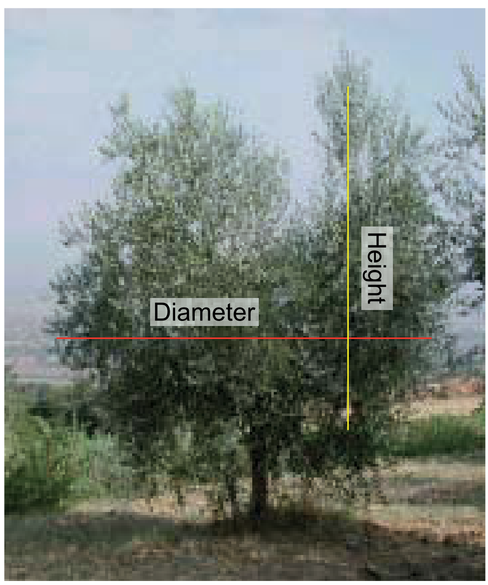


Figure 12. Determination of cylindrical volume where diameter and height are indicated.

When the canopy volume is around 30-40 m^3, the results are definitely good; up to 50 m^3 the results are good again, but more care has to be taken over other factors like variety, harvest timing and shaker power. Consequently, when planning an olive orchard, canopy volume is the yardstick, and the canopy width and height have to be determined on the basis of physiological measurements and tree management considerations (Fig. 12).

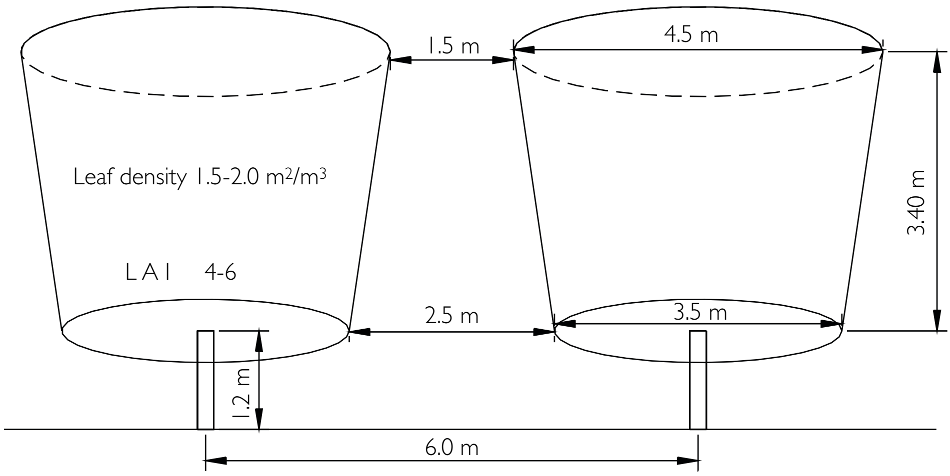


Figure 13. Tree dimensions for a density of 278 trees/ha and a canopy volume of 12,000 m^3.

One first requisite is to intercept the maximum amount of radiant energy. This is done by widening the canopy but leaving enough space beside the canopy of adjacent trees to avoid reciprocal shading.

The other aspect is canopy height. This should be limited to prevent forming an over-voluminous framework of branches which use up energy for their maintenance and annual growth. Moderately tall canopies facilitate pruning, crop health treatment and harvesting, whether it is done by hand, with aids or by shakers or other machinery.

A third factor to bear in mind is the canopy leaf area, which should ensure maximum carbohydrate synthesis.

Canopy functionality depends on the moisture and nutrient resources made available to the tree through the soil, climate and cultural practices, be they natural environmental resources or resources added through fertilization and irrigation. Tree volume per hectare at a set leaf density is closely linked to area rainfall. In the arid environments found in some parts of Tunisia where yearly rainfall is 250 mm, there are olive orchards with a canopy volume of 3,000 m^3. In Andalusia (Spain), with a rainfall of 600 mm, the volume can reach 9,000-10,000 m^3/ha. In some regions of central Italy where the rainfall amounts to 850 mm, volumes of 12,000-13,000 m^3/ha can be found, always in rainfed conditions. When blocks of trees with a canopy volume of 9,500, 10,500 and 13,000 m^3/ha growing on medium-textured, minimally worked soil were compared during a dry summer, no differential symptoms of shortage attributable to canopy volume were noted in the trees. Canopy volumes of around 14,000-15,000 m^3 are recommended as acceptable in the irrigated areas of many Mediterranean olive-growing regions. At a canopy volume of 12,000 m^3/ha, if there are 278 trees planted on a 6 x 6 m layout the individual trees will have a volume of 43 m^3, which can be handled by shakers. Tree size is compatible with the size expressed by the environmental conditions and by the vigour of the majority of cultivars. It is important for each variety to be able to expand its canopy according to its vigour, which is determined by its genetic characteristics and by the climate and soil in which it is grown. In such cases, pruning is designed to select the most efficient branches and to correct and preserve the shape without sharply modifying the vegetative-productive balance of the tree.

Once the reference volume has been fixed, the extent of the outward and upward expansion of the canopy has to be determined (Fig. 13). Width-wise development is necessary to intercept the maximum amount of radiant energy and is correlated with height. At a canopy height of 3.4 m, each canopy expands over a maximum area of 15.9 m^2, which equates with a diameter of 4.5 m and leaves a distance of 1.5-2.5 m between adjacent trees, which is just enough to allow machinery to manoeuvre easily and to avoid daytime shading. The 3.4 m height is a good benchmark because it ensures good leaf distribution and, at a density of 1.6-2 m^2 of leaves per m^3 of canopy, it gives a maximum leaf area index (LAI) of 6, which is considered optimal for achieving high olive yields at the end of the vegetative season. At the same time a canopy height of around 3.4 m allows good access for pruning, harvesting and pest and disease treatment. In such conditions, the lower parts of the canopy also receive sufficient light, equivalent to more than 10-15% of the light received on the top part of the canopy, which makes sure they are sufficiently functional and allows moderate growth of the fruit that forms there. These parts of the tree also benefit from the light that reaches them as the angle of the rays of light changes through the day, and light exposure can be improved by evenly distributing the vegetation. When the orchard is irrigated, the canopy can be slightly higher. This increases the overall volume but does not greatly alter canopy functionality or suitability for machine harvest.

Shakers equipped with catching frames are easier to use on orchard layouts of 7 x 7 m.

1.5. AREAS SUITED TO OLIVE CROPPING

1.5.1. Climate

The areas suited to olive growing are characterized by minimum temperatures of -6/-7 °C. Below this threshold, substantial damage can occur to the leaves. Temperatures of -3/-4 °C can injure the more moisture-rich fruit if they have not yet been harvested, with the resultant negative repercussions on oil quality. In northern growing regions olive orchards are therefore sited on hill slopes at intermediate altitudes where the temperature is appropriate. The areas where olive cultivation is most widespread have mild winters, with temperatures rarely falling below zero, and dry, hot summers. Warm growing areas must be able to meet crop chilling requirements because temperatures constantly above 16 °C prevent the buds from developing into flowers; temperatures must therefore drop below 11-12 °C for one month. High temperatures during fruit ripening lead to an increase in the linoleic acid content of the oil and to a sudden drop in its oleic acid content.

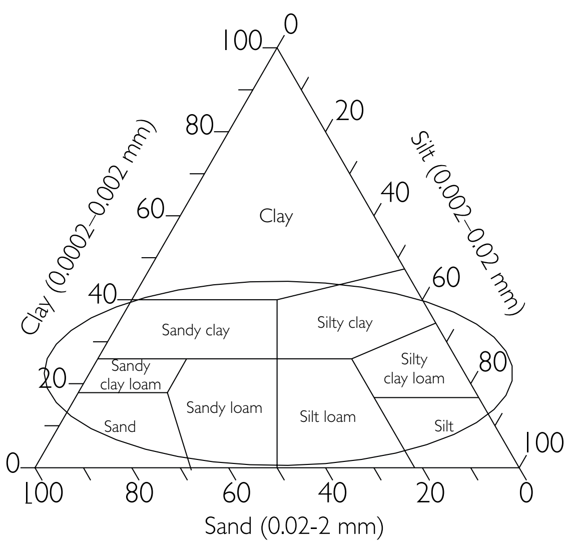
Rainfall should be above 400 mm. Up to 600 mm is considered sufficient, 800 mm is considered moderate and 1,000 mm is considered good. Rainfall should be distributed in such a way as to avoid dry periods of more than 30-45 days and extended wet periods. The area should not be subject to hail, or to excessive snow to stop it building up on the canopy and causing limb breakage.

1.5.2. Soil

The root system of the olive is concentrated in the top 50-70 cm of the soil although it may send out roots to a depth of more than one metre in search of supplementary water resources. The soil must therefore have an optimal texture, structure and composition to a depth of at least one metre. Root system development in the soil can be hampered by the formation of calcareous, ferruginous or tuffaceous concretions, but if they are thin and superficial they can be broken up by deep tillage to make the soil ready for planting. One frequent barrier is the hardpan which forms when fine soil particles under the tillage layer are cemented by the compacting pressure exerted by the plough when the ground is always tilled to the same depth.

Olive responds best in soil textures with balanced proportions of sand, silt and clay (Fig. 14). Soils that are primarily sandy do not have good nutrient or water-holding capacity, 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. One of the chemical properties of olive is that it adapts to different pH values. However, close attention needs to be paid to sub-acidic and acidic soils with a pH of less than 6.5 when toxic, interchangeable aluminium and manganese ions are released. In addition, acidic soils are characterized by low micro-organism activity and blocked mineralisation, which causes nutrient shortages. Acidity can be remedied by adding alkaline calcium compounds such as finely ground calcium carbonate (lime), quick lime or chalky marl.

Figure 14. Soil texture triangle for determining soil type. The sides of the triangle are scaled for the percentages of sand, silt and clay. The intersection of the three sizes gives the soil type (international classification).



At high pH levels, phosphorus and iron tend to become insoluble. Up to a level of 8.3, calcium carbonate is present and this is tolerated by the olive; however, when lime content and pH levels are high, it is wise to look for tolerant varieties.

Generally, it is hard to correct anomalous chemical characteristics in the soil although some measures can be taken to improve severe cases. To lower the soil pH it may be useful to apply acidifying amendments such as sulphur and organic matter, dung and green manure, which make the calcium carbonate soluble, so forming organic acids and carbon dioxide. Sodium carbonate is present in soils with a pH of more than 8.3 and prevents clay flocculation and particle structuring; as a result, the soil is hard, asphyxial and impervious. Such soils are found in arid climates where little or no leaching occurs and where the intense evaporation causes the soluble salts to rise from the deep layers. Three to ten tonnes of gypsum (calcium sulphate) per hectare is applied to remedy this problem. This releases Ca, which shifts the sodium out of the exchange complex which then has to be leached.

Root absorption is hampered when the soil solution has a high concentration of soluble salts such as sulphates and chlorines. The electrical conductivity of the soil measures the concentration of the salts. When above 4 dS/m, negative effects start to be seen; at values of 10-15 dS/m they become considerable. Salinity can be reduced through irrigation leaching and efficient drainage. As a guideline, saturation irrigation eliminates 50% of the salts.

The terrain should not have a slope of more than 20-25% to allow machinery to operate easily; flat or slightly sloping land is therefore to be preferred.

When the gradient is up to 5%, the soil can be worked in any direction. At gradients of 5-10% erosion starts to appear, making it necessary to take soil protection measures, for instance by shortening the slope length of the plots. At gradients of 30-40% it is advisable to terrace the orchard, which adds to costs and hampers mechanization.

South, west and east-facing aspects are the best options and guarantee good crop volume and quality.

Deep, fertile, medium-textured soils provide an optimal basis for development and their chemical and physical characteristics should lie within the ranges shown in Table 1. In any case, clay content should not be more than 40-45%, total lime content should not exceed 50-60%, organic matter content should be a minimum of around 1% and nitrogen content should be just over 0.1%. When the cation exchange capacity of the soil is below ten, the minimum values of available P_2O_5 and K_2O are 5 ppm and 50 ppm, respectively. Conversely, the optimal pH is between 7 and 8.

The olive manages to absorb the limited amounts of phosphorus it needs even from soils with a low content, whereas the potassium and nitrogen available in the soil have a direct impact on the concentrations of these elements in the shoots, leaves and fruits.

Before preparing the orchard site, it is therefore wise to assess the soil profile and to analyze the soil layer of the rooting zone. To make sure the soil sample is representative of the plot it should be taken from at least five, uniformly distributed spots. Take the samples up to a depth of 50 cm, discarding the sod layer, and then mix them together. Separate 1-2 kg of soil, place it in a plastic bag and send it to the laboratory for physico-chemical testing.

TABLE 1
Characteristics of good olive-growing soil

Texture	Sand Silt Clay	20-75% 5-35% 5-35%
Structure	Crumbly	
Water holding capacity	30-60% (Lambe)	
Permeability	10-100 mm/h	
pH	7-8	
Organic matter	>1%	
Nitrogen	>0.10%	
Available phosphorus (P_2O_5)	5-35 ppm	
Exchangeable potassium (K_2O)	50-150 ppm	
Exchangeable calcium ($CaCO_3$)	1,650-5,000 ppm	
Exchangeable magnesium	10-200 ppm	

The soil should not contain causative agents of disease which could infect the new orchards. Above all, attacks from verticillium wilt (*Verticillium dahliae* Kleb) should be prevented by using healthy plant material, by avoiding establishing the orchard on soils where horticultural crops like tomato, potato, sweet pepper and melon have been grown previously, and by applying effective pest and disease control.

Although the olive can live in a whole spectrum of conditions, it is advisable to choose orchard sites where the constraints are limited and where olive growing can be competitive in terms of crop production and management.

Lastly, olive-growing areas should be backed by efficient technical and business advisory networks to help the product successfully through the post-harvest stages.

1.6. SELECTING TREE SPACING AND ORCHARD DESIGN

The ultimate size and growth rate of the trees are determinants of planting density. Tree spacing should allow the trees, when fully developed, to intercept the largest possible amount of radiant energy without shading adjacent trees (Fig.15). On the other hand, if the rate of growth is slow and it takes the trees a long time to reach full development, the orchard may not capitalize on sunlight in the early periods of growth.

Figure 15. Rationally spaced olive trees with open, well lit canopies and enough room between adjacent rows.

In the majority of cases ultimate tree spacing ranges from 5 m x 5 m to 6 m x 6 m and 7 m x 7 m. In areas where the climate is particularly favourable, bigger distances are required because tree development is greater than normal.

Depending on their rate of development, olive trees only achieve good light interception at around their 10th-15th year. Until then, crop yields are smaller than the potential of the space allotted to the orchard.

To use sunlight more efficiently during the initial stages of development, experiments have been conducted to increase orchard density by planting 'filler' trees, which are later removed when competition starts to appear.

Orchard density trials conducted around 1970 reported considerable yields as of the 5th year on average and tree-to-tree competition after 3 or 4 years in the case of densely planted trees. In Spain, the largest cumulative crops were obtained after 10-12 years at densities of around 320 trees per hectare planted on a square design. In irrigated orchards, densities of 200-240 trees per hectare have been more reliable for mid-term performance. In trials conducted in Greece Psyllakis did not record any statistically significant difference between densities ranging from 280 to 620 trees per hectare after eight harvests. Hence, lower densities are considered more viable because yields can rise in the medium term, unlike what occurs at higher densities.

Other trials run in France compared orchards planted on a square 6 m x 6 m design with trees planted on a rectangular 6 m x 3 m layout. The results showed that although crop production was greater in the higher density orchard in the first years, after ten years only small differences were noted which did not justify the temporary, higher densities.

The results of trials conducted in central Italy on orchards planted on a rectangular 6 m x 3 m layout reported cumulative yields of 30-40 kg per tree for the first five harvests, before the negative effects of competition started to make themselves felt. Net of harvesting costs, the returns they generated were either lower than for the 6 m x 6 m layout or almost equalled the expenditure on the orchard and on growing the 'filler' trees.

The trials conducted in Mediterranean countries on tree spacing and orchard design have demonstrated that high-density rectangular patterns lead very quickly to the formation of a continuous hedgerow along the rows. This lowers productive capacity, causes crop health problems and leads to an imbalance between vegetative and reproductive activity which is not easily controlled through pruning, leaving no option but to remove the superfluous trees.

The results of the planting density trials therefore confirm the effects of light intensity on the reproductive activity of olive and the relationship between light interception and productivity (Fig. 16).

It is also clear that the short time between the start of bearing and the appearance of competition phenomena curbs the use of higher filler densities, especially in 6 m x 3 m rectangular designs where the trees compete for light along the rows while in between the rows the radiant energy hits the ground and is largely lost. Consequently, spacings ranging from 5 m x 5 m to 7 m x 7 m allow the trees to perform to full satisfaction. The design of each orchard will depend on tree development, which is determined by varietal vigour, soil fertility, water availability and cultural practices. Planting distances of 6 m x 6 m and 7 m x 7 m are a sound yardstick for many Mediterranean olive-growing conditions.

Figure 16. Trees that are too tightly spaced become inefficient because of overshading.

When the trees are to be machine harvested by shakers equipped with catching frames, slightly wider planting distances are needed.

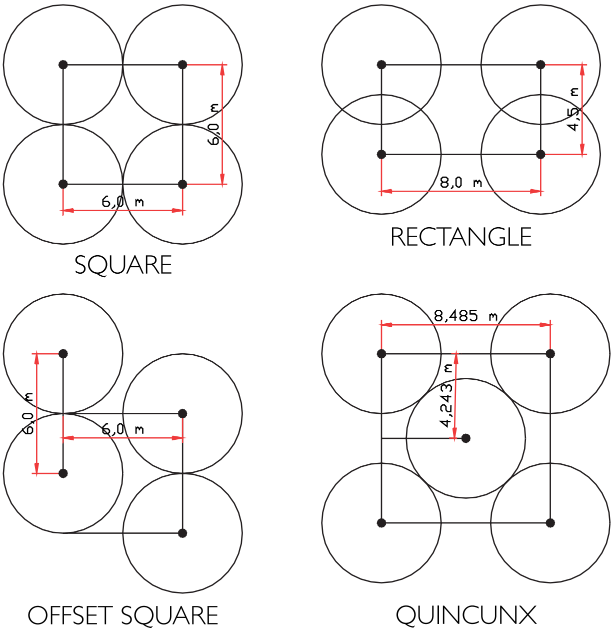


Figure 17. Trees planted on a square, rectangular, offset square and quincunx design at a density of 278 trees per hectare in all four cases.

There are several orchard designs for olive: square, offset square, rectangle and quincunx. Figure 17 shows how the designs are spaced in each case; the circle around each tree is the space for each canopy. When planted at the same density of 278 trees per hectare, the square design allows the trees the same amount of space in both directions and cultural practices are easily carried out lengthwise and crosswise. In the offset square design the trees are better exposed to light. Machinery can move easily in one direction, and slightly less easily on the oblique. In the rectangular design the canopies may be shaded along the row with the shortest spacing distances while they are well exposed to light on the inside of the rows; the greater the difference between the two distances, the lower the efficiency of canopy light exposure. Increasing one of the distances will facilitate the use of machinery along that direction.

The quincunx design is quite complicated, the canopies are better exposed to the light than in the square design while machinery finds it less easy to manoeuvre. The square and the offset square are therefore the most efficient designs and the ones used most widely. The rectangle is only used when required for mechanization purposes and when the canopy volumes are not at a maximum owing to environmental stress.

1.6. 1. Superintensive orchards

High density cropping systems have been proposed in recent years using high yielding varieties like 'Arbosana', 'Arbequina' and 'Koroneiki', which exhibit limited development. Spacings of 4 m x 1.5 m are recommended along the rows. The trees ready for planting out are small in size, about 18 months old, 40-50 cm tall and they have a good root system. They have to be managed carefully to keep them to the right size for over-the-row harvesting and to ensure a balance between vegetative and reproductive activity. Close attention also has to be paid to controlling pests and diseases, which are more virulent and cause more damage in such conditions.

1.7. CHOOSING THE VARIETIES

The established varieties in each growing area have been chosen from the plant stock available. Few have spread outside their area of distribution. It is only recently that the best varieties grown in countries with a long tradition of olive cultivation have been introduced in new orchards in North, Central and South America, South Africa and Australia. As product quality, mechanization and resistance to pests and diseases become prime concerns, varietal choice is gaining in importance. Nowadays, the characteristics of the main varieties cultivated in the world are better known thanks to the collections set up in recent years. The list below has been drawn up from the information available and categorizes the varieties according to the most important requisites for developing olive growing.

- Early start of bearing and crop volume: 'Koroneiki', 'Arbequina', 'Maurino', 'Picual', 'Manzanilla'
- Oil quality: 'Frantoio' 'Arbequina', 'Moraiolo', 'Picual'
- Cold resistance: 'Nostrale di Rigali', 'Leccino', 'Orbetana', 'Dolce Agogia'
- Lime tolerance: 'Picudo', 'Cobrançosa', 'Galego', 'Lechín de Sevilla', 'Lechín de Granada', 'Hojiblanca'
- Salinity tolerance: 'Picual', 'Arbequina', 'Lechín de Sevilla', 'Canivano', 'Nevadillo'
- Tolerance of *Spilocaea oleagina*: 'Lechín de Sevilla', 'Leccino', 'Maurino', 'Ascolana tenera'
- Tolerance of *Verticillium dahliae*: 'Frantoio', 'Arbequina', 'Cipressino'
- Tolerance of *Bacterium savastanoi*: 'Leccino', 'Dolce Agogia', 'Orbetana', 'Gentile di Chieti', 'Cordovil de Serpa', 'Galega vulgar', 'Picholine marocaine', 'Gordal sevillana'

When choosing varieties it is advisable to take into account the experience in each olive-growing area because the established varieties are the ones that are best adapted to the area and which help to characterize oil quality. A mention should be given here to the varieties allowed under the regulations for the designations of origin in each area. However, as cost-effective management and extensive machinery use are the key objectives, all other things being equal, the preference will be for cultivars which are suited to machine harvest, which are resistant to pests and diseases and which give large, quality crops (Table 2).

TABLE 2
Olive variety productivity and adaptability to machine harvest (three-year averages)

Cultivar	Crop production kg	Machine harvest yield %
Frantoio	11.28	87.00
Leccino	12.91	85.90
Maurino	14.08	89.91

At present, the varieties found most widely in Italy and the other major producing areas give good quality oil, but they perform less well as regards yields and resistance to pests and diseases. Research needs to continue to overcome or attenuate drawbacks, with the emphasis on adapting cultivars to the mechanization of cultural practices. The large body of existing genetic material needs to be tapped for specific traits such as strong resistance to pests and diseases, high yields, product quality, adaptability to machine harvest and large fruits. In the medium term, crossbreeding of the best varieties will lead to the selection of new varieties. Lengthy performance trials need to be run for this purpose on the best cultivars available to demonstrate they are superior, at least as regards some important traits.

1.7.1. Flowering and pollinizers

Flowering and pollination are particularly critical stages in the crop production process. An abundance of flowers is the cornerstone of a good harvest. The presence of flowers in June depends on bud development, which begins on growing shoots in April-May of the year before. Flower differentiation takes place later. This important process is complex and begins with flower bud induction, i.e. the creation of the physiological conditions such as nutrient and hormone availability for the bud tips to form the inflorescence axis and flowers. Flower formation and organ development occur from March until May-June, when bloom takes place. The fruit is formed by fertilization of the egg cell in the flower pistil. Fertilization happens when the pollen lands on the pistil; it then germinates and the pollen tube penetrates through to the ovule in the ovary. Very few cultivars are capable of giving satisfactory harvests by pollinating themselves; instead, they need the pollen of compatible cultivars for successful fertilization of the egg cells and fruit development. Consequently, pollinizer varieties accounting for 10-15% of the trees in the orchard need to be placed alongside the main variety grown. The most effective pollinizers have to be used for each cultivar (Figs. 18 and 19). For instance, pollinizers are used for the most widespread varieties grown in Spain; some of the combinations recommended are: 'Manzanilla de Sevilla'-'Gordal sevillana'; 'Hojiblanca'-'Picual'; 'Picual'-'Arbequina'. To overcome precarious weather conditions and possible alternate bearing in the pollinizers, it is advisable to grow several interfertile pollinizer varieties of commercial interest. They should be placed in blocks of 3-4 rows each to ensure good pollen dissemination and to facilitate the pest control and harvesting techniques specific to each variety.

Pollinizer / **Chief variety**	Carolea	D. Agogia	Frantoio	Leccino	Maurino	Moraiolo	N. di Rigali	Kalamon	Orbetana
Carolea			*	*		*			*
D. Agogia						*			
Frantoio	*			*		*		*	
Leccino	*	*			*				
Maurino			*			*			*
Moraiolo					*			*	
N. di Rigali				*					*
Kalamon				*		*			
Orbetana	*							*	

Figure. 18. Effective pollinizers of the chief oil-olive cultivars.

Chief variety	Ascolana tenera	Grossa di Spagna	Nocellara Etnea	S. Caterina	S. Agostino	Itrana
Ascolana tenera				*		*
Grossa di Spagna						*
Nocellara Etnea	*			*		*
S. Caterina	*	*			*	
S. Agostino			*			*
Strana					*	

Figure 19. Effective pollinizers of the chief table olive varieties.

1.7.2. Fruit ripening and optimal harvest timing

When choosing varieties for the orchard it is wise to know their optimal harvest period, i.e. when the olive fruits picked from the tree contain the maximum amount of top quality oil. This is judged by several indices such as fruit weight gain, change in oil content and fruit drop, plus polyphenol content and organoleptic appraisal for extra virgin olive oil. A further factor in varietal choice is the possibility of phased harvesting, compatible with the characteristics of the cultivar, in order to employ staff and machinery regularly over a long period.

1.8. PLANTING TECHNIQUES

This is when the earlier choices are put into practice. It involves the preliminary jobs of site preparation, deep tillage and planting and the subsequent steps to create a fertile environment and to allow the new orchard to settle and start to develop.

1.8.1. Preliminaries

The first step is to remove debris of previous crops, including the root system of any trees, shrubs or hedges on the site. The site should then be levelled to make the land flat or evenly sloping; this is done in large plots of more than one hectare to reduce idle time during cultural operations (Fig. 20). If ground preparation requires moving more than the active soil layer, the surface soil layer should first be piled up on one side, the ground should then be levelled and lastly the fertile soil should be spread on top of the areas where the earth has been moved. Although costly, this allows the orchard to develop uniformly. Scrapers and high-power tractor loaders are used for this kind of earthmoving.

Figure 20. Levelling the site.

Figure 21. Drainage ditches.

Another important aspect of site preparation has to do with surface and subsurface water drainage. Olive is very sensitive to waterlogging and to the virulent fungal attacks that go with it and which cause root rot. If the ground is flooded by water running down from land higher up, a sufficiently deep channel should be dug around the orchard to remove the water before it floods the land below. Ditches should be dug every 20-30 metres across the orchard to prevent surface soil erosion and the formation of deep crevices along the lines of maximum slope; these should run into closed side channels, which take the water downstream. Waterlogging and landslips occur frequently in clay soils without natural drainage, as well as in soils with an impervious or hardpan layer and in holes where water tends to collect naturally. Owing to poor surface water drainage such areas remain wet for long periods of time and the profile has grey and bluish layers indicative of oxygen shortage. This is detrimental to the activity of the root system and should be remedied by installing perforated PVC drainage pipes clad with coconut fibre or laid on brick or stone fill bedding. They should be laid in ditches about 1.5m deep, spaced at intervals of 20-40 m, at a slope of more than 2 per thousand (Figs. 21, 22 and 23).

Figure 22. Perforated PVC piping clad with natural or artificial fibres.

Figure 23. Digging and laying drainage pipes.

1.8.2. Deep tillage

Deep tillage is crucial to make sure the rooting zone is fertile. It is particularly necessary in compacted soils where empty spaces between the deep soil particles become more and more impoverished. These conditions oblige the roots to spread to the surface, which heavily limits the water and nutrients available. Deep tillage is therefore required when impervious or hardpan layers prevent the roots from exploring deeper and when it is advisable to homogenize the texture and chemical composition of the soil. Soil tillage improves aeration and particle structure, so increas-

Figure 24. Deep tillage with a plough.

ing the nutrients available to the plant. It is less important in sandy soils which are naturally very porous; in such cases the ground can be ploughed to a lower depth. However, deep tillage is recommended in the kind of soils best suited to olive growing and found most extensively. It is usually done to a depth of 80-100 cm, using large ploughs pulled by high powered, caterpillar track-type tractors (Fig. 24). When done from higher to lower ground it also creates a helpful subsurface channel for disposing of infiltration water. Summer is the best time to deep till, although it can be done at other times of year provided the soil tilth is right. If deep tillage is not wanted because of the fear of landslips or to avoid bringing deep, unfertile or stony layers to the top, the ground can be cross ripped at a distance of 40-50 cm and then worked on the surface as usual (Fig. 25). If manuring is envisaged the manure should be ploughed in before deep tillage to avoid reducing tractor grip on the ground. Any clods left after deep tillage should be broken up by the elements, aided by harrowing to intermediate depth. If deep tillage brings stones to the top, they should be removed or crushed.

Figure 25. Ripping.

1.8.3. Weed control

If weeds have not been controlled through deep tillage and soil preparation, they should be removed by applying herbicides. The most worrisome species are bermuda grass (*Cynodon dactylon*) and creeping thistle (*Cyrsium arvense*). These are particularly pernicious for young olive trees when they infest the planting holes because they compete for water and nutrients. They can also cause allelopathy through their root excretions which are damaging to the olive roots. They are easily controlled with glyphosate, which is actively absorbed and translocated when the weeds are at the start of flowering and not subject to water stress. Micro-applications of a mix of glyphosate and MCPA (40% potassium salt) plus mineral oil can be applied to protect the olive orchard from tree weeds like *Asparagus, Rubus* and *Crategus*.

1.8.4. Planting out

Before planting the olives the orchard is marked out to identify the planting positions according to the chosen spacing and layout. If a rectangular layout is chosen the longer spacing is related to the working direction of the machinery, which prefers following the slope of the land.

After positioning two stakes to be able to find the exact position for planting the olive trunk (Fig. 26), the next step is to dig the planting hole 40 cm wide and deep with a planter or spade (Fig. 27).

The planting holes should be dug when the ground is dry, especially when the soil is clay-rich, because when it is very wet the action of the planter causes glazing on the sides of the hole. This limits root growth and can cause asphyxia of the root system owing to water collecting in the planting hole. It is a

Figure 26. Planting position.

good idea for the holes to be dug in advance of planting to allow atmospheric agents to improve particle aggregation by making the soil crumbly.

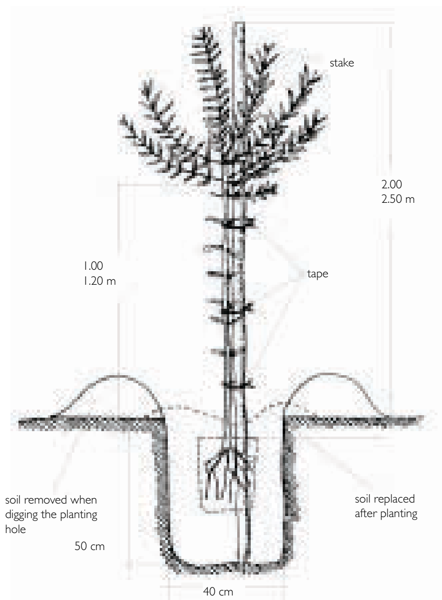


Figure 27. Planting diagram.

A stake, usually made of chestnut wood, about 6 cm in diameter and at least 2 metres high is then placed in the bottom of the planting hole; at least 1.5 m of the stake should be above ground. Another option is to use ¾" iron piping, 27 mm in diameter. If the stakes will have to hold hanging irrigation lines, they should be about 0.5 m higher. Next, the plant is removed from its container and planted 'balled' 5-10 cm below ground level, especially if self-rooted plants are being used to stimulate deep growth of the root system. The trees for planting are 18-24 month old plants raised in 3-litre containers at least. They should be 1.5-1.8 m high, the canopy and trunk should be well developed, without vigorous branching, and they should have leaves (Fig. 28).

Figure 28. Olives usually used for planting out.

The planting hole is filled with well structured soil and tamped firmly, while leaving a small hollow in the middle. The tree is tied loosely to the stake with plastic tape and it is watered with

Figure 29. Fastening the plant to the stake.

approximately ten litres of water to make the soil stick to the roots (Figs. 29 and 30).

In Central Italy, where the winters are cold, spring is the time to plant. In areas where there is no danger of cold winter periods it is a good idea to plant in the autumn. Container-grown trees can be planted at any time provided water is available. The irrigation can be set up at the same time as planting out. The dripper lines are hung from metal lines anchored to trellis

Figure 30. Watering after planting.

posts and tied to the stakes at a height of around 1.9 m from the ground to allow cross tillage, or else the lines are buried in the ground and a feeder line emerges near each tree to which the drippers are fitted. In areas where there are rodents (wild rabbits) it is a good idea to protect the trees with cheap, easy-to-fit metal guards or guards made of other impermeable materials permitting the use of herbicides for weed control near the plant and along the row.

1.8.4.1. Planting out superintensive orchards

Varieties whose development is limited should be used, such as 'Arbosana', 'Arbequina' or 'Koroneiki'. Spacing of 4 m x 1.5. m along the row is recommended. The plants should be small, 18 months old, 40-50 cm high, with a good root system. They are planted in smaller holes or using tree planters which dig a furrow at the bottom of which the plants are placed and covered with the soil moved by opposite mouldboards. They need a light bamboo cane or iron stake 6-8 mm wide and 1.8 m above ground. The wall of trees is held up by wooden stakes positioned at a distance of around 30 m and by two trellis posts, which are connected by three horizontal wires positioned at a height of 0.40, 0.80 and 1.20 m (Fig. 31).

1.8.5. Subsequent operations

Plastic sheeting (about 1 m wide) can be positioned around the trees for weed control and to ensure better moisture and temperature conditions close to the root system (Fig. 32). Mulching al-

Figure 31. Superintensive orchard with over-the-row harvester.

lows better development and easier orchard management. It is important to avoid any stress after planting out; this means ensuring a constant supply of water by irrigating when natural resources are low. This is fundamental, especially in the first two years, in order for the olive to send out roots in the deep-tilled layers of soil, which are better supplied with water. In the first two years of development, each plant needs 2-3 litres of water per day to keep growing actively. When rainfall is lacking, weekly supplemental irrigation should be envisaged during the dry months.

Figure 32. Plastic mulch around tree trunks.

From the first year, the plants need to be applied small amounts of fertilizer, especially nitrogen, every month from March to August, preferably with water. The annual amount applied should be 30 g of nitrogen per plant, which works out at 65 g of urea.

The canopy should be well developed or at the training stage (Fig. 33). At planting, pruning can be skipped or practised very lightly to remove any strong shoots along the trunk. During the first year of planting out, shoots emerging directly from

Figure 33. Ideal, well developed tree for planting out.

Figure 34. Checking fastenings.

the trunk should be removed as they form while they are still herbaceous, or as soon as possible. Besides inspecting for shoot growth along the trunk, the stake fastenings should be checked at two-monthly intervals and extra ones added to keep the tree upright at all times (Fig. 34). The low shoots growing under the crotch which were left to encourage width-wise development of the trunk but which have become vigorous and vertical should also be removed gradually. No cuts or topping is done to the canopy, which is left to develop to its natural spherical shape (Fig. 35). Some of the more vigorous shoots are later identified as the future scaffold branches. Check the fastenings do not wound or constrict the tree; if they do, retie them and position the tree properly alongside the stake. Close attention should be paid to pest and disease control by implementing a treatment calendar during tree training to avoid growth-reducing damage. Particularly formidable damage is caused by the olive moth (*Prays*), jasmine moth (*Margaronia*) and mites, which dry the tips. This forces the tree to develop axillary buds for shoot elongation, which causes a 10-15 day halt in growth. Products based on carbaryl, dimethoate and *Bacillus Thuringiensis* are recommended.

Figure 35. Checking shoot development along the trunk.

1.9. REPLANTING POOR-YIELDING OLIVE ORCHARDS

When olive trees become obsolete they are inefficient and do not respond to cultural care; as a result, they give small crops. As time goes by it is no longer worthwhile cropping the orchards and they end up being abandoned. At the first signs of decline in areas suited to olive growing the orchards should be replanted to regain full orchard responsiveness to cultural practices and, in commercial and productive terms, to grow more and better crops.

In these cases action involves pulling out the old trees with scrapers, trying to move the tree base and old roots and uncovering the parts infested with pests and disease (Fig. 36). Soil fatigue is not a particular concern because the olive tolerates the presence of toxins left by preceding crops.

Figure 36. Trees that are no longer efficient are knocked down.

The wood removed is used for carpentry or fuel. Next, the ground has to be levelled to even out ridges and hollows to facilitate the mechanization of cultural practices and, where possible, to mark out rows that are sufficiently long. Areas subject to frequent waterlogging should be drained.

Soil fertility should be improved until the organic matter content is at least 1-1.5%, available phosphrous pentoxide is 5 ppm and potassium oxide is 100 ppm. This is achieved by applying slurry, perphosphate and potassium sulphate prior to deep tillage or, if a ripper is used, prior to slip ploughing the soil.

The steps for planting new orchards are then implemented.

1.10. SUMMARY AND RECOMMENDATIONS

New orchards are most instrumental in raising production, facilitating mechanization and expanding olive growing. When establishing them:

- Create optimal conditions for developing the root system, making the canopy functional, achieving heavy fruiting and obtaining product quality.
- Make sure they are adapted to full harvest mechanization.
- Choose the right areas in terms of climate, soil and technical and commercial facilities.
- Choose tree spacing adapted to the requirements of the species and cultivar and suited to efficient mechanization.
- Choose high-yielding cultivars which bear quality product, are resistant to pests and diseases and adapted to mechanization.
- Place a large number of pollinizers.
- Plan designs and use cultivars which allow phased harvesting at the optimal time.
- Level the ground to facilitate mechanization.

– Deep till with a plough or ripper and then plough normally.
– Make sure water drainage is correct and if waterlogging persists, drain.
– Plant well-developed, container-grown plants and fasten them to a sturdy stake.
– Water after planting and monitor the trees carefully, especially for the next two years when growth is at a maximum, to avoid water stress and nutritional deficiencies and to ensure rational crop health protection.

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2

Olive pruning and training

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2.1. INTRODUCTION

Pruning is practised in all the olive-growing countries and is considered essential to orchard management. It takes different forms depending on orchard characteristics, environmental conditions and long-standing traditions. It also has to adapt to the changing trends in each country, notably in terms of the establishment of new orchards, the increase in the number of trees per hectare, the expansion of irrigation, the preference for certain types of training, the adaptation of orchards to mechanization and orchard rejuvenation. Consequently, if the right pruning choices are to be made to achieve the best results, it is necessary to understand the purposes of pruning, particularly in raising crop production, facilitating some stages of fruiting, mechanizing cultural practices and lowering the costs of production.

2.2. EFFECTS OF PRUNING

Figure 1. Tree left unpruned for several years.

Olive trees are pruned in order to enhance productivity and to ensure early, regular, profitable fruiting.

If not pruned, the olive tree grows large and bushy. If it is abandoned after being trained to a single trunk, it becomes dome-shaped: the foliage is concentrated in the upper, outer part of the canopy and the inner branches lose their leaves and are gradually replaced by other outside branches that have better access to light (Fig. 1). Development places priority on the structural organs, but reduces fruiting and makes the trees ill suited to cultural practices.

Pruning entails removing part of the tree, generally a portion of the canopy consisting of branches, shoots and leaves no longer considered to be of use for the correct management of the tree.

It aims to prevent any part of the tree from dominating over the others and to optimize the contribution that each part makes to crop production and to the application of cultural techniques.

2.2.1. Pruning and leaf exposure to light

Pruning should help to establish optimal conditions for the synthesis of the products necessary for crop production, which depend on the leaf area, light exposure, temperature and the availability of water and nutrients.

Leaves synthesize the assimilates which provide food for all the plant functions. Points to bear in mind are that:

- there should be enough leaves to ensure an adequate leaf area, which is achieved through shoot development;
- they reach full efficiency early when the lamina accounts for more than 50% of the final area and they are active as long as they remain on the tree;
- activity is heavily influenced by access to light in that leaves are very efficient in direct sunlight but barely self-sufficient in inner, heavily shaded areas of the canopy;
- they function at an optimal temperature of 15-30 °C;
- they decrease assimilation when soil moisture levels are below 50% of available water;
- enhanced photosynthesis is stimulated by pruning and by actively growing fruit and shoots.

Pruning reduces leaf area, but this recovers during the period of vegetative growth. Leaves adapt to the light conditions in which they grow or which result after pruning; in the meantime canopy light penetration improves, allowing more light to reach leaves and fruit.

Pruning can heighten photosynthesis by increasing individual leaf area, mesophyll thickness and chlorophyll and by enhancing daily activity because available water is used more economically.

More active growth leads to increased demand for assimilates, which could stimulate photosynthesis.

Consequently, besides ensuring soil fertility and moisture availability, it is essential to make sure that the leaves are rationally spaced in order for the largest possible leaf area to be exposed to light. Pruning and training do so, in the first case by achieving the right canopy density to ensure sufficient light penetration, including to leaves located in less favourable positions, and in the second case by spatially positioning the shoots and leaves on a framework that is as small as possible.

2.2.2. Pruning, shoot growth and build-up of nutritional reserves

By removing part of the canopy, pruning reduces the number of buds, which produce more vigorous shoots because they take up more hormones, nutrients and water from the root system.

The heavy formation of new shoots depletes reserves, particularly of the carbohydrates stored in the structural parts of the tree. Pruned trees start to build up starch later than non-pruned trees, but by the end of the summer both have the same level of nutrients.

Combined with pruning, nitrogen and water regulation can encourage this process. After pruning, the tree displays less overall growth but instead of being spread amongst old branches and exhausted shoots, growth is concentrated on a smaller number of more vigorous shoots. Consequently, when pruning is carried out during the juvenile stage, characterized by great vigour, it subsequently accentuates shoot vigour and delays fruiting. Conversely, when practised during the mature stage, it can improve fruiting by invigorating weak shoots.

Thus, heavy pruning of the whole canopy causes vigorous shoots to develop whereas light pruning leads to the development of potentially weak shoots.

When a branch on a lightly pruned tree is pruned heavily it may subsequently become weaker, thus helping to strike a balance with the other parts of the canopy.

2.2.3. Pruning and fruiting

Pruning lowers the crop production of young trees because it stimulates their already marked vegetative growth even further. Conversely, it enhances shoot vigour, encourages flower formation and increases fruit set and fruit development in mature trees, which are characterized by weak development.

Vegetative shoots, mixed shoots and fruiting shoots have to develop in a balanced manner on the tree to ensure stable fruiting. However, depending on how many there are, the fruits are a strong attractant of nutrients, thus reducing shoot growth, flower bud differentiation and tree reserves.

When affected by the presence of the fruits, shoot growth first competes actively with root growth and the build-up of reserves and lastly with flower bud differentiation.

Flower buds form when the tree has enough nutrients and when there is no competition with fruits, shoots and roots. They are positioned on shoots that are well lit and of average size, which means they are neither too weak nor too vigorous.

A shortage of nutrients and the presence of over-vigorous shoots that grow for a long period of the year impede flower bud differentiation because the constantly active shoot tips monopolize the synthesized nutrients.

Moderate vegetative activity should therefore be encouraged during spring growth and then attenuated to make way for the build-up of reserves, fruit growth and flower bud differentiation. The aim should be to strike an optimal balance between vegetative and reproductive activity. Pruning of medium intensity stimulates moderate shoot growth, which comes to a halt with time, thus allowing the tree to build up carbohydrates, to supply the fruits with nutrients and to differentiate the flower buds.

The ratio between the canopy and the roots should be kept constant to avoid immobilizing supplementary resources when one or the other grows larger. Canopy development is reduced by periods of water shortage, which instead stimulates the growth of the root system to make it spread to new, deeper soil zones to guarantee sufficient moisture supply. Such changes in the ratio, prompted by a temporary shortage of water, immobilize assimilates in the roots to the detriment of fruiting. As a result, even when shading occurs and few assimilates are available, the formation of new shoots and leaves is stimulated on the outer shell of the canopy, so increasing the share of nutrients used up by vegetative organs.

2.3. PRUNING OBJECTIVES AND ORCHARD CHARACTERISTICS

Olive orchards that are efficient and competitive in terms of management costs should be the reference marker for pruning. It is therefore a good idea to have a reference standard for each environment. One standard that is considered widely applicable takes into account the requirements of trunk shaker harvesters. For shakers to operate well, canopy volume must not be more than 50 m^3 and the minimum planting layout must be 6 m x 6 m. The trees must intercept the maximum amount of radiant energy, which is achieved when the canopies are sufficiently elongated and not too high in order to reduce the structural parts of the canopy and to facilitate cultural practices and pruning, harvesting and crop health care operations. Leaf density should be close to 2 m^2/m^3 canopy and the leaf area index (LAI) should be 5-6. Hectare volumes are then correlated with area rainfall and vary from 2,000 to 3,000 m^3 at a rainfall of 250 mm, from 9,000 to 10,000 m^3/ha at a rainfall of 600 mm and from 11,000 to 12,000 m^3/ha at a rainfall of 850 mm. Values of up to 13,000-15,000 m^3/ha can be reached on irrigated orchards. These are tentative guidelines, which have to be adjusted to working conditions. It is important for each canopy to expand according to its vigour, which is determined by genetic traits, climate and soil. The task of pruning is to select the most efficient shoots and to preserve the shape without greatly altering the vegetative-productive balance of the tree.

The canopy should expand to take up approximately 50% of the orchard floor area allocated for the tree (50% of 6 m x 6 m = 18 m^2). A canopy height of 3-4 m facilitates pruning, harvesting and crop health care. In these conditions the lower parts of the canopy will also receive sufficient light, over 10-15% of that on the top of the canopy. This guarantees they are functional and ensures moderate development of the fruit growing in this area, which also makes use of the light received by the portions of the canopy through the day owing to the regularly distributed vegetation. Canopies can be slightly higher on irrigated orchards with a greater overall volume, but without causing any significant change in the functionality of the canopy or in its suitability for mechanical harvesting.

2.4. PRUNING, RESISTANCE TO COLD AND TREE HEALTH

Pruning makes trees more sensitive to cold because:

1) it prolongs growth and reduces tissue maturity;
2) it reduces the leaf area and the quantity of reserves;
3) it interrupts dormancy;
4) it facilitates the formation of ice in the cells close to wounds caused by cuts made prior to low temperatures.

Pruning cuts increase the possibility of fungal and bacterial infections but facilitate pest and disease control by opening the canopy and improving access for crop health treatment.

2.5. VEGETATIVE PARTS OF TREE

The following vegetative parts are found on olive trees:

– *Suckers* are vigorous shoots which grow at the base of the tree, especially when the trunk or canopy has growth problems (Fig. 2).
– *Watersprouts* are vigorous shoots that grow from adventitious buds positioned at the base of weak limbs and are of little use to the general economy of the tree (Fig. 3).
– *Lateral shoots* are erect and vigorous and have vegetative feathers (Fig. 4).

Figure 2. Suckers grow at the base of the trunk and are not usually useful.

Figure 3. Watersprouts develop from adventitious buds inside the canopy.

Figure 5. Medium vigoured fruiting shoots.

Figure 4. Vigorous shoot with feathers, useful for future fruiting.

– *Pendulous or drooping shoots* are of medium vigour; they produce flowers and send out shoots at their point of curvature and terminal sections (Fig. 5).
– *Primary, secondary* and *tertiary branches* and *the trunk* form the framework of the canopy.

2.6. PRUNING OPERATIONS

2.6.1. Branch thinning and heading

Thinning entails removing entire branches that are exhausted or that hinder light penetration to nearby areas. Heading is a fundamental practice in pruning for fruit production where the terminal section of the branch weakened by fruiting is cut back to just above a vigorous shoot, which with time will replace the old branch (Fig. 6). Pruning implements should be kept sharp and the cuts should be made at a slight slant to encourage water drainage and healing. If very large cuts are made it may be advisable to coat the surface with pruning dressings.

2.6.2. Shoot thinning and heading

One-year-old shoots can be cut at their point of origin or they can be pinched. The first operation is done to thin overcrowded canopies and to thin the tops of the branches in order to debilitate them and give the underlying shoots a chance to grow and cover the branch uniformly. Pinching is done to stimulate the growth of the shoots that form from distal buds on the cut shoot. The central axis is pinched when the aim is to simulate the formation of lateral or main branches.

Figure 6. Tertiary branch whose terminal section has fruited and which is undergoing renewal by cutting just after a medium-vigour shoot.

After fruiting, shoots of medium vigour tend to bend and, as a result, new shoots form at the point of curvature. Pruning aims to remove the middle-terminal section of the shoot that has fruited, replacing it by one or two of those which grow from the base. Fruiting shoots also tend to develop new shoots from the apical bud. Pruning to select this apical bud causes excessive elongation of the fruiting shoots and increases the structural portions of the tree. The fruiting areas at the end of bare shoots lose vigour and quickly become exhausted. However, fairly severe pruning makes the olive send out new shoots and those lying closest to the scaffold branches are used as replacements for the exhausted branches.

2.6.3. Bending

This entails bending the shoots or branches to alter the angle of the axis with respect to vertical. It heightens the basitonic tendency of the olive, causing vigorous shoots to develop at the base of the shoot or branch and stimulating the weakened tip to fruit (Figs. 7 and 8).

2.6.4. Girdling

This involves removing a ring of bark 1-cm wide when the sap is on the flow. It is designed to prevent the substances elaborated by the portion of girdled branch from being used by other parts

Figure 7. Shoot bent to stimulate fruiting.

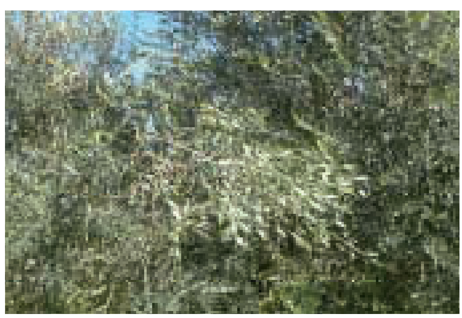

Figure 8. Watersprout bent to stimulate fruiting.

of the tree. It encourages bud differentiation (if done for some time), fruit set and fruit development; however, it halts vegetative growth, which means that the girdled portions become exhausted, and nutrients are limited in the rest of the tree (Fig. 9)

Figure 9. Girdled watersprout.

2.6.5. Shoot tipping

This entails removing the tip of the shoots. If done when the shoots are developing, it causes a temporary halt to growth and the subsequent formation of feathers. Conversely, if done towards the end of growth it blocks shoot elongation without causing the emission of new vegetative shoots. It allows the shoot to use the substances it has formed for tissue formation and flower organ differentiation. The central axis of the tree can be tipped to encourage the formation of lateral branches to build the tree framework. Tipping replaces one vigorous shoot by several medium-vigour shoots that respond better to fruiting.

2.6.6. Topping

This involves cutting one or all of the scaffold branches to their point of insertion, or to 40-50 cm from that point (Fig. 10). It is used in rejuvenation work to replace ailing canopies or canopies damaged by the weather or pests and diseases.

Figure 10. Branch cut flush.

2.6.7. Coppicing

This is the removal of the aerial part of the tree by cutting back to varying trunk heights or to ground level. This approach is used on olives that have been badly damaged by frost or fire or which are ailing due to pests or disease. In some cases trees are coppiced to lower the canopy or to facilitate cultural operations.

2.6.8. Removal of decayed wood

This entails cutting out decayed wood from the branches, trunk or stump. The operation is complete when healthy wood is reached (Fig. 11).

Figure 11. Removal of decayed wood from a tree trunk.

2.6.9. Size of most efficient shoots

On mature trees, medium-sized shoots about 25 cm long are the most productive because they have high flowering and fruit set. Shoots that are around 40 cm long flower less, although fruit set is the same or even slightly higher than on medium-sized shoots. On young trees, shoots measuring 15-50 cm are equally efficient. Longer shoots exhibit less flowering but fruit set is just as high.

2.7. SUMMARY OF THE EFFECTS AND MAIN OBJECTIVES OF PRUNING

To summarize, when pruned, the overall development of the tree decreases because it synthesizes fewer substances and it has to replace the removed limbs. When parts of the canopy are removed, the remaining parts benefit temporarily from a larger supply of reserves accumulated in the root system, as well as of water, minerals, and hormones produced by the roots. As a result, fewer shoots develop, but they are more vigorous.

Consequently, pruning during the juvenile stage accentuates vigour and delays fruiting. During the mature stage it can improve fruiting if it invigorates weak shoots, or it can have a depressant effect on fruiting if it overstimulates shoot vigour.

Pruning of overcrowded canopies improves light and air penetration and increases fruit size.

When single tree organs are pruned, pruning reduces their development but it also has an effect on the rest of the canopy by increasing the supply of substances supplied by the root system. For this reason, a pruned branch grows weaker while the other, non-pruned limbs become stronger.

This process of weakening or strengthening the vegetative organs should take into account the effects of other cultural techniques.

The chief objectives of pruning are to improve light penetration, to establish a balance between the branches and to obtain shoots of medium vigour that are constantly renewed to ensure abundant, regular crops.

2.8. TIMING OF PRUNING AND TYPES OF CUTS

Olive trees should be pruned preferably in winter, between harvesting and budding. Pruning should be later in areas where winter temperatures are low because it has a negative effect on cold resistance and low temperatures stop wounds from healing quickly.

Pruning after budding weakens the tree because the nutrient reserves accumulated in the roots and large limbs during the winter have already been mobilized in the parts intended for removal.

Sucker removal can be brought forward from winter to August. Eliminating watersprouts during summer may only prove worthwhile when the canopy is overcrowded and badly lit or to ease the consequences of scarce water availability.

Summer pruning is recommended for trees infected with olive knot because the cuts heal quickly and the conditions are not conducive to the spread of the bacteria that cause the disease.

The cuts made to the branches and shoots should not be too deep to avoid notching branches underneath. To facilitate healing, they should not leave stubs.

2.9. TRAINING

During training, the chief goal is to reach the definitive shape as quickly as possible in order to stimulate subsequent crop production.

For initial, rapid growth, container-grown nursery plants should be used that have grown to a good height and have little lateral branching. The soil should provide the young plants with the best possible conditions to grow when they are planted out and subsequently.

During this stage pruning should be kept to a minimum to maximize development. However, limited intervention is required to control lateral branching on the trunk; such branching is necessary to stimulate the width-wise expansion but it must be stopped from gaining the upper hand because it is encouraged by the basitonic nature of the olive. Almost all the shoots should be removed, leaving only a few weak, pendulous ones. When these start to grow vigorous, they should be cut straight away (Fig.13).

During the early years of development, canopy thinning should not be a great concern because the small size of the canopy does not raise problems of shading.

When training the tree and choosing the position of the crotch, points to remember are that the branches grow strong and sound when they are spaced 5-10 cm apart at their insertion point, when they are positioned at an angle of 30-40 ° from vertical and when they emerge from the trunk at least 100 cm above ground level to allow mechanical harvesting (Figs. 12 and

13). Their formation and development are encouraged by the basitony of the olive, which is more conducive to the growth of the side branches than of the top. Hence, during this phase, it is advisable to avoid reducing the leaf apparatus, or to limit intervention to tipping and thinning a few competing limbs to help the best positioned ones which have been selected to form the main branches.

Figure 12. Avoid choosing branches with the same insertion point because they tend to break.

In the second or third season it is wise to fasten a different part of the stem to the

Figure 13. In the first two years of planting out pruning is only needed to control the shoots along and at the base of the trunk.

stake to avoid injuring the bark and to ensure that the section in contact with the stake is not left without shoots.

While the branches are still supple they should be spread out by supporting them on three sticks positioned like a tripod or by encircling them with a hoop to push the branches outwards. A similar effect is obtained by using various types of spreaders (Figs. 14, 15 and 16). This process of opening out makes the inner and bottom shoots of the canopy assume the function of the main axis of the branches, while the other external shoots act like under-branches or temporary branches.

When the tree canopy has a long axis, branch formation is stimulated by bending the axis at the point where the crotch is desired. The branches should be angled differently according to their vigour.

If any gaps occur where there are no branches, they should be filled by new, vigorous shoots, which the trees will form from the numerous adventitious buds.

A year after spreading out the branches, the trees can be lightly pruned by removing inner shoots on the branches and by cutting crooked or overcrossing branches.

It is only in the fourth or fifth season that anomalies of shape can be corrected by removing supernumerary branches (Fig. 17).

Training builds a strong, functional framework. This is achieved by distributing the leaf apparatus to ensure that light can penetrate the largest possible area with the least possible branches and that machinery can perform all the cultural practices.

Figure 14. Branches are spread out with the support of a stand.

Figure 15. Branches spread out with spreaders.

Figure 16. Scaffold branches spread out with the aid of a hoop.

Figure 17. After four or five years, pruning is designed to single out the scaffold branches and remove the shoots that develop inside the canopy.

2.10. PRUNING FOR FRUIT PRODUCTION

When the trees have attained their chosen shape they have to be kept to size through production pruning to provide large, regular crops.

The first goal of pruning to manage production is to maintain the optimal canopy volume (see section 2.3). If the trees grow to a bigger volume than what the environment can optimally bear, water supplies are used up more quickly in summer and fruit drop increases. Leaf drop also occurs in serious cases, which alters the leaf-to-wood ratio and can cause alternate bearing, smaller crops and lower product quality.

Crop production is the result of striking a balance between root absorption and photosynthate production by the canopy. When these two activities are balanced, the shoots that develop are medium-sized (20-40 cm long) and have primarily fruiting buds.

If the tree has vegetative shoots, the balance can be improved by light thinning to make the canopy expand and intercept more light to produce the carbohydrates needed for fruiting (Fig. 18). However, if canopy expansion accentuates shading inside the canopy or between adjacent canopies, this does not work because the increase in leaf area is not accompanied by an increase in photosynthetic products and the activity of the tree continues to be primarily vegetative.

If the trees have weak, densely clumped shoots, moderate pruning can help to improve light and air penetration of the canopy and to produce medium-sized shoots with a high fruiting capacity.

 

Figure 18. Pruning of mature trees for fruit production entailing reduction of volume and canopy thinning.

Unpruned trees produce more fruit than the nutrients are able to feed: the olives are small, they have a low oil content and summer fruit drop is pronounced. The heavy fruit uptake of nutrients leads to the formation of small, weak shoots to produce the next season's crop. This pushes the tree towards alternate bearing, which becomes more marked in harsh soil and climatic conditions and when the trees do not receive cultural care.

Heavy pruning in 'on' years can lessen excessive reproductive activity and prevent the appearance of alternate bearing.

As the branches grow longer the fruiting shoots tend to be borne at the end, leaving the proximal section bare. This anomaly should be avoided by making careful renewal cuts of the shoots positioned at the curvature of the fruiting shoots and by periodically cutting the shoots that appear at the base of the fruiting branches. However, care must be taken to avoid shifting the vegetative cover towards the upper, outer parts of the canopy.

Special care should be taken to thin the canopy constantly to ensure that all the leaves have access to the right intensity of light (Fig. 19). Consequently, during the training stage when light penetration is still good and vegetative activity is prevalent, concomitant pruning for fruit production should be light. Conversely, during the mature stage, fruit production pruning should be carried out regularly to remove suckers and the whole or parts of exhausted branches, to control tree height by lowering the top and to keep vegetative cover as close as possible to the scaffold branches. This kind of pruning should be carried out in the following sequence:

1) Check the tree is the right shape, cutting the main or secondary branches if something has to be corrected.
2) Remove watersprouts, possibly retaining a few to replace debilitated branches.

Figure 19. Thinning of the canopy of a cv. Chemlali olive tree in Tunisia.

3) Thin the tips of the branches to keep them within the maximum training height.
4) Thin the secondary and tertiary branches to remove any that are misshapen, exhausted or decayed, and head overlong branches to points where there are replacement shoots. Remove dichotomous branches and thin overcrowded shoots and branches.
5) Cut suckers at their point of insertion in the tree base.

It is essential to ensure a balance between the parts of the tree, to keep it to the chosen training shape and height, to ensure a high ratio of leaves to structural parts and to avoid bare branches.

Watersprouts growing inside the canopy should be carefully controlled, leaving only a few weak ones to provide shade and keep the branches active.

Vigorous shoots should not be left at the tips of the branches because they would make them grow upwards too much, besides causing shading and drawing away nutrients from underlying branches. Vigorous shoots growing on secondary or tertiary branches should also be cut because they tend to compete with the main branch.

When the opportunities for competition have been eliminated, the remaining branches should be thinned to remove crossing shoots and any exhausted, diseased or broken limbs and to prevent the formation of long, pendulous shoots.

If the removal of the vigorous shoots has sharply decreased the leaf apparatus, some shoots of medium vigour may be retained. These should be pinched to reduce their growth and to encourage the development of fruiting shoots. This solution is sometimes advisable to fill gaps in the canopy.

Weak shoots, the predominance of structural parts over leaves and large numbers of watersprouts and suckers are signs that some structural parts of the canopy are on the decline. Such signs need to be identified quickly because rejuvenation pruning is needed to remove the ailing parts before substantial crop losses occur. The most effective action is to remove the entire branch and to replace it by one of the shoots that emerge below the cut. The replacement of the branch restores the leaf-to-wood ratio of the canopy and considerably improves light penetration to the rest of the canopy.

2.11. PRUNING CHOICES: INTENSITY AND FREQUENCY

When pruning, growers should follow the recommendations given at the stages of planting, training and production in order to shorten the initial non-bearing period, to make the bearing period as long and regular as possible, to delay orchard decline and to make pruning cost-effective. A number of approaches and results of trials conducted on pruning intensity and frequency could be of help for making pruning choices.

One trial tested three different pruning intensities – light, medium and heavy – and three pruning frequencies – every year, every two years and every three years – on a ten-year-old orchard where the trees were trained to the vase shape. The orchard was established on a medium-textured soil, it was rainfed and it was rationally fertilized, primarily with nitrogen.

The leaf area index (LAI) at the start of the season was 5.1, 3.2 and 2.7 respectively in the cases of the light, medium and heavy pruning, which was carried out annually, biennially and triennially. Pruning entailed reducing the canopy to its assigned volume by cutting back the scaffold branches to make the tree the desired height (Figs. 20, 21 and 22). Pruning was harsher when carried out at longer intervals.

Figure 20. Before and after light pruning.

Figure 21. Before and after medium pruning.

Figure 22. Before and after heavy pruning.

Next, all the vigorous watersprouts were removed except for a few weak ones expected to fruit shortly, which were left to fill out the canopy. Any dead or densely clumped tertiary branches were then thinned.

Any small branches that were too low, shaded or drooping were removed or headed. Individual shoots were not touched to avoid decreasing the aggregate number of leaves and adding to work time.

The overall canopy was balanced and leafy, and the top was sufficiently open to allow the light to penetrate inside.

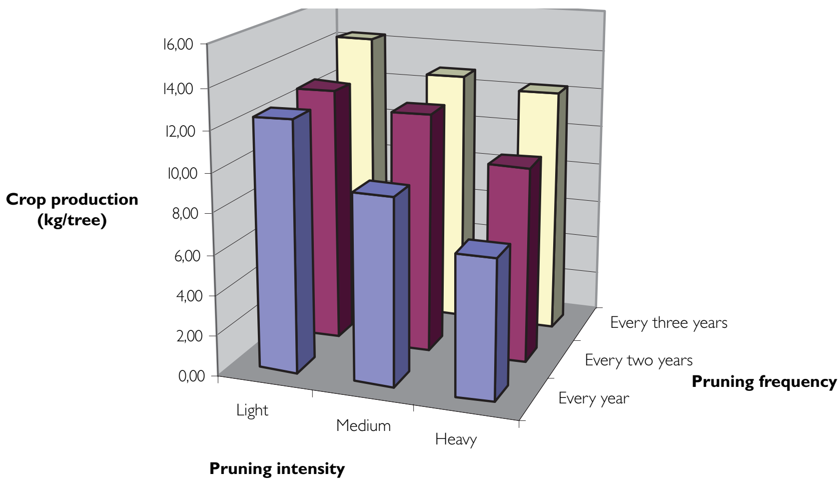

Figure 23. Influence of pruning intensity and frequency on crop production.

The results revealed that crops were distinctly higher when the trees underwent light pruning as opposed to medium or heavy pruning (Fig. 23). The larger leaf area of each tree was decisive in crop terms. Crop production was also encouraged by the development of medium-vigour shoots, which tend to be more productive, whereas medium and heavy pruning led to the development of primarily vegetative watersprouts and suckers.

Crop production was low when medium pruning was carried out annually, but proved to be good in the two- and three-yearly cycles. When the trees were heavily pruned, crops were small when pruned every year or every two years but good in the three-yearly cycle. The larger crops were mainly due to increased canopy volume as the productive efficiency of all the combinations was similar in terms of kg olives/m^3 canopy (Fig. 24). Statistically significant differences were not noted between the varieties.

The underlying causes of these findings emphasize the need for the trees to have a large leaf area and medium-vigour shoots, which should be retained for over a year to tap their productive potential before being removed by pruning. Hence, they will not contribute to crop production if pruning is done yearly, but will be useful for crop purposes if it is carried out at longer intervals. When it is necessary to keep the canopy volume to within specific limits, medium and heavy pruning can be practised if applied with the right frequency. However, there are limitations if shading and irrational canopy distribution come into play.

Such a solution would make pruning less detailed because the two-yearly and three-yearly cycles are sufficient to exploit the full crop potential of the trees.

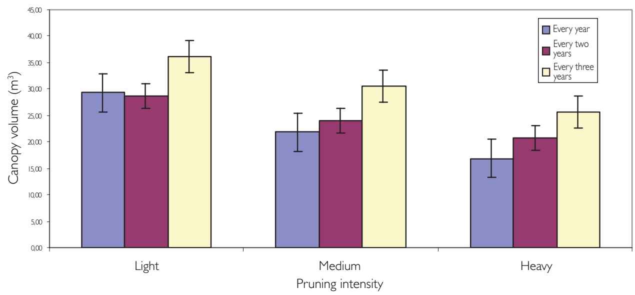

Figure 24. Influence of pruning on canopy volume.

The limit that should not be overstepped is the size of the shoots that develop in between pruning and which should be removed in the next pruning. When they grow too big, they compete with the main branch where they grow and they leave the canopy too exhausted to begin the new cycle efficiently.

This brings us to the question of varietal adaptability to longer or shorter pruning cycles because varieties with a limited tendency to produce watersprouts can tolerate longer pruning cycles.

For instance, 'Frantoio' is more demanding in terms of pruning than 'Leccino' and 'Maurino', which means that after two years, or three at the most, the training shape needs to be tidied; also, when pruned at long intervals, it is more sensitive to attacks from olive leaf spot. The same considerations apply to olive scale: other conditions being equal, excessive canopy density is conducive to this pest. So, while greater leaf density does raise production, it might be wise to avoid exaggerating this parameter and to apply medium pruning at longer intervals than every year in order to limit the spread of pests and diseases.

Medium pruning ensures more effective renewal of the fruiting shoots and improves canopy light and air penetration until the tree leaf area is increased.

The longer the pruning cycle, the more wood has to be removed, but this is necessary to select the structural and functional parts of the canopy (Fig. 25). Variety has a bearing on the amount of wood that has to be eliminated, for instance less needs to be removed in medium-vigour varieties and a larger amount of the dry matter elaborated by the tree can be channelled into fruiting.

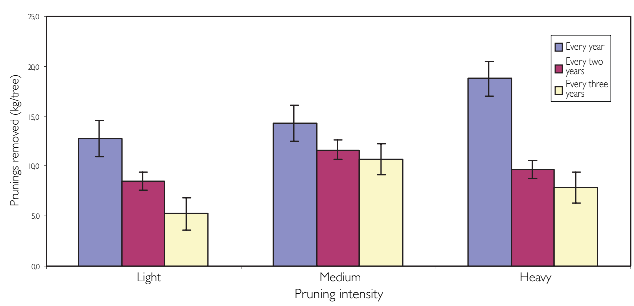

Figure 25. Prunings removed per year and tree.

2.12. TRAINING SHAPES

The training shape is designed to make the olive canopy expand according to the vigour allowed by the soil and climatic conditions and to distribute the leaf apparatus in such a way as to ensure good light penetration. The training system chosen on this basis encourages fruiting and can be controlled through pruning; otherwise excessive vigour or shading occurs, causing unsatisfactory crops.

The olive tree responds to more severe pruning because of the many adventitious buds at its base and along its branches and therefore tolerates many forms of training. However, the further the pruning shapes move away from the natural vegetative growth of the olive, the less efficient they become because they require constant, severe pruning which decreases the productive potential of the tree.

The best shape is therefore the one that respects the natural growth habit and which ensures high crop efficiency in terms of the photosynthetically active leaf area. Training systems are divided into the following groups according to their geometrical shape:

– Vase shapes (polyconical vase, inverted vase and bushy vase).
– Globe shapes.
– Leader shapes (monoconical and central leader).
– Flat-plane shapes (trellis hedgerow, palmette).

2.12.1. Vase

The vase shape is found widely in olive growing. There are many variations on the same theme which differ primarily in terms of the inclination of the branches and the distribution of the surrounding vegetation. The underlying concept is to distribute the vegetation amongst several well-spaced axes, which allows the tree to grow to a larger volume and to intercept more light.

It also allows the olive to grow to a large volume in step with the strong development it shows in favourable environments. In such conditions it is easy to balance the vegetative and reproductive activity of the tree.

The polyconical vase shape is the most popular variant. It is formed by a trunk 1-1.2 m high with three or four primary branches initially angled at 40-45 °, then growing almost vertically (Fig. 26).

Figure 26. Tree trained to a polyconical shape.

To achieve the vase shape the trees are allowed to grow freely for two or three years after being planted out; during this time shoot development along the trunk is controlled. At a height of 1-1.2 m along the main axis, the most vigorous, best-positioned shoots are identified to form the branches. At first, these should be allowed to grow almost vertically; they should be angled as late as possible but while the branches are still supple.

The slanting branches should be allowed to grow to the desired canopy width, at which point they should be guided upwards. Each primary branch is covered with fruiting shoots, which are shorter at the top of the branch and longer at the bottom to avoid excessive reciprocal shading. The top of the canopy is thinned to allow the underlying branches to develop and it is kept at a maximum height of about 4 m by heading. Watersprouts should not be allowed to develop on the inclined branches because they damage the branches they grow on and cause excessive shading inside the canopy without making any significant contribution to fruiting. Vase shapes are suited to mechanical harvesting although it is necessary to shorten and stiffen the secondary and tertiary branches and to reduce drooping branches.

The bushy vase (or vase-bush) shape evolved from the polyconical shape and can be made up of one or three trees. In the first case, six to seven branches are inserted in the trunk at a height of 50-70 cm; in the second, the olives are planted in the vertices of a metre-wide equilateral triangle. This allows a large number of trees per hectare and facilitates hand picking because the canopy is close to the ground (Fig. 27).

Figure 27. Tree trained to a bushy vase shape.

The concept of a rigid geometrical shape is gradually being replaced by that of a more freely growing shape in which pruning is restricted. This means more flexibility as regards the number and angle of the branches and how they are reciprocally balanced, so moving closer to globe shapes.

2.12.2. Globe

The globe is a shape where the canopy is spherical and distributed evenly around 3-5 scaffold branches. It is used in hot climates where sunlight is intense in order to protect the branches from possible high-temperature damage by keeping the bark out of the direct rays of the sun.

Fruit crop tends to develop in the upper, outer part of the canopy, the depth of which depends on the amount of thinning. When planted out, the tree is topped to a height of 1-1.2 m and three branches are trained from which secondary branches emerge to form a fruiting surface on the periphery of the canopy (Fig. 28).

In this kind of system the trees need to be pruned for fruit production to renew exhausted branches and to stimulate the annual formation of medium-vigour fruiting shoots. It is also wise to keep the canopy height to 4.5-5 m by cutting back the apical sections of the branches, which should be kept free of watersprouts on their undersides because these eventually exhaust the branches.

Canopy development also has to be kept under control to avoid shading adjacent trees. Planting distances therefore have to be tailored to tree development.

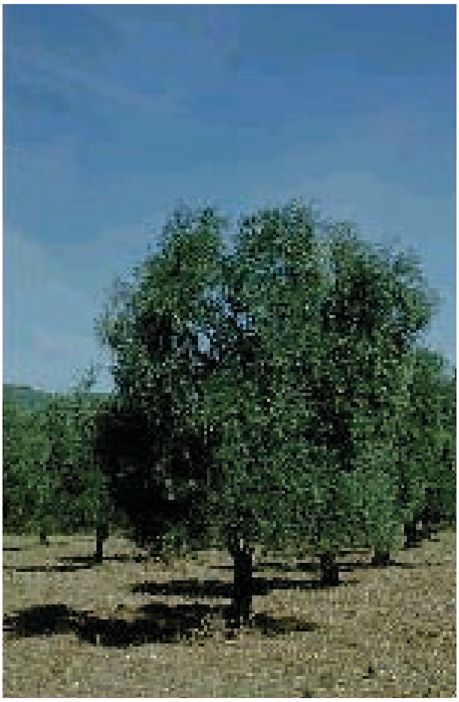

Figure 28. Tree trained to a globe shape.

2.12.3. Monoconical

The monoconical (or spindle) shape comprises a central leader and lateral branches which are shorter at the top of the tree and longer at the bottom. The trunk may be short or long depending on whether hand or machine harvest is intended.

When planted out, the olive is tied to a stake 2.5 m long and it is allowed to grow freely; only the top is thinned for as long as it is wanted to expand. Vigorous shoots or shoots inserted at a narrow angle along the trunk should be removed as soon as they appear. The branches around the central leader should be positioned at a broad angle. Pruning for production should concentrate on these branches, which should be thinned, and any exhausted branches should be replaced as is done for the polyconical vase.

This shape responds to crop requirements as long as the olive can be kept to a moderate size, with short lateral branches ensuring that the whole of the canopy is uniformly lit (Fig. 29). If the tree

Figure 29. Initial stages of training to a monoconical shape.

Figure 30. Bearing olive trees trained to a monoconical shape.

grows bigger, severe pruning is required which disrupts the balance of the tree, making it excessively vigorous; if not pruned, the tree grows to such as size as to cause excessive elongation of the branches, which become bare on their proximal sections. As a result, the tree is less efficient and is not suited to machine harvest, at least not until the overall development of the tree is reduced (Fig. 30).

2.12.4. Central leader

This shape consists of a central leader, approximately 3 m in height, covered with lateral branches of equal length, which are renewed cyclically. Pruning for fruit production entails thinning the shoots and pinching any that have fruited in order to stimulate them into producing numerous medium-vigour shoots. This shape performs well in high-yielding cultivars but it needs thorough testing because controlling tree development is a problem here too. If not controlled, there is a risk that the essential balance between vegetative and productive activity will not be achieved.

Figure 31. Over-the-top harvester in super-intensive orchard.

2.12.5. Super-intensive trellis hedgerow

This entails training the trees to a central leader on a tight 4 x 1.5 m spacing; they are supported by a stake and by a frame of trellis posts and wiring (Fig. 31). They are intended for harvesting by over-the-row grape harvesters with a maximum operating height of 2.5 m. Irrigated, well fertilized orchards are planted with medium-vigour, good yielding varieties; 'Arbequina' and 'Arbosana' are recommended. Significant yields are obtained as of the 4th or 5th year on a par with crops during the constant bearing period, and harvesting productivity is very high. Orchards are expected to last 13-15 years.

2.12.6. Palmette

When trained to a palmette shape the tree is grown along a flat plane to ensure good light penetration and to facilitate cultural care.

It consists of a central leader and branches growing along one or two tiers. At the nursery, half of the lateral shoots and half of the basal shoots are removed alternately. The result by the third year is a vigorous plant with well developed lateral shoots, two of which are used to form the first crotch.

Figure 32. Trees trained to a palmette shape.

When planted out, the central leader is fastened to a stake and pinched at a height of around 1.2 m to stimulate the production of the shoots needed to form the second tier. The lateral branches, which are made to develop at an angle of 40-45 °, are covered with vegetation.

Pruning for fruit production involves removing watersprouts, thinning shoots, replacing exhausted branches and bending vigorous shoots (Fig. 32).

2.13. CRITERIA FOR CHOOSING PRUNING AND TRAINING SHAPES

The choice of pruning type and training shape calls for careful analysis of the surrounding conditions, in particular the soil and climatic factors, the characteristics of the cultivar and the effects of pruning, and it means identifying the objectives pursued in terms of productivity and of the mechanization of cultural techniques.

Bearing in mind the physiological and biological conditions regulating development and fruiting, it is important to achieve swift, initial development. This is done by creating the most favourable agricultural conditions and pruning as little as possible, only to correct any anomaly or to remove any shoot that is not useful in forming the definitive structure of the tree.

The next step is to ensure large, well-lit fruiting surfaces and to balance the vegetative and reproductive phases through suitable training, planting distances and pruning.

In areas where the olive trees grow to a large size it is wise to adopt training shapes that allow ample development and to space vegetative cover in such a way as to avoid shaded areas. Shapes that do not allow this possibility drive the tree to low productive efficiency characterized by numerous, weak branches which are bare along the base, and a poor ratio between active leaves and the frame.

In terms of tree suitability for shaker harvesting, training shapes should consist of a small number of stiff, upright branches where fruiting is concentrated in the middle-upper part of the canopy and there are no drooping branches. Medium-sized trees respond the best. When the trees are large it is advisable to attach the shaker clamp to the scaffold branches.

In this context, cultural techniques such as irrigation, fertilization and crop health protection take on a decisive role owing to their influence on orchard productivity and functionality.

Super-intensive hedgerow orchards have attracted interest from growers but they are still at the experimental stage. Such methods have in fact been proposed over the years. One example is the hedgerow system applied in Apulia in 1960 on a 5 x 1.7 m spacing. With limited pruning, yields of 5, 5 and 19.8 t/ha were obtained at the 4th, 5th and 6th years. However, this kind of solution was abandoned owing to poor orchard yields at the 10th-12th year, and traces of such attempts are no longer found today. Likewise, intense research conducted around 1970 on planting densities in Mediterranean countries reached the conclusion that average densities of 200-400 trees per hectare were the most reliable. It is necessary to wait for the results of experimental trials to check the tenability and real advantages of such proposals. At present, doubts remain about the negative effects that shading and vegetative activity may have on fruiting, as well as on the possibility of controlling tree development within the limits imposed by harvesting machinery and by financial crop considerations. It is therefore wise to advise caution when using systems like super-intensive trellis hedgerow orchards which have not yet been tried and tested and require huge outlays. However, once they have been properly investigated, they could be swiftly introduced because of the early fruiting entailed.

Consequently, emphasis has to be placed once again on the importance of gleaning a thorough understanding of the needs of crop production processes. These can be satisfied through careful application of pruning, in which training shapes should be an essential complement for achieving the goal of maximum productivity.

The broad adaptability of the olive permits an assortment of solutions, provided they do not exacerbate any of the factors involved in crop production and they help to maintain the right balance between the vegetative and reproductive activity of the tree.

In any case, the training shape should adapt the tree to allow cultural techniques such as tillage and harvesting – and pruning too to a certain extent – to be carried out by mechanical means.

In this scenario, trees more than 4 m in height may not equate with good economic management.

2.14. FREE VASE: THE SHAPE IN WIDEST USE

Nowadays, the free vase shape is the training shape found most widely in new orchards around the world. Its recognized merits are that it is similar to the natural shape of the olive tree, it intercepts a large amount of radiant energy and it exposes the leaves and fruiting area to the light. Trained to a single bare trunk to a height of up to 1.20 m, it is suited to the efficient machine harvest methods available to date.

This training shape is obtained by applying the pruning method described for the vase shape and incorporating the distinctive details described in sections 2.9 and 2.12.1. Some degree of flexibility is required, severe pruning should be avoided and other cultural techniques should be used to speed up development.

Figure 33. Tree trained to a vase shape.

The applicability of this training shape is backed by the results of experimental trials and the experience of farmers who in recent decades have had the opportunity to try out other solutions such as the palmette, bushy vase and monoconical shapes.

The continuous labour required to maintain the palmette shape has made it no longer worthwhile. The multi-trunk bushy vase shape slows down shaker harvesting. After 10-15 years the monoconical shape poses problems because of the excessive height of the trees, the limited exposure of the canopy to light, the prevalence of vegetative activity and the limited leaf-to-wood ratio.

As a result, the farmers who opted for these training shapes have already switched to the free vase shape or are moving towards it because it is considered to be more efficient, to afford more guarantees and to be backed by longer experience (Fig. 33).

2.15. PRUNING FOR MECHANICAL HARVEST

Trunk shakers coupled with mechanical catching frames give the best, most reliable performance for machine harvesting olives. Tree characteristics have to be adapted to ensure optimal use of this machinery. Besides varietal suitability in terms of fruit size, stalk length and fruit ripening pattern, other factors of interest from the point of view of pruning are training shape, canopy volume, canopy distribution, and type and suppleness of the fruiting shoots.

The vase shape is the most suitable training shape, amongst other things because of its capacity to intercept large amounts of radiant energy. The single trunk should be kept bare to a height of at least 1.2 m; drooping branches should be limited to avoid hindering the catching frame; branches should be regularly spaced and inserted at an angle of 40 ° with respect to vertical; the secondary and tertiary branches should be inserted without sharp twists and every part of the tree should be healthy.

Canopy volume should be kept inside the limits compatible with the power of the shaker. Volumes up to 40-50 m^3 are considered suitable for shakers mounted on 50-80 kW powered tractors.

The canopy should have a medium density to ensure the leaf area needed for crop production and to avoid creating resistance to shaker vibration of the canopy. The canopy should be distributed preferably in the middle-upper part while the lower part should consist mainly of short, thick branches.

2.16. REJUVENATION PRUNING

This kind of pruning is performed on olives whose crop functionality is reduced and which no longer respond to cultural care because they are too old or their productive organs are exhausted. Their fruiting area is located solely in the distal portion of the shoots, which grow on numerous branches covered with sparse or no foliage.

Trees in this state need severe pruning to rebuild a strong, physiologically active canopy. Pruning depends on the viability of the plant organs and the objectives pursued.

If the trunk and scaffold branches are viable and the canopy needs to be lowered, the branches should be cut to just above a pre-identified lateral shoot. The secondary branches should be shortened, ensuring that the higher they are the shorter they are (Fig. 34). If the tree intended for rejuvenation is not too high, only the secondary branches in the apical area need to be removed, leaving those in the lower section.

If a scaffold branch is not sound, it should be cut back to its origin where numerous shoots will sprout and should be left to grow freely for a year. Then they are thinned to choose the one that is to be the prolongation of the main branch on which the secondary and tertiary branches will be inserted.

When all the branches are cut at the same time, the new shoots form at the expense of tree reserves; they are vigorous and juvenile

Figure 34. Rejuvenation pruning.

and take 4-5 years to start bearing. Consequently, it is wise to prune the tree gradually, completing rejuvenation over a period of a few years.

When the tree so permits, part of the bearing canopy can be left unpruned to reduce the vigour of the new shoots and to ease the crop losses ensuing from rejuvenation.

When the crotch of the trees is too high the trunk should be cut to the required height, which causes vigorous shoot growth. After being left to grow freely for two or three years, the best-positioned shoots should be chosen as the scaffold branches of the future canopy. As they become covered with secondary branches, the remaining watersprouts should gradually be removed. It is necessary to limit the number of branches. Otherwise they grow bare, which lowers the leaf-to-wood ratio required for good fruiting. When the trees are excessively high and have various crotches the approach is to cut the trunk above the first crotch, leaving 3-4 scaffold branches to renew and expand the canopy. Two years later any badly positioned shoots, branches and watersprouts should be lightly thinned to ensure correct tree formation.

Tree canopies are systematically rejuvenated in Spain when scant vegetative growth is observed, the leaves are a pale green, brownish colour and the tree sends out vigorous watersprouts and buds. The portion of the canopy showing signs of decline is removed and the operation is repeated whenever the symptoms reappear. Rejuvenation is phased over the entire canopy. After an ailing limb is removed, no more cuts are made until the new replacement growth starts to bear; then, the adjacent branch is renewed and so on until the entire canopy has been renewed. If performed at the right time in the life of the tree, this solution bears good results because it renews the canopy before it starts to be inefficient. Even intensive orchards need periodic rejuvenation to simplify the framework by eliminating any superfluous branches and to adapt the trees to shaker harvesting. Though heavier than normal pruning, this type of pruning should maintain a good ratio between the canopy and roots to avoid imbalances.

When the canopy is reduced drastically in size a good number of the shoots that emerge from the adventitious buds distributed regularly in the terminal sections near the cuts should be allowed to develop to ensure the sap flow reaches every part of the tree; otherwise, the tree would decline.

Rejuvenation is practised widely. However, it calls for overall economic assessment, not only of the yields obtained but also of its suitability in terms of the productive efficiency and adaptability to cultural practices required of new orchards.

2.17. PRUNING FROST-INJURED TREES

2.17.1. Most frequent signs of frost injury

One of the first signs of frost damage is that the leaf stalk tissue becomes necrotic, causing some or all of the tree leaves to fall. This occurs at temperatures of -6 or -7 °C. When damage is greater and affects the shoots, the leaves turn a dark brown or black colour but remain on the tree because it does not have time to stimulate leaf drop. The bark of one or two-year-old shoots may be split right through or only on the outside. Damage is caused in particular by quick temperature changes between night (low temperatures of -10 to -12 °C) and day (mild temperatures of 5 to 6 °C) or by the formation of ice when leaves and shoots absorb water after prolonged contact with rain, snow or mist. This causes rapid tissue dehydration and the death of the shoots or branches concerned.

Figure 35. Frost crack on the bark of an olive trunk.

When the cambium and sapwood are severely damaged and are not replenished with water and nutrients, extensive patches of the bark turn a dark brown or black colour and gradually decline until they are completely devitalized. Living, vertical portions of bark and cambium may survive close to the necrotic areas and form bundles which help to feed the distal parts of the branches. However, such areas cannot be considered feasible as a solid basis for crop production.

Bark cracking and sloughing on the scaffold branches and trunk are other signs of frost damage (Fig. 35). Alternating low and medium temperatures make the tissues expand and contract. The outer tissues of the trunk and branches expand in volume at low temperatures; then, when the peripheral parts become warmer, this reduces dilation and causes differing strain between the layers of the bark. As a result, the bark shifts on the wood towards a layer of cells that is particularly rich in water or that has a capacity for taking up water quickly. This occurs in all olive trees and causes deep vertical wounds when the bark is not springy. Such wounds are seen in some sensitive cultivars, in mature trees with a stiff bark and in trunks injured by previous frosts or with wounds that have not yet healed. They are not seen in young trees or cultivars with a springier bark.

Damage to the sapwood and cambium is one of the most widespread types of injury. The outer rings of the sapwood become necrotic and die (Figs. 36 and 37). In the process a large portion of the cambium cells is injured. Depending on the extent of the damage the whole of the ring may be necrotic, or only specific areas; in fact, some sapwood rays often remain intact and connect to the bark through the cambium. These give rise to new tissue which starts to develop in order to re-establish a connection between the bark and live wood. Concurrently, cell groups or a chain of new cork tissue elements differentiate in the bark in order to isolate the damaged portion and to protect the areas that are still alive. Recovery may affect only one area, in which case the remainder

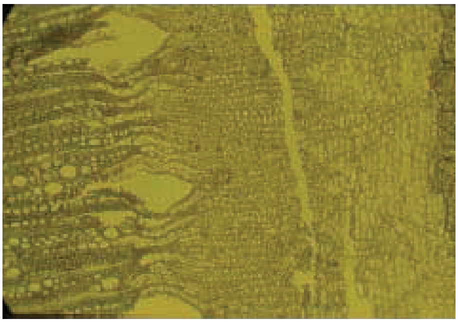

Figure 36. Frost damage to external sapwood.

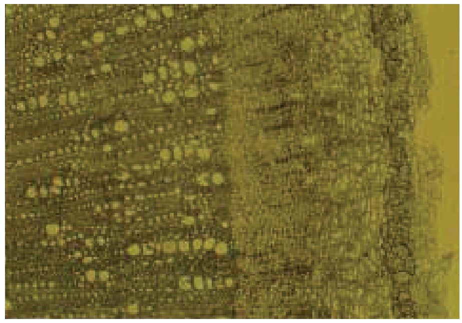

Figure 37. Wood and bark of an uninjured branch.

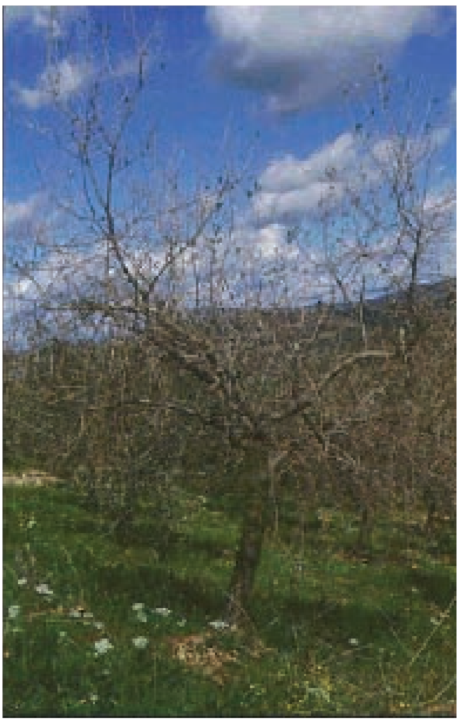

Figure 38. Tree which has lost 80-90 % of its leaves.

starts to decline: the bark starts to darken and the underlying wood dies and is easily infected by the fungi responsible for decay. All the shoots and branches that are not cracked can recover from the wounds, up to a point, and resume tree activity (Figs. 38 and 39).

If the bark tissue is torn and necrotic in several places no recovery is possible. It turns a brown-reddish colour until it becomes completely necrotic, with the ensuing death of the shoot or branch to which it belongs.

Figure 39. Formation of a layer of necrotic cells on the outside of the wood and attempt by the bark to repair the damage.

2.17.2. Methods of recovery

Defoliation affects flower bud formation and development. If no more than 20-25% of the leaves fall, its effects may be barely perceptible. At higher percentages it reduces flowering to the point where it is non-existent.

1) When the tree has undergone only light defoliation it should be treated in the normal way by first removing the shoots damaged by frost. It should then be pruned to ensure the right canopy density before the tree starts to bud in order to avoid wasteful dispersion of reserves.

2) When 80-90% of the leaves have fallen but most of the branches and shoots are still viable, the trees should be pruned to remove superfluous branches and to achieve a structure with a well-lit canopy that facilitates cultural operations, including mechanical harvesting. Overall, the tree will be pruned severely (Fig. 40).

3) When 70-80% of the leaves have dropped and the least damaged shoots are concentrated on the tips of the branches, these shoots should be heavily thinned and the shoots and branches with cracked bark should be removed. The shape of the canopy can then be rebalanced.

4) When one-year-old shoots and two-year-old wood have extensive, deep cracks in their bark they will wither rapidly. Pruning should concentrate on the scaffold branches (Fig. 41). The most responsive primary branches in terms of shape and number should be chosen and the top should be lowered to ensure even vegetative cover along the axis. If this is done in late April, the start of adventitious bud development will confirm whether the pruned branches are viable.

Figure 40. Renewal of trees whose leaves have almost all fallen off.

5) Another situation that occurs is where all the leaves have fallen but the bark of the scaffold branches and trunk is still intact although it has come away from the wood in some hollows (this can be detected by the hollow sound when knocking on the branch). Although one possibility is to prune the scaffold branches, it is best to wait until vegetative growth starts in order to check which organs are still alive. Only then is it advisable to prune, avoiding cuts on terminal sections which have shown vegetative growth and cutting lower down in order to avoid leaving partially necrotic areas. This should be done in May.

6) When the bark of the scaffold branches and trunk is cracked, the aerial part of the tree is jeopardized and the decision can be taken straight away to cut the tree back to ground level and even to uproot it all together. If tree injury is at several levels and the shape is not responsive it is wise to alter the shape of the tree. One approach is to switch from a monoconical shape to a vase shape. Cutting back the main leader to a height of 1.30-1.40 m is the starting point; the next step is to select 3-4 of the best positioned watersprouts to form the scaffold branches.

Figure 41. Renewal of trees with damage to 1-2 year-old shoots.

When cutting the tree back to ground level it is necessary to bare the roots of the base and then cut it about one-tenth of a metre below ground level in order to remove the dead areas and to promote the development of suckers from the lower, outermost ovules. As a complementary measure, any decayed portions of the base should be eliminated.

When the tree has to be uprooted, tractor loaders can be used to remove the entire tree base and thick roots.

2.18. CUTTING TOOLS

Tools can be divided into three groups: hand, mechanized and mechanical. Hand implements include pruning shears, saws and hatchets. There are basically two types of pruning shears: 1) anvil-action shears with a single cutting blade which strikes an anvil of solid metal; 2) scissors-type shears (bypass shears) with two blades which both make the cut. The scissors-type make a better cut, do not cause bruising and require minimum effort. Steel saws with teeth of varying length are light, easily handled and efficient; they are used for pruning branches up to 7-10 cm in diameter. The hatchet performs the same functions as the hand saw and requires some skill. Tools used for making bigger cuts and for exploring areas at a greater height include lopping shears with handles 60-80 cm long. These can make cuts up to 5 cm in diameter and can be worked from the ground up to a height of 2.8m.

Figure 42. Worker safety is improved by using shears and pneumatic shears from ground level.

Mechanized tools include pneumatic or hydraulic shears with/without a light-fibre extension arm 1, 2 or 3 m in length, and pneumatic or hydraulic saws (Fig. 42). They are powered by a compressor or oil pump. Pneumatic shears mounted on a light two-metre long pole, hand-held lopping shears and bypass shears give good results when training moderately sized olive trees or pruning them for fruit production. These tools are employed in the upper, middle and lower sections of the tree, respectively.

Standard and light chain-saws are widely used and appreciated for their cutting efficiency and speed. They are used in renewal or rejuvenation pruning and in ordinary pruning when the branches are quite large.

Mechanical implements include machinery equipped with hydraulically powered disc cutter bars which can make cuts of 150 mm or more or cutter bars for branches of limited diameter. These require hand finishing or hand pruning every second year.

2.19. MECHANICAL PRUNING

Mechanical pruning uses machinery equipped with a cutting bar consisting of 4-5 discs which rotate at a speed of 2,000-3,500 rpm and are powered by hydraulic motor. The bar cuts the shoots

Figure 43. Topping of olive trees trained to a vase shape.

Figure 44. Hedging of olive trees trained to a hedgerow shape.

and branches in a vertical or horizontal position or at an angle at various levels of the canopy (Figs. 43 and 44).

Mechanical pruning is most effective when the upper part of the canopy is removed to a depth of 1-1.5 m because it stimulates the growth of vigorous shoots while lateral cuts 0.75 m deep are less effective. Machine pruning is carried out at intervals ranging from 2 to 4 years. When applied to olive trees trained to the hedgerow system, topping (cutting the canopy across a horizontal plane) leads to the formation of watersprouts, which are eliminated by hand about every two years along with any dry wood inside the canopy and the numerous stubs of the pruned branches. This can be done in summer to avoid subsequent growth of parts that later have to be removed.

In the case of trees trained to the vase shape, watersprouts form in the middle of the canopy after topping and have to be removed.

Machine-pruned olive trees are not suited to hand picking but they can be harvested with shakers. The fruit is smaller and more care is required over plant health treatment, but the canopy volume is renewed rapidly and workforce with limited experience can be used (Fig. 45).

Figure 45. Vase-trained olive trees which have been mechanically pruned.

The best results have been obtained in pruning for fruit production in intensive irrigated olive orchards where crop yields are on a par with those of hand-pruned orchards; yields are lower, however, if the orchards are rainfed and grow on poor soil where the trees do not respond to the cuts. It has been confirmed that it is useful to prune at intermediate intervals and that good crops can be produced by quickly re-newing the fruiting vegetation (Fig. 46).

Figure 46. Trees one year after topping and removal of watersprouts.

Nowadays, simpler machinery with enhanced cutting capacity is a useful aid to hand pruning,, which is also carried out with efficient, easy-to-use, worker-safe implements in order to reduce labour input and to lower overheads.

2.20. MANAGEMENT OF PRUNING RESIDUE

Intensive orchards planted at a density of 300 olive trees per hectare can generate approximately 3-4 tonnes of fresh prunings (with a moisture content of about 50%) made up of wood more than 4 mm in diameter, shoots and leaves. The wood can be separated and used for fuel while the shoots and leaves can be shredded and worked into the ground in the same way as for other fruit crops. Other approaches such as collecting and burning the prunings are more expensive and do not capitalize on the potential source of organic matter.

2.21. CONCLUSIONS

The modernization of pruning is linked to the developments in world olive growing. With the establishment of new orchards, the use of irrigation to remedy water shortage, the increase in orchard densities to 200-300 trees/ha and the need to mechanize cultural operations, pruning needs to focus on aspects of fundamental importance to the production systems that are coming into wider use. The objective is to optimize olive production by making the best possible use of the technical means available. At this stage, to make it easier to understand the operations involved, pruning should focus on the processes at the core of crop production, i.e. they should help to create the conditions necessary to optimize assimilates production and maximum build-up in the fruit. This is done by achieving a maximum, well-lit leaf area free from pests and diseases and without limitations as regards the environment or cultural techniques. Another requisite is to ensure the high, long-term efficiency of the orchard and to make it competitive in terms of management costs by applying the right techniques and providing reliable solutions.

It is important to obtain rapid initial development by creating favourable agricultural conditions and keeping pruning to a minimum, i.e. merely to correct any anomaly and to remove any shoot not useful to the formation of the definitive structure of the tree. The next step is to achieve broad, well-lit fruiting surfaces and a balance between reproductive and vegetative activity through suitable training, planting distances and pruning. At the same time the trees have to be adapted to machine shaker harvest by forming a small number of stiff, upright branches where fruiting is concentrated in the middle section of the upper canopy and by making sure there are no low-hanging branches. Irrigation, fertilization and plant health protection influence orchard productivity and functionality. The free vase shape is the shape used most widely in new orchards because it comes closest to the natural growth of the tree, it intercepts a large amount of radiant energy and the leaves and fruiting area are exposed to light. As it is trained to a single trunk devoid of any branching up to a height of 1.00-1.20 m it is suited to machine harvest by the efficient methods available to date.

Pruning can affect canopy efficiency but it must be backed by other techniques which increase soil fertility. If applied with suitable frequency and intensity it should be cost-effective and should allow for mechanization. It has to be understood and applied by the up-and-coming generations who should learn from the accumulated experience of pruners who have practised the art of pruning for many years. It is necessary, therefore, to reactivate or continue generating interest in pruning from a modern perspective so that it helps, as in the past, to develop olive growing. At the same time, pruning has to be made easier to understand by introducing precise reference markers in terms of tree size, planting and canopy density and experimental results, with a view to its being applied on extensive areas with limited labour.

2.22. IMPORTANT REFERENCE MARKERS AND RECOMMENDATIONS

- Pruning entails removing part of the tree, generally a portion of the canopy consisting of branches, shoots and leaves no longer considered to be of use for the purposes of efficient tree management.
- Pruning and training should make sure the maximum leaf area is exposed to light.
- Pruning reduces overall development and encourages the growth of a smaller number of more vigorous shoots.
- Shoots measuring 15-50 cm long are the most efficient shoots in terms of crop production.
- Pruning improves light penetration, helps to balance the branches on the tree and produces medium-vigour shoots.
- During training, pruning should be kept to a minimum to encourage growth and should chiefly entail removing almost all the shoots that grow at the base of the trunk.
- Vase-shaped olive trees should have 3-4 scaffold branches growing at 5-10 cm from each other at an angle of 30-40° in relation to the vertical and the branches should be spread out before they stiffen.
- Canopy anomalies should be corrected in the 4^{th} or 5^{th} year by removing a few supernumerary branches.
- When pruning for fruit production: (1) prune the tree to its optimal volume and to the correct shape; (2) remove watersprouts; (3) thin and lower the canopy; (4) thin the secondary and tertiary branches; (5) cut suckers at their insertion point in the tree base.
- Light pruning gives the highest yields while medium pruning only gives high yields in two-yearly or three-yearly cycles. It allows fruiting shoots to be renewed and improves air and light penetration into the canopy.
- Varieties that grow only limited numbers of watersprouts and that are resistant to pests and diseases tolerate longer pruning cycles and lighter pruning.
- The training shape should be adapted to tree vigour and should ensure canopy expansion in order to allow light penetration and to facilitate cultural practices.
- The free vase shape, with a trunk between 1 and 2 m in height, is the shape used most widely because it is suited to mechanical harvesting with trunk shakers, it allows the canopy to expand and it ensures the leaves are well lit.
- To adapt trees to mechanical harvesting with trunk shakers and catching frames make sure the trunk is at least 1-1.2 m in height, cut back drooping branches, allow branches to grow regularly, without brusque distortions, at an angle of no more than 40° with respect to vertical. The

canopy volume should be kept to 40-50 m^3 and secondary and tertiary branches should be short and thick, i.e. as stiff as possible.

- When the trees show symptoms of poor functionality or have lost their original shape, reshape them by making cuts on the secondary and tertiary branches or scaffold branches, gradually selecting the shoots that grow after the cuts.
- Pruning of frost-damaged trees entails removing all the parts where the cambium and external part of the wood have turned necrotic by making cuts on the tertiary and secondary branches, or on the scaffold branches and even on the trunk. When severe action is required, assess whether it is worthwhile renewing the orchard or uprooting the trees and establishing a new orchard.
- Mechanical pruning using disc bars can be applied to lower the canopy by making horizontal cuts at a depth of 1-1.5 m from the top, or deep lateral cuts of 0.75 m. It is efficient if applied every four years and alternated every two years with hand pruning. When combined with hand pruning using efficient tools, it can help to reduce labour input and costs.

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3

Soil management in olive orchards

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Soil management in olive orchards

3. Soil management in olive orchards

3.1. INTRODUCTION

Nowadays, olive cultivation practices have to set their sights on achieving high returns and product quality, both organoleptic and health, while being environmentally sustainable. These three conditions are the foundation stones of any agricultural activity which aims to satisfy food requirements without endangering the future of generations to come.

There is some controversy as to the best soil management system for olive growing. Several questions come into play: the need to make good use of rainfall, weed control, erosion, herbicide use, or the risk of oil contamination or water pollution. Coupled with the immense diversity in soil, climatic, topographical and insolation conditions and in crop characteristics (differences in development, planting layout, number of trunks, varieties, which affects harvest timing, etc.) this precludes recommending one sole form of soil management.

It is necessary, therefore, to evaluate the factors which affect productivity and the environment and, depending on the environmental conditions in each olive orchard, to decide which techniques are most suitable for application at any given time.

Ancient texts and popular wisdom are a source of interesting recommendations. One instance is the works of Lucius Iunius Moderatus Columella, a famous Roman writer who took up farming. Born in Gades, now modern-day Cadiz in Spain, in the times of Jesus Christ, he gave very precise recommendations for tilling olive orchards in Book V of his work *On Agriculture:*

"...but it ought to be ploughed at least twice a year and dug deep all around the trees with hoes; for after the solstice, when the ground gapes opens from the heat, care must be taken that the sun does not penetrate to the roots of the trees through the cracks. After the autumn equinox, the trees ought to be trenched all round, so that, if the olive-grove is on a slope, ditches may be formed from the higher ground to convey water to the trunks of the trees".

The same author cites an ancient popular saying which fixes clear priorities:

"He who ploughs the olive-grove asks it to fruit; he who manures it, begs for fruit; he who lops it, forces it to yield fruit".

Fourteen centuries later, Gabriel Alonso de Herrera, in Book I, chapter V of his *General Treaty on Agriculture* tells agriculturalists to kill weeds for, if they grow too much, they draw the substance from the other plants; so, they are told to cut off their moisture, to strangle them and kill them altogether.

The Spanish Collection of Agricultural Proverbs (Hoyos Sancho, 1954) also has some interesting popular sayings, for instance:

"Free of weeds do always keep the olive tree"
"When March does come, the soil do upturn"
"If the olive be in flower let not the farmer go near"

Avoiding competition from weeds, taking advantage of water, adding organic matter in the form of manure and avoiding injuring the roots of the tree or damaging it during flowering were the cornerstones of soil management in olive orchards in these times, and continue to be so.

Advances in technology such as the advent of mechanical traction, which has replaced animal traction in many countries, and herbicides have made weed control easier, but tillage and herbicides have often been used to excess. In contrast, the addition of organic matter to the soil has not increased to the same extent, not just because the possibility of manure or compost incorporation is very limited, but also because weed removal has been intensified and weeds provide organic matter for the soil. Moreover, tillage stimulates mineralization of the existing organic matter, so making more nutrients available to the olive trees. In many cases all this has led to higher crop production; however, at the same time, it has heightened erosion, soil degradation and the risk of crop chemical and fertilizer pollution, sometimes going so far as to jeopardize future olive productivity.

Technological progress should not be rejected. On the contrary, tractors, machinery, herbicides and inorganic fertilizers are tools which allow us to carry out agricultural practices. They help us to achieve our aims more easily, and even to time them better, but we must be aware of their drawbacks and avoid them. This chapter will therefore outline soil management fundaments and recommended practices to allow olive growers to choose the most suitable method at any given time. Two prime objectives are pursued:

- *TO CONSERVE THE SOIL AND PREVENT EROSION in order to maintain future productive capacity.*
- *TO ACHIEVE A GOOD WATER AND NUTRIENT BALANCE in order to achieve high crop production.*

Soil conservation techniques are applied to reduce erosion and avoid soil degradation or contamination. A good water balance is basically achieved by increasing water infiltration, whose biggest enemy is soil compaction, particularly in the middle of the orchard lanes where machinery goes up and down; by preventing evaporation, which makes it advisable to ensure ground cover; and by limiting transpiration of live plant covers, which entails removing the cover at the right time. A good nutrient balance is achieved by fertilizing the soil and plant covers if necessary, and organic matter content should be improved until it reaches suitable levels for each soil so that the highest possible yields can be obtained.

3.2. SOIL EROSION AND DEGRADATION

3.2.1. Importance of soil

The Food and Agriculture Organization of the United Nations (FAO) defines soil as the top layer of the earth which has slowly formed through decomposition of the underlying rock material (parent rock) under the action of atmospheric conditions (climate) and vegetation or through the deposit of materials transported by rivers, seas (alluvial soils) or the wind ("loess" or volcanic ash soils).

Soil has the following functions, in particular:

Soil stores water and nutrients. **Water is the most influential factor in olive production,** something which is especially important in dry-farming conditions when rainfall is scarce. Furthermore, a well nourished tree makes better use of water and stands up better to adverse climatic conditions and attacks from pests and diseases. Soil depth largely determines water storage capacity.

Soil is the space where the tree roots and base develop. Anything which hinders their development, e.g. rocks or compact layers, should be removed, the water table and areas subject to temporary waterlogging should be drained and the build-up of salts due to poor irrigation or fertilization or insufficient drainage should be avoided.

Soil is the place where the majority of plant chemical adsorption-desorption and degradation processes takes place. These processes are mainly linked to the substances in the clay-humus complex and to microbial activity. For this reason, the presence of organic matter and micro-organisms in the soil helps to prevent problems of water pollution by plant protection products.

Soil is a fundamental medium for the agrosystem, flora and fauna where beneficial micro-organisms and pathogens live. The balance of this agrosystem is one of the lesser known aspects of olive growing. This is why it is important to monitor and control crop intensification and the potential loss of diversity because imbalances could increase and problems such as pest and disease attacks could be heightened.

Olive orchards are located on very different soils. Some, however, place limitations on growing, notably soils subject to poor drainage or susceptible to waterlogging because they are conducive to pest and disease attacks and hence to plant death. Other factors, such as excess lime, high salinity or high gypsum levels and the tendency to form large, deep cracks greatly limit productive capacity. Nevertheless, in general, the olive tree can grow in practically all agricultural soils. In the majority of cases, a depth of 60-80 cm is enough to achieve adequate tree development and profitable crops.

3.2.2. Soil formation rates and soil loss

One aspect which should be highlighted is that soil formation is a slow process. Besides varying, it depends on the nature of the parent rock and environmental factors. Formation rates in agricultural soils can vary between 3 and 15 t/ha per year. As it is a natural phenomenon, a "tolerable" soil loss rate can be established; however, it is hard to determine quantitatively because it depends fundamentally on the formation rate of each type of soil and on soil depth. Hence, for a soil depth of 25 cm, soil loss should not be more than 2.2 t ha^{-1} $year^{-1}$; for a depth of 150 cm, losses of up to 11 t ha^{-1} $year^{-1}$ are tolerable. Adopting a different scale of measurement, losses can be considered to be light at values under 10 t ha^{-1} $year^{-1}$, moderate at between 10 and 50, marked at between 50 and 100, heavy at between 100 and 200 and very heavy at upwards of 200.

In many olive orchards, however, actual soil loss is much greater than the formation rate. Owing to the climatic conditions, soil loss in the Mediterranean countries is mainly due to water erosion, although wind erosion is also a cause in some places. Water erosion is the biggest environmental problem of cropping. The consequences for olive production are very serious (Fig. 1), i.e.:

- Reduction of water storage capacity
- Reduction of the amount of nutrients available
- Loss of tree root system
- Risk of pesticide pollution through run-off and the transport of soil particles

Figure 1. Decrepit olive tree as a result of soil loss over the years. The trunk is large, indicating that the tree was vigorous years ago.

For all these reasons, soil management must necessarily aim to prevent soil loss (erosion) or degradation.

3.2.3. Development of erosive processes

Raindrops strike against the soil surface and detach soil particles. Moving at a specific velocity, runoff transports the soil particles, which are then deposited when the velocity has slowed down sufficiently. Hence, there are three stages: detachment, transport and deposition. Erosion takes four forms:

- *Sheet erosion.* This involves the loss of surface soil particles. It is very important but tends not to be detected visually.
- *Rill erosion.* This occurs when there is a buildup of runoff and is easily covered up by tillage.
- *Gully erosion.* This is very spectacular and cannot be fixed by the usual tillage practices.
- *Mass movements.* This is a problem of soil stability and is normally beyond the farmer's control.

Morgan (1995) provides extensive information on this subject while Bergsma (1981) and ICONA (1988) give the estimated and calculated rainfall aggressiveness indexes for the Mediterranean countries and Spain, respectively.

Factors involved in erosion: infiltration rate and runoff

Erosion is linked to the rate at which water passes into or infiltrates the soil and to the generation of runoff, which is the real culprit of soil loss. When a high-rainfall event occurs, a low infiltration rate will lead to runoff-mediated water loss. The velocity of the water increases its erosive capacity or erosivity. To sum up, **it is not the water which causes erosion, but the velocity at which it moves**. Any factor or element capable of improving infiltration and reducing the velocity of runoff will help to lower erosion rates. The most notable factors involved include the following:

- *Soil texture:* This cannot be modified by soil management techniques or the application of amendments. Coarse-textured sandy soils have higher infiltration rates; as a result, less runoff occurs. Soils with higher contents of fine sand and silt are more susceptible to erosion (erodibility).
- *Bulk density of the soil:* This is related to *porosity*. Pore volume, and hence infiltration rate, is greater at lower bulk densities. This density can be affected by soil management in two ways: it can be lowered by tillage or it can be raised if compaction occurs, for instance by machinery traffic. Hence, tillage of compacted soils promotes water infiltration, so decreasing runoff, and facilitates erosion control. However, in the case of soils on sloping land, this effect is heavily influenced by tillage depth and rainfall intensity in that superficial tillage of compacted soils and torrential rain can trigger very intense erosive processes. The proportion of macropores is also very important. These are the largest pores capable of carrying more water and they occur in the presence of vegetation (dead roots) and mesofauna (worms, for instance). The effect of macropores is more pronounced in clay soils because they have a low infiltration rate. When the bulk density is too high, i.e. in compacted soils, macroporosity is of little importance in absolute terms because compaction is the real problem.
- *Organic matter:* This reduces bulk density, so increasing infiltration. It promotes the formation of stable aggregates, structuring the soil and making it more resistant to compaction and less sensitive to raindrop impact and surface sealing caused by crust formation.
- *Soil moisture:* This limits water infiltration capacity with respect to dry soil. If a soil already contains a certain amount of water, the possibility of continuing to store water will be limited. The risks of erosion are heightened in soils which already contain moisture.
- *Roughness of terrain:* This promotes the formation of depressions or hollows that retain runoff, so encouraging infiltration. Tillage practices which heighten roughness can help to reduce erosion through this effect.
- *Ground cover:* This prevents the impact of raindrops and wind which cause particle detachment. Green vegetation or plant residue makes the ground rougher, helps to retain water in small hollows which form owing to the build-up of residue and makes runoff slower.
- *Horizons with a high bulk density,* such as the subsurface horizons with accumulation of clay or the underlying parent rock horizons: These limit infiltration and can cause subsurface waterlogging, so encouraging erosion.
- *Hard pans:* These occur under the tillage layer owing to the continuous crossing of machinery and implements. They are not reached by deeper tillage and lower the velocity of infiltration. The presence of hard pans depends on the soil type, frequency and timing of tillage and type

of implement used. Clay soils tilled with heavy machinery when very wet are very prone to form persistent hardpans, which usually last years even though the soil is not tilled or machinery is not used on it. Conversely, hard pans tend to disappear more quickly in Vertisols because the cracks which form expand with moisture. They do not occur at all in sandy soils.

- *Surface sealing* by the fine particles generated by detachment, either through rainfall or tillage. This creates a non-porous surface layer which hinders infiltration. Ground cover reduces surface sealing because it protects the soil from the direct impact of the raindrops and it prevents soil particle detachment. Loamy soils are very prone to this kind of sealing.

- *Slope steepness and slope length:* These affect runoff and infiltration in that the greater they are, the higher the velocity of runoff and the lower the infiltration rate. One of the keys to reducing erosion is to decrease the slope and shorten slope length. These principles underlie traditional systems of soil conservation and water accumulation such as terraces or bench terraces.

- *Size of the basin:* This permits the accumulation of a specific volume of flow water. Special measures should be taken to protect the areas where this flow accumulates.

When rainfall is abundant it is inevitable for some amount of runoff to occur. Morgan (1995) and Gómez and Fereres (2004) provide methods of calculation for designing ways of minimizing damage (see section 3.7 of this chapter).

Differences under the olive canopy and in the middle of the orchard lanes

- Owing to the tree canopy, raindrops are larger and have more energy under the olive tree; as a result, their erosive capacity is also greater. However, due to the accumulation of olive litter and to the greater porosity and presence of the root system, the soil under the canopy offsets the erosive effect of the larger raindrops. For this reason it is not advisable to remove the plant residue from underneath the canopy (Fig. 2), especially not systematically every year.

Figure 2. Clearing away leaf litter and dry debris under the olive canopy leaves the soil without protection and makes it more vulnerable to erosion. Consequently, this practice should not be done systematically.

- The continual running up and down of machinery along the middle of the orchard lanes compacts the soil (Gil-Ribes *et al.*, 2005) and lowers infiltration rates, besides hindering the development of the plant cover which helps to raise these rates (Fig. 3). In contrast, the area under the canopy tends to have a much higher infiltration rate because it is nearly always more porous, it has a higher content of organic matter owing to the accumulation of olive litter, and the impact of machinery passing up and down is much less. The runoff flow is concentrated in the middle of the lanes because the ground is more compacted and erosion rates tend to be higher than underneath the canopy.

Figure 3. (A) Machinery traffic, especially harvesting machinery used in winter during the rainy period, causes heavy soil compaction in the middle of the orchard lanes (B) which goes so far as to impede plant cover development, especially on clay soils, and makes tillage necessary to break up the ground.

3.3. WATER BALANCE AND NUTRIENTS

The water balance is equal to the infiltrated water less the water evaporated directly from the soil or consumed by the plants through transpiration. The previous section (section 3.2.2.) analyzed the factors which affect the first component, i.e. the infiltration rate. The techniques employed to improve infiltration and reduce erosion also help to improve the water balance. However, it is necessary to conserve this water to ensure good crop production.

Soil moisture conservation: evaporation and transpiration

The following prominent factors affect evaporation and transpiration:

- *Ground cover.* Evaporation-related water losses can be reduced by mulching the soil, for instance with stones, straw or plant residue.
- *Live vegetation.* Whether spontaneous weeds or crops, this also provides ground cover and lowers evaporation, but at the same time it consumes water through transpiration. Although water is very scarce in the majority of Mediterranean olive orchards, excess precipitation tends to occur in autumn-winter. This excess water can be used to maintain a plant cover during this period to improve soil characteristics and reduce erosion. However, at a specific date, which will vary according to the climatic conditions in each locality each year, the cover will have to be killed by tillage, the application of herbicides (chemical mowing), mechanical mowing or grazing. In areas where water is in short supply all year round

or in years when rainfall is very low, growing a live plant cover can considerably lower olive fruit production.

- *Tillage.* Tillage where wet soil is brought up to the surface and left to dry leads to major water loss; however, it has a different effect if the land is tilled when the soil is quite dry and when the object is to cover up deep cracks. The effect of tillage on evaporation can therefore vary widely according to soil moisture conditions and type.
- *Chemical mowing.* This can be done by applying contact or translocated herbicides. Contact herbicides manage to eliminate the green parts of the plants, but the plants may resprout, especially hemicryptophytes and geophytes whose replacement buds are not affected by the herbicidal treatment (see section 3.4.3). Conversely, very little regrowth or none at all occurs when high-translocation herbicides are applied; in addition, plant cover transpiration is controlled straight away, which translates into less moisture loss (Fig. 4).

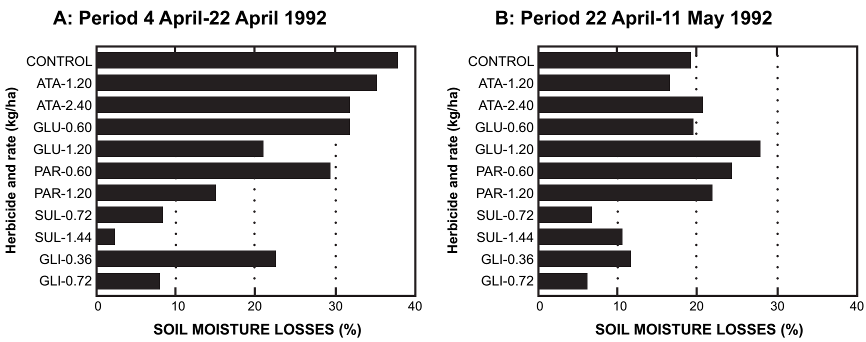

Figure 4. Moisture loss in plots growing barley cover applied different herbicides on 12 March 1992: ATA = amitrole; GLU = glufosinate ammonium; PAR = paraquat; SUL = glyphosate trimesium; GLI = glyphosate amine salt. Less soil moisture loss implies better herbicide effect and a better water balance (Castro, 1993).

- *Mechanical mowing.* This provides even less transpiration control than contact herbicides because it does not manage to eliminate the hemicryptophytes and geophytes, or all the creeping habit annuals and little developed species. Regrowth capacity depends not only on the biological type but also on the morphology and phenological stage of the species. It is worthwhile to have species which display little or no regrowth capacity after mowing. A paper by Alcántara *et al.* (2004) deserves a special mention here. It deals with cruciferous winter-cycle species of plants found frequently in olive orchards, which are easy to sow and display little regrowth after one or two mechanical mows at the end of winter or beginning of the spring.
- *Grazing.* This has a very similar effect to mechanical mowing. It is distinctive in that the animals can select and eat the most palatable species and disregard the ones they do not like or which are thorny.

Nutrients and the role of organic matter

The macronutrient balance and the macronutrients which will have to be applied will depend on soil management techniques and plant cover. It should be highlighted that tillage causes mineralization of organic matter and provides readily assimilated nutrients, most importantly nitrogen, while live plant covers immobilize them. In most Mediterranean olive orchards the period when it is necessary to mow live covers to control transpiration coincides with temperature increases in late winter and early spring, when the olive tree emerges from vegetative rest and also requires nutrients. When mowed, the plant residue starts to decompose and gradually feeds the soil with the nutrients (Fig. 5). To avoid a temporary deficit, it is recommended to fertilize the plant cover, satisfying requirements at least in part, and to do so independently of the fertilization applied to the olive trees.

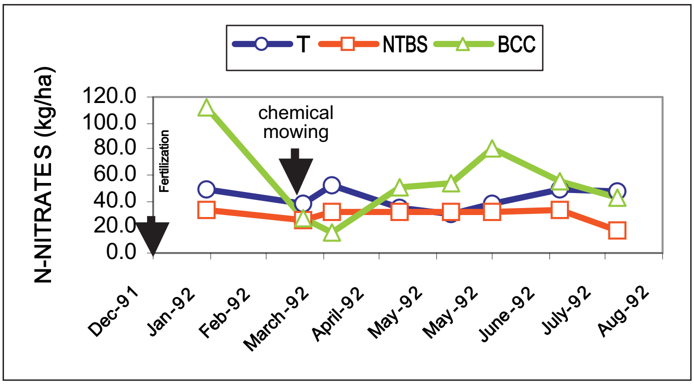

Figure 5. Changes in soil nitrate content under conditions of tillage (T), no tillage with bare soil (NTBS) and barley cover crop (BCC) at a depth of 0-60 cm. At the time of chemical mowing, soil nitrate content decreases in the barley cover despite nitrogen fertilization at a rate of 50 kg/ha (108.6 kg/ha of urea per hectare). (Castro, 1993).

As for micronutrients, most soils have adequate contents, but they are found in forms which cannot be assimilated by the olive tree. However, together with the majority of these nutrients, the organic molecules form compounds, such as chelates, which can be taken up by the plants. Iron is one case in point. Although it is abundant in many calcareous olive-growing soils, iron chlorosis still occurs and places enormous limitations on olive tree growth. Consequently, it is always wise to increase organic matter content, which is poor in most olive orchards, because it makes fertilization management easier and more effective.

3.4. OLIVE ORCHARD FLORA (WEEDS)

The flora of olive orchards is one of the most important parts of the agrosystem. It is referred to as "weeds" because of the damage it causes, but it also has its advantages and contributes to environmental equilibrium. Soil management necessarily involves weed management. Extensive information on the biology and ecology of the species and their interrelationship with crop systems can be found in Saavedra and Pastor (2002).

3.4.1. Weeds: the cons

The occurrence of spontaneous vegetation in olive orchards has several important drawbacks:

- *Competition for water and nutrients*. This occurs especially during the period of water shortage and fruit development, in spring and summer, and is more intense where root density is greater.

Figure 6. (A) Strong competition for water from the weed cover has caused water stress in the olive trees (B) Water shortage leads to symptoms of stress in the olive fruits and causes crop losses. This cover should have been killed some weeks earlier to prevent this from happening. Photos taken in the province of Jaén, Spain, in late April and October, respectively.

The effect on small olive trees is very evident (Fig. 6). As early as the sixteenth century, the Spanish writer Gabriel Alonso de Herrera warned against allowing weeds to grow too much because they draw away nutrients. Things have not changed, even though cultural practices and means of production have evolved and improved, and conservationism is alive and well. While cultural practices should be aimed at maintaining cover to prevent erosion and soil degradation and to encourage species diversity, adequate weed control is clearly a priority to avoid crop losses.

- *Interference with harvesting and other cultural operations.* When there are weeds on the ground it is very expensive to harvest fallen olive fruits; it is also difficult to check drippers, to prune the trees or to apply plant protection products (Fig. 7). These drawbacks are more evident underneath the canopies of the trees while they are almost insignificant in the orchard lanes. Consequently, closer control is required under the canopies than along the middle of the lanes. Also, some species can cause physical discomfort to operators, for instance thorny species or species such as *Capnophyllum peregrinum* which cause skin rashes.

- *Possible increased incidence of specific pests and diseases, and of climatic damage.* Sufficient information is not yet available on these aspects. It is known, however, that the presence of vegetation, including sown plant covers, leads to higher environmental humidity and a greater incidence of air-borne fungi like olive leaf spot. Heightened incidence of certain pests such as olive psyllid has also been observed. When very developed, weeds also hinder checking

Figure 7. Heavy weed growth underneath the olive canopies hinders harvesting and other cultural practices such as pruning, watersprout removal, plant health treatment or irrigation monitoring.

for olive tree rodents, such as rabbits, moles and mice. Likewise, damage from spring frosts can be greater in olive orchards covered with vegetation because the frosts are longer and more intense (Figs. 8 and 9).

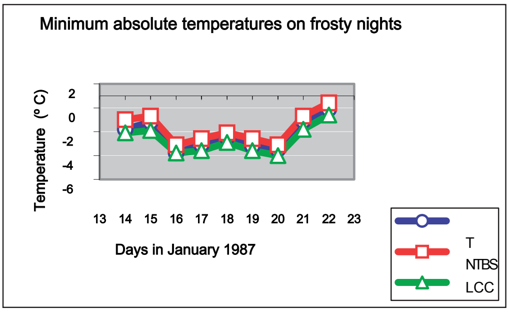

Figure 8. Frosts tend to be more intense and to last longer when there is a plant cover. The graph shows the minimum temperatures recorded under conditions of tillage (T), no tillage with bare soil (NTBS) and live cereal cover (LCC) in 1987 at Alameda del Obispo (Pastor, 1988).

Figure 9. Small olive trees killed by frost owing to temperature inversion. In low areas, the presence of a plant cover increases the risk of frost damage, especially if the olive trees are small.

3.4.2. Weeds: the pros

Weeds have important direct and indirect benefits for olive orchards, notably:

- *They protect the soil, contribute to soil formation and considerably lower erosion rates.*
- *They encourage the presence of fauna and biodiversity.* The abundance of birdlife, for instance, is very often linked to the presence of spontaneous vegetation. Nevertheless, the fauna may give rise to some of the drawbacks already mentioned (see section 3.4.1).
- *They supply organic matter and fix nutrients and atmospheric* CO_2, so reducing the impact of the pollution produced by industrial and urban activity.

3.4.3. Characteristics of flora in Mediterranean olive orchards

Ninety-seven percent of the world's olive orchards is found in the Mediterranean region. From the agri-ecological standpoint, the region's olive orchards could be considered a sparse Mediterranean forest as the olive is a cultivated, autochthonous tree species which is extraordinarily adapted to the environment and which has a very distinctive flora characterized by the following:

- *There is a very great diversity of species.* In Spain alone there are calculated to be some 800 species and in Andalusia it is frequent to find 100 species in a single hectare.
- *The species are largely of Mediterranean origin* and are very well adapted to soil and climatic conditions. However, species from other origins can also be found, such as subtropical aloctonous species which occur for instance in irrigated land where the high-temperature climatic conditions and high water availability simulate this warm, humid ecosystem.
- *Therophytes predominate* (these are annuals which spend the unfavourable period of their life in the form of seeds), mainly because tillage is the most extensive control method used. However,

hemicryptophytes (plants typical of pastureland with ground-level buds) and geophytes (difficult-to-control perennials with underground buds) are also widely found.

– *Phenological cycles differ greatly.* Owing to scarce water availability during the summer, most of the species have autumn–spring cycles, or they are species which are very resistant to drought, although winter species also exist in olive orchards. Furthermore, the duration of the plant cycles can also differ greatly, varying between 2–3 and 10–11 months in annuals and several years in perennials.

Hence, there are numerous species, many of which are capable of adapting to different environments and to every cultivation system imaginable. As a result, this flora has a great capacity to colonize different environments and to evolve in step with the techniques applied, as will be seen farther on.

Olive orchard flora differs elsewhere, outside the Mediterranean region, and each area has its own specific species. Generally, however, the following sections also hold for such situations, except for the diversity of species which will be specific to each area.

3.4.4. Evolution of flora

The flora in an olive orchard is not static. The populations which make up a community change every year in response to multiple factors relating to climate, soil, interspecific competition (between different species) and intraspecific competition (within the same species), intrinsic regulation of the populations or cultural techniques. When such changes occur repeatedly in the same direction, the term flora evolution can be used. Some of these changes, which are very evident from both the theoretical and practical standpoints, are now discussed.

Adaptation of species to each cultivation system

Several of the different species existing in olive orchards adapt to each system of cultivation. Put differently, each cultivation system favours the establishment and development of particular species. As the years go by and physico–chemical modifications occur in the soil, the populations evolve towards those best adapted to the management system employed and which are most difficult to control. This can be illustrated by some examples:

– If mechanical mowing is chosen as the management method, the geophytes and hemicryptophytes will not be controlled because their buds, at ground level and underground respectively, allow them to survive; nor will annuals (therophytes) with a creeping growth habit be controlled (Fig. 10) because the machinery cutting bars do not reach them. Logically, these species will proliferate until they become dominant to the detriment of the weeds which are easy to remove by mowing.

Figure 10. Creeping habit species like Anthyllis tetraphylla *are not removed by mechanical mowing.*

– In contrast, no tillage with bare soil encourages the establishment of species which need light to germinate because the seed is not buried and remains exposed to the light.
– Very frequent, continuous tillage every two to three months controls the majority of species; however, annuals with shorter cycles will be less affected because they are capable of producing seeds to survive during this period of time. On the other hand, if tillage is carried out at longer intervals, the species with longer cycles will be able to develop. Figure 11 shows an olive orchard with a high population of *Diplotaxis erucoides*, a cruciferous winter-cycle species found in tilled olive orchards.

Figure 11. Diplotaxis erucoides *is a cruciferous winter species found preferably in tilled orchards which are not ploughed for 4-5 months in autumn-winter, which allows it to complete its cycle and produce seeds. It is frequently found in vine groves for the same reason.*

Spring–summer flora

Cultivation systems aim to achieve maximum crop production and hence to have a maximum supply of water and nutrients on hand for the olive trees during their period of growth. In Mediterranean-climate conditions, where autumns and winters are rainy and summers are dry, keeping soil moisture at a maximum in spring and summer favours species with later cycles, which vegetate in spring and summer and need water during this period (Fig. 12). Furthermore, they are the most competitive because this is also when the olive tree requires more water, as will be seen later on in the chapter on irrigation.

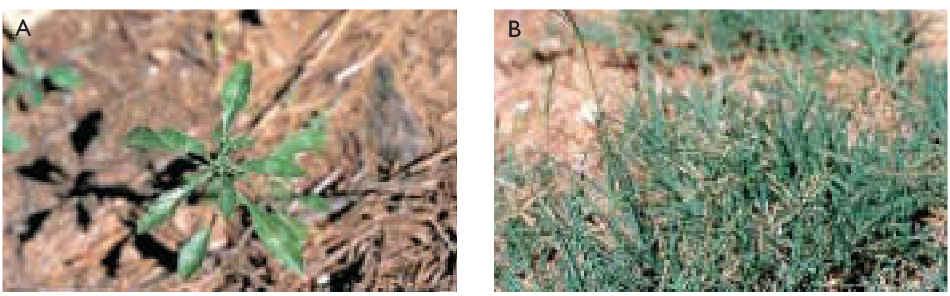

Figure 12. (A) Amaranthus blitoides *(annual) and (B)* Cynodon dactylon *(perennial) are examples of very competitive species representative of the spring and summer flora of Mediterranean olive orchards.*

Herbicide tolerance and resistance

Over the years, species which escape herbicide control increase in density and eventually become dominant (Fig. 13). This is why it is important to alternate herbicide use. An added advantage of doing so and of targeting treatment to control some species and select others is that the composition of the flora in the olive orchards can be changed. For instance, if a grass- or legume-selective herbicide

*Figure 13. Olive orchard treated repeatedly with glyphosate where mallow species (*Malva *spp. and* Lavatera *spp.) were not fully controlled and became dominant.*

is applied it is possible to obtain a live plant cover of spontaneous species of grasses or legumes, respectively.

Competition between species

The presence of some species which consume water and nutrients hinders the appearance of others with later cycles, which have to establish themselves when resources are scarce because they have already been used up by the earlier species and because there is more interference for light, space, alelopathic substances, etc. This effect of interspecific competition is one of the most worthwhile weed management tools because it is a way of encouraging the presence of less competitive species to the detriment of more competitive ones. Put differently, it helps to encourage the presence of specific species in winter when there are more than enough water resources and the olive trees are at vegetative rest, and to prevent the presence of summer flora which competes heavily for water with the olive trees.

3.5. CULTIVATION SYSTEMS: EFFECTS ON EROSION, POLLUTION, WEEDS, ORGANIC MATTER AND CO_2

The term cultivation system refers to the set of practices and techniques which can be applied for soil and weed management. Table 1 provides an outline of the options open according to the soil cover and type of management.

No one cultivation system can be considered ideal *per se*. Every holding, and even different areas within the same holding, may require different management. Two very distinctive areas have to be singled out:

- Underneath the canopy, where it is necessary above all to facilitate harvesting and where infiltration rates are normally higher.
- Along the lanes, where soil compaction and the susceptibility to greater runoff and erosion will influence the choice of system.

The pros and cons of each system will now be analyzed.

TABLE 1
Outline of olive cultivation systems

Soil cover	Management systems and type		
Bare soil	Conventional tillage, fairly frequent and deep		
	No tillage, with application of herbicides		
Covered soil	Inert mulch: stones and other materials		
	Plant residue mulch: leaf and crushed pruning litter, straw, etc.		
	Live plant cover	Weeds (spontaneous flora)	Chemical mowing
			Mechanical mowing
			Grazing
			Chopped and incorporated through tillage
		Plants cultivated under controlled growth conditions • Cereals or grasses • Legumes • Crucifers • Other	Chemical mowing
			Mechanical mowing
			Grazing
			Chopped and incorporated through tillage

3.5.1. Tillage

Tillage entails moving the soil with the prime aim of managing weeds and facilitating infiltration. It continues to be the system used most by olive growers, but excessive tillage causes damage to the olive trees and the soil.

Effect on erosion

The drawback to tillage is that it *detaches the soil particles* and theoretically makes them more vulnerable to erosion processes. However, tillage of compacted soil encourages water infiltration and makes the ground more rough, so helping to decrease runoff and erosion (Fig. 14). Nevertheless, it is advisable to avoid ploughing along the direction of the maximum slope, which leads to the formation of channels where the water moves at great speed and is highly erosive, and on wet soils in spring and summer because water is lost through evaporation.

Figure 14. Tillage to a medium depth crosswise to the direction of the slope was effective against erosion because the detached particles remained at the bottom of the furrows.

Tillage encourages the formation of *hardpans,* which are detrimental to olive root development and decrease infiltration rates; however, this can be avoided through deep tillage to break up the pans and above all by tilling the soil when the tilth is right. The hardpan tends to disappear when the soil is not tilled for several years.

Rollers for flattening the ground and facilitating harvesting should be used solely and exclusively in the area under the canopy because surface compacting of the soil increases run off and reduces infiltration.

Very superficial tillage (2-5 cm) is detrimental on compacted soils. It is usually done in summer to cover over cracks but it exposes the overturned layer of soil to the erosive effects of the first autumn rains. On the other hand, when done to break up a surface crust, it promotes infiltration.

Tillage is not advisable under the canopy of the olive trees because of root breakage and because soil compacting and infiltration problems do not usually occur in this area. However, the soil is tilled under the canopy in specific circumstances to force the formation of a deeper root system and to avoid bigger problems, for instance in vertic soils in which large cracks form in summer which are capable of bursting roots over 5 cm in diameter and of drying up the deep root system.

Herbicide pollution

Tillage helps to reduce or remove the risk entailed in herbicide use and from this point of view it is to be recommended.

Figure 15. Conyza canadensis *frequently infests plots kept under no tillage and sprayed with herbicides. In this case it is a population resistant to simazine.*

Weed management

Tillage helps to control annual and biennial weeds, but it is not always effective against perennials. It is very useful for controlling flora adapted to no tillage which is difficult to manage by other means, for example *Conyza* spp. (Fig. 15), of which populations resistant or tolerant to herbicides like simazine, diuron or glyphosate tend to appear in non-tilled plots with bare soil.

Organic matter and CO_2 fixation

Tillage promotes mineralization of organic matter and makes easily assimilated nutrients available to the olive tree, but if done too often, it causes gradual loss of organic matter and contributes to the increase in the amount of CO_2 released into the atmosphere. In line with this criterion, tillage must be justified because if done continuously and very frequently it promotes the degradation of agricultural soils.

3.5.2. No tillage with bare soil

This involves keeping the soil weed-free by applying herbicides, without any tillage.

Effect on erosion

There is some controversy in research circles about the effectiveness of this system compared with tillage in olive orchard erosion control and the water balance. Further research is needed, therefore, to determine the limits to its application.

It has gone down well with growers because it increases olive and oil production in the short term (Fig. 16A). However, in the medium and long term, the compacting that occurs in many soils is limiting on the crop owing to the reduction in the infiltration rates (Fig. 16B) and the increases in runoff, which give rise to crop and soil losses and the formation of gullies on soils on slopes. No tillage with bare soil under the canopies of the trees facilitates harvesting and does not usually have these disadvantages. Whether or not the system performs well in the orchard lanes will depend on the specific conditions of each holding, especially as regards the risk of compacting.

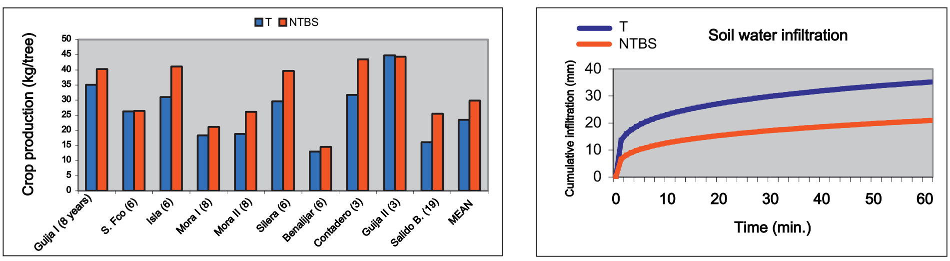

Figure 16. (A) Crops obtained on different farms and (B) different infiltration rates under conditions of tillage (T) and no tillage with bare soil (NTBS). As can be observed, crops increased on most of the farms under no tillage with bare soil; however, the reduction of the infiltration rate can be a limiting factor in some soils.

Herbicide pollution

Herbicides have to be used in no tillage with bare soil. Careful choice of the active ingredient, timing and dose are crucial to prevent problems of pollution. This risk is lowered considerably by avoiding widespread introduction of the system throughout the orchard, by using wide bands of plant cover, by applying organic matter to the surface (for instance olive oil mill waste) and by alternating the herbicide treatments (active ingredients and timing). The availability of a larger number of registered active ingredients would help to diversify herbicide treatments and reduce the risks of pollution. These aspects are dealt with in greater depth in chapter 4.

Weed control

The herbicides currently authorized (in Spain) allow effective control of most olive orchard flora. It would still be desirable, however, to have access to more active ingredients to help improve control and prevent the emergence of resistant and tolerant populations.

Organic matter and CO_2 fixation

Organic matter is not supplied through this system (except for the leaves falling naturally off the olive trees). Consequently, CO_2 fixation does not occur, although existing matter is not lost.

3.5.3. Application of inert mulches

This entails keeping the soil untilled and mulching it with inert, inorganic materials such as stones or synthetic materials.

Effect on erosion

Inert mulches have an important effect on erosion control because they prevent direct raindrop impact on the soil and they are a major obstacle to runoff. However, depending on their size and distribution, stones can facilitate the concentration of runoff and accentuate erosive processes. On the other hand, if they are placed around the olive trees and in the lanes, they make it easier to harvest fallen olives and they are effective in erosion control (Fig. 17).

Figure 17. Olive orchard with stone mulch around the trees and in the orchard lanes.

Herbicide pollution

With this type of mulch, herbicide application does not need to be as intense as in the case of no tillage with bare soil. It should be noted, however, that herbicides falling onto stones are easily washed away by runoff because they are not retained in the clay-humus complex, with the ensuing risk of pollution.

Weed control

Inert mulches are a very important barrier to the emergence and development of weeds, but they do not manage to eliminate them altogether. Their effectiveness depends on the thickness and type of mulch. For instance, a dense layer of stones eliminates a large part of the annual flora and black weed-barrier meshes can control almost all the flora, except for species like *Cyperus*, spp. Black plastic sheeting and weed-barrier meshes are used under young olive trees.

Organic matter and CO_2 fixation

These mulches do not have a direct effect on the levels of organic matter or on CO_2 fixation.

3.5.4. Application of plant residue mulches

This entails leaving the soil untilled and covering it with prunings, olive litter or other plant residues of other origins.

Effect on erosion

They are very effective against erosion because they prevent direct raindrop impact, they are an obstacle to runoff-induced water loss and the transport of sediment and they increase the organic matter content and infiltration rates.

Herbicide pollution

They have a very positive effect on pollution control because less herbicide is used and they improve the clay-humus complex by increasing adsorption and promoting degradation. They also reduce the transport of herbicide-containing sediment and water.

Weed control

They help to ensure partial weed control because they form a physical barrier and produce alelopathic substances when the mulch decomposes. For the same reason, they limit the development of live plant covers (Fig. 18).

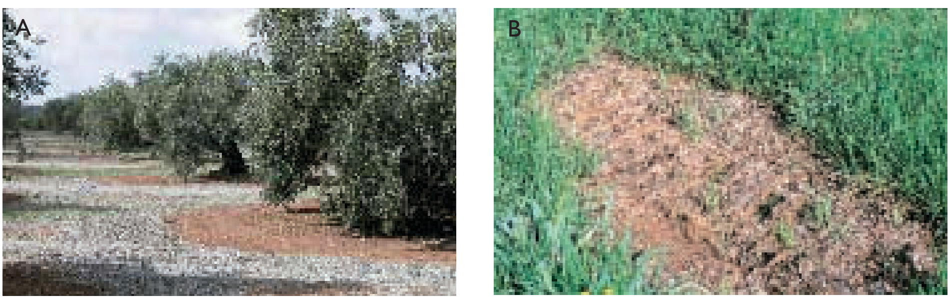

Figure 18. (A) Olive orchard with plant residue mulch (Photo: Miguel Pastor). (B) The close-up shows how the accumulated residue impedes the development of weeds and of the live plant cover.

Organic matter and CO_2 fixation

The great advantage of these mulches is that they supply the soil with organic matter, but there is a risk of introducing pathogens like *Verticillium dahliae* through leaves and prunings from sick trees. The prevention of infections by this soil-borne fungus is a priority for orchard survival. Consequently, if infection occurs, residue should be eliminated and should never be incorporated into the soil or left on the ground.

3.5.5. Live plant covers

This system involves allowing weeds to grow or sowing crops and keeping them alive for a specific period over the whole surface or in strips. They are then removed at a specific point in time to stop them from competing with the olive trees for water and nutrients. Management techniques are detailed in the next section of this chapter. This system is highly recommended for application in the middle of the orchard lanes, but under the tree canopies such covers can be overcompetitive and difficult to manage.

Effect on erosion

They have a very positive effect in erosion control. They provide ground cover, improve soil structure, permit high water infiltration and reduce runoff velocity, so causing sedimentation in the strips of vegetation (Fig. 19). Because they are live vegetation, the root system breaks up the soil, which is very important when the aim is to reduce or do away with tillage.

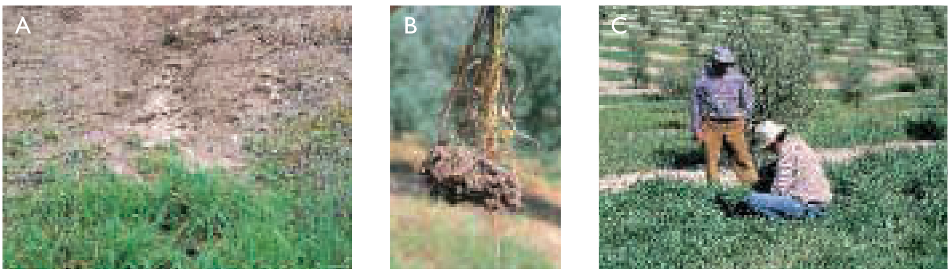

Figure 19. (A) The live cover lies over the soil, protects it from direct raindrop impact, reduces the velocity of runoff and promotes sedimentation (B), its roots break up compacted soil and when it dies it provides a high density of macropores which enhance water infiltration and reduce runoff, (C), but it is necessary to monitor moisture and nutrient changes in the soil profile to avoid crop losses.

Herbicide pollution

They help to reduce herbicide use and hence the risk of pollution. Herbicides can be done away with altogether in areas growing certain species which can be incorporated by a combination of mechanical mowing and/or tillage. They supply organic matter and improve the clay-humus complex, so promoting the adsorption and degradation of plant protection products. They reduce the amount of runoff and the risk of transportation of polluted sediment and water.

Weed control

Live cover crops compete with the spontaneous flora and make weed control easier.

Organic matter and CO_2 fixation

They help to increase the organic matter content of the soil and to fix CO_2.

3.6. LIVE PLANT COVER MANAGEMENT TECHNIQUES

It is preferable to establish live plant covers along the middle of the orchard lanes. They are sown or allowed to emerge spontaneously in autumn and winter, during the cold rainy period when water is available (Fig. 20), and should extend over approximately one-third of the surface (Fig. 21). The cover should emerge early to take maximum advantage of the rainy period and to produce as much biomass or organic matter as possible and to cover the ground as quickly as possible. Choose hardy species which show fast initial growth and which are adapted to olive-growing conditions and resistant to trampling during harvest.

Figure 20. (A) Barley cover crop in orchard lanes, sown exceptionally by direct drilling, although on most farms superficial tillage will be required to sow and lightly bury the crop. (B) The barley is allowed to grow during the autumn and winter. (C) Then it is controlled in late winter or early spring, in this particular case by chemical mowing.

The cover should be fertilized independently of the olive tree because as it grows it may immobilize nutrients the tree will need after budding for shoot and fruit development. The recommendation for live cereal covers in areas with an average rainfall of 500-600 mm is to apply a minimum 50 kg of nitrogen per hectare covered (approximately 100 kg of urea at a strength of 46%). This fertilization is also very important to allow the plant cover to develop vigorously in its initial stages and to compete with undesired weeds, so avoiding the need for subsequent control by herbicides, mowing or tillage.

Figure 21. (A) Olive orchard with cover of spontaneous species with and (B) without sufficient cover.

The plant cover should be killed off before it starts competing for water (normally in late winter or early spring in the Mediterranean region). To ensure effective competition control it is advisable to apply a translocated herbicide (chemical mowing) at the right dose for each species according to its phenological stage, for instance glyphosate at a rate of 0.72-1.08 kg of active ingredient per hectare in the case of grasses. Mechanical mowing is another option, but this technique can occasion crop losses basically due to the fact that it does not provide full control of the plant cover (Fig. 22), which continues to compete. Grazing has a similar effect to mechanical mowing because the animals do not eliminate all the cover either. On the other hand, chopping the plant cover and incorporating it into

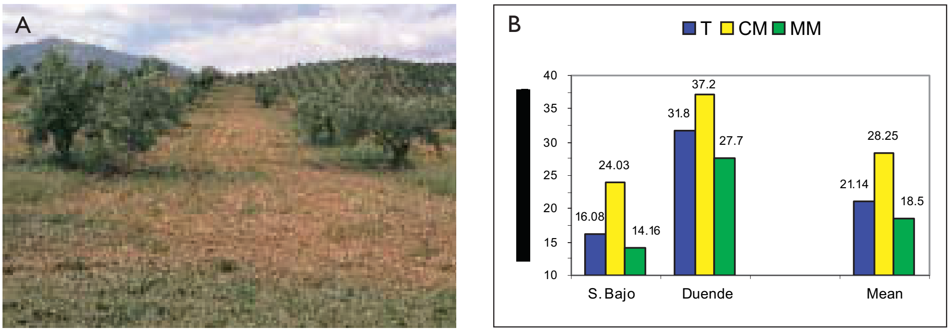

Figure.22. (A) The mown cover of spontaneous species has not been fully controlled and sprouts. (B) Hence, the management system combining plant cover and mechanical mowing (MM) can cause crop losses compared with other soil management and cover control systems such as tillage (T) or plant cover + chemical mowing (CM).

the soil through tillage provides good control although evaporation-induced soil moisture loss will occur due to the tillage. This loss of water may lead to a decrease in harvest compared with control systems which do not entail turning the soil. However, this may be partly offset by the effective control of the live cover which consumes water through transpiration. When managing plant covers, particularly in dry-farming conditions, *the most important thing to prevent competition and crop production losses is to ensure effective, timely control of the plant cover and to avoid evaporation losses;* crop production is dependent on doing so. Models for calculating water requirements can help to determine them roughly, but the precise crop coefficients of the plant covers are not known, although the coefficients for the most similar species can be used as an approximation.

When the cover crop is a cultivated species like barley, it will have to be sown every year. However, if it is a spontaneous species whose seeds remain in the soil, it will grow again the next year. However, the soil seed bank has a limited duration. Consequently, the strategy is to leave narrow bands or patches of uncontrolled plant cover to produce seeds and so make sure that the plant cover will be established the next year after the autumn rains. Only part of the plant cover should be mowed, therefore, to allow seed production and regeneration in subsequent years (Fig. 23). This system is very effective in the case of spontaneous grass species like *Hordeum murinum*, *Bromus madritensis*, etc., which are found frequently and abundantly in olive orchards. They can be established simply by applying a herbicide that is selective for these grasses in the intended

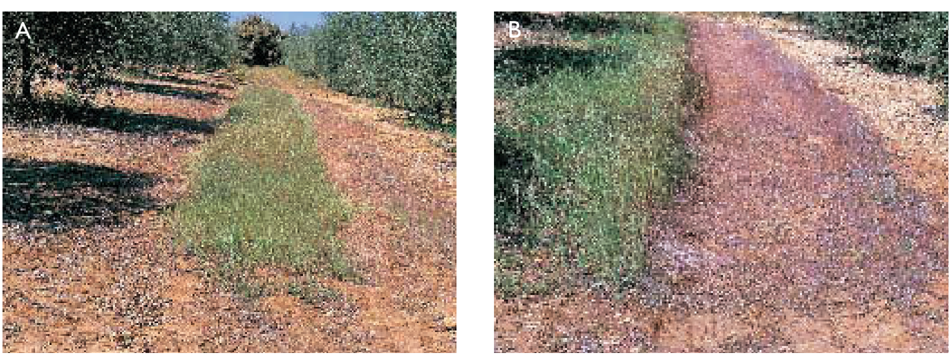

Figure 23. (A) Spontaneous grass cover controlled by herbicide treatment, leaving part of the area untreated to allow seed production in the centre of the lane and (B) new position of the seeding strip the following year.

plant cover area and eliminating most of the broadleaves. Furthermore, these species disperse their seeds between 0.5 and 2 m, which is sufficient to regenerate the plant cover from the seed produced. To prevent flora inversions in the seeding strips, they should be located in different positions every year, so facilitating plant cover uniformity in successive years.

If the chosen cover species have short phenological cycles, i.e. if they complete their cycle before they compete with the olive trees for water, they will need less control, which is desirable from the economic (no costs) and environmental points of view (no tillage and no herbicide treatment). Short-cycle, native grasses have recently been selected from spontaneous Mediterranean flora (Soler *et al.,* 2002), and seed of species such as *Brachypodium distachyon,* which are suitable for use as cover in olive orchards (Fig. 24), is currently available on the European market.

Figure 24. The native annual grass, Brachypodium distachyon, *varieties of which have been selected for use as plant covers for olive orchards.*

Plant covers can be maintained by following these guidelines for several years, but problems of compacting frequently occur. Several cruciferous species, both spontaneous and cultivated, have been tested and studied to mitigate the problems of compacting. Two spontaneous species, *Sinapis alba* and *Eruca vesicaria* (Fig. 25), have been selected initially. These can be managed by mechanical mowing because they do not sprout or do so very little (Alcántara *et al.,* 2004). When left on the ground, they

Figure 25. Sinapis alba *and* Eruca vesicaria *are native species frequently found in olive orchards and may also be sown. They compete with weeds and facilitate their control and, when chopped and incorporated into the soil, they have proved effective in reducing* Verticillium dahliae *inoculum in the soil.*

reduce and slow down the emergence of spring–summer cycle weeds (Alcántara, 2005) and, when chopped and incorporated into the soil, they have been found to be effective in reducing *Verticillium dahliae* inoculum (Cabeza and Bejarano, 2005). This line of research and technological development calls for work in two lines: running field trials and gaining a deeper insight into the ways in which cruciferous species act on weeds and soil pathogens in the search for a balanced ecosystem in the context of INTEGRATED PRODUCTION.

Rotation of cover species

In the same way that there is no ideal cultivation technique, there is no ideal cover. Each type has advantages and disadvantages. Moreover, soil conditions change and flora and plant covers evolve more quickly the less the cover is handled, in other words ecological succession takes place (see section 3.4.4.). It may be possible to maintain the chosen system easily for three or five years, or perhaps longer. However, if changes occur that hinder its management, it is advisable to change the type of cover, i.e. to establish a rotation, as if it was a herbaceous crop, and to alternate the management systems too, although this does not need to be done annually.

3.7. EROSION AND RUNOFF CONTROL PRACTICES COMPLEMENTARY TO THE MANAGEMENT SYSTEM

Excellent soil management is often not enough to control erosion and maintain fertility and crop production. Consequently, complementary methods are needed to control runoff and prevent its devastating effects over the whole surface or at specific points where water disposal occurs. Such practices aim to: reduce slope steepness and length to decrease the velocity and erosive capacity of the water; promote infiltration and reduce runoff by harvesting the water in specific zones; protect channels and drainage areas; and apply soil amendments to reduce soil erodibility.

Practices which involve earth moving are limited technically by the stability of the ground. For instance, the construction of water collection pits or terraces in gypseous soil will probably not work because sooner or later they will collapse, causing even more erosion than before.

Design of orchards and irrigation networks

The first step before establishing a new orchard is to design the layout of the lanes in such a way as to prevent the concentration and high-speed circulation of runoff from an extensive area. The aim is for water circulation and disposal to take place in areas protected by vegetation or infrastructure works. Useful elements for protecting the soil from erosion should also be maintained: small hedges, small structures, etc.

In tandem, soil conservation practices should be borne in mind when designing new irrigation facilities, especially as regards the direction of machinery traffic and tillage, which should preferably be perpendicular to the slope.

Drainage

Soils susceptible to waterlogging or which cause serious problems owing to soil pathogens should be ruled out for olive growing, or else they should be properly drained to prevent temporary waterlogging, especially near the trunk.

Ridges

These are constructed almost always to prevent temporary waterlogging in clay soils or soils with impermeable subsurface horizons or in ground which is simply too flat and where the surface drainage is very slow (Fig. 26). They prevent the buildup of salts caused by continuous waterlogging. They are also constructed across slopes to break up and distribute runoff water and make it less erosive.

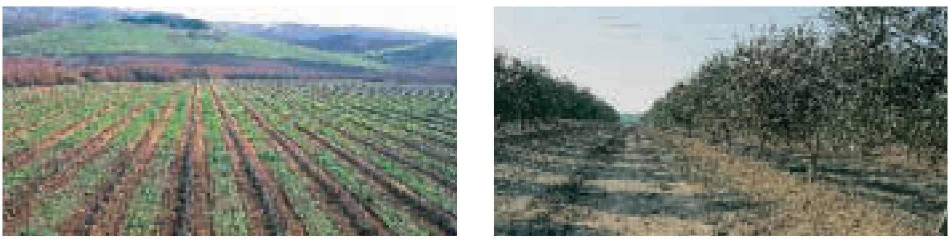

Figure 26. Olive orchard with ridges to avoid disease problems caused by temporary waterlogging, with (A) and without (B) plant cover along the lanes.

Terraces

Terraces can be built on steep slopes. Morgan (1997) describes the characteristics of various types of terrace and their limitations depending on slope steepness and length. They are expensive, but very effective, and should be designed by an expert.

Bench terraces and earth dykes

Bench terraces consist of a series of alternating shelves and risers and are constructed if the soil is very erosionable or the slopes are very steep. The risers are usually faced with stones or other resistant materials, such as concrete or masonry (Figs. 27 A and B). In very arid areas, dykes are constructed on the streambeds or sides to harvest water and sediment and create platforms for cropping (Fig. 27 C).

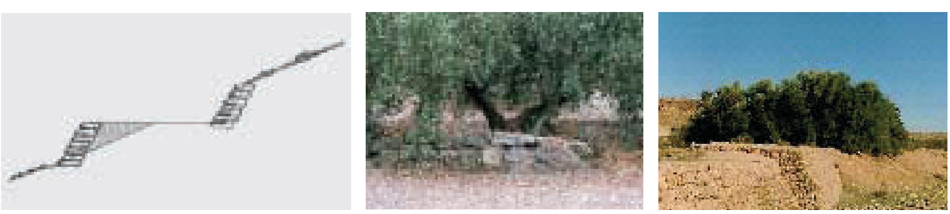

Figure 27. (A) Design of a bench terrace faced with thick stones, (B) olive orchard protected by this system and (C) traditional Jessour dyke constructed in Tunisia to harvest water and sediment (Photo: Taïeb Jardak).

Water collection pits

These are constructed on medium-gradient slopes, but they are not recommended on steep slopes because too much earth would have to be moved. They should not be built on ground that is not easily consolidated, because they will collapse and cause serious damage. They make it possible to collect large amounts of water and to harvest sporadic, intense rainfall that would otherwise be lost; they also harvest sediment, which substantially improves crop production. However, they are a hindrance to machinery traffic, especially harvest machinery, and require continuing maintenance. It is very important to customize them for each holding according to slope, orchard layout, possibility of torrential rain, customary cultural practices, etc.

They can be constructed in different ways. Some are built in half moons, usually in the upper part of the row of trees, and they are usually connected by furrows for running the water from pit to pit and disposing of excess water (Figs. 28 A and B). Others are constructed separately, on gentle slopes; these are normally larger and require more widely spaced layouts (Fig. 28 C). Extensive collection pit systems can be found in Tunisia where the whole ground is divided up into small water and sediment collection basins.

Figure 28. (A) Machine digging small collection pits; (B) pits dug in sandy soil did not take and collapsed easily (C); large, perfectly consolidated pits.

Trenches

These are constructed across the slope using a back digger. The soil that is dug up is usually spread around the olive trees, particularly in the most eroded area (Fig. 29). They are usually made 2-4 m long, 1-1.5 m deep and 0.5-0.7 m wide. Ground stability has to be taken into account before making them, because once full of water they could cause erosion through mass movements. They are easier to construct than collection pits, and they work better on steep slopes because there is not such a high risk of collapse if they are overtopped, nor do they require continuous maintenance. They are very effective in degraded and compacted soils as well as in stony soils, because they retain the most fertile elements of the soil surface and greatly improve olive productivity. Clearly, care has to be taken to avoid falling into the trenches, but they take up less space than collection pits at similar volumes of retained water.

Figure 29. *Olive tree with trench dug with a back digger to harvest water and sediment.*

Revegetation of rills, gullies and channel banks

Revegetation prevents erosion of the side-walls and slows down water velocity. Sometimes it suffices to let spontaneous flora grow. Other times it is advisable to sow or plant suitable species adapted to each climatic zone and soil type (Fig. 30).

Figure 30. Small gully with spontaneous vegetation and small structures to slow down runoff velocity.

Correction of gullies

Basically, this involves reducing water velocity and erosive power. It can be done in many ways, although limited tests have been carried out to check the suitability of each one for different soil characteristics. The following methods are singled out for attention:

Figure 31. Pruning residue laid at the bottom of rills to slow down runoff velocity.

– Laying pruning residue or other plant residue at the bottom of rills and small gullies (Fig. 31).
– Building structures to reduce the slope, for instance steel wire-mesh baskets (gabions) packed with stones (Fig. 32) or concrete slabs placed upright across the channel, or 100% concrete structures if the gully is very big and a lot of water circulates.
– Planting species with strong roots, such as *Arundo donax* (Fig. 33).
– Constructing dams made of upright stakes and water-permeable cross netting which holds back shoots, plant residue and stones (Fig. 34).
– Laying hay bales on the bottom of the channel, which is effective in expansible soils.

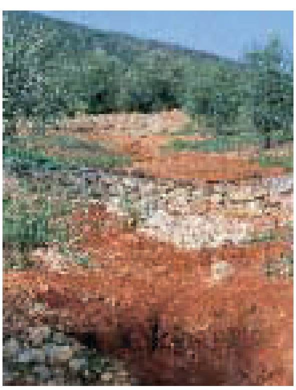

Figure 32. Gabions packed with stones designed to slow down water velocity.

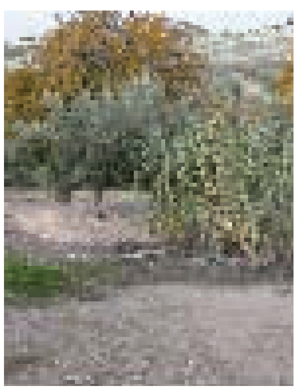

Figure 33. Arundo donax *planted in the channel of a large gully helped to reduce the erosive effect of the water and to fill the channel with sediment upstream, so facilitating machinery transport inside the orchard.*

Figure 34. Example of a simple, cheap dam constructed with angled metal posts and galvanized wire in the channel of a small gully.

Breaking up of ruts

This is very advisable and effective in improving infiltration in areas compacted by continuous machinery traffic where it is virtually impossible for any vegetation to grow. It facilitates water infiltration and the establishment of plant species, which cover the soil. It is usually done with a single-share implement, but it is important for the furrow not to be too long and to be divided into sections to prevent it from turning into a drainage channel and causing the formation of a rill.

Subsoiling perpendicular to the slope

This method has to be used with care because it bursts tree roots. It should only be used if serious problems of soil compaction and infiltration occur. It should be done along the middle of the lanes, keeping to lines as perpendicular as possible to the slope, and in short sections to avoid the formation of runoff channels (Fig. 35). Furrows should be interrupted in areas close to gullies or stream channels to avoid creating new gullies.

Figure 35. Furrow made with a subsoiler to a medium depth to encourage deep water infiltration.

Geotextiles

These are made from synthetic or plant materials. Many types are available commercially, e.g. organic mats made of straw, coir or esparto, woven with their own fibres or with plastic materials; others are 100% synthetic. They are designed to facilitate the establishment of vegetative cover in areas sensitive to erosion, such as steep gully sidewalls. They are laid on the surface and anchored with pins or stakes driven into the ground, or else they are placed over other elements such as gabions or dams. They can incorporate plant seeds and fertilizers.

Amendments

These are applied to the soil to improve its structure and facilitate infiltration and to improve fertility or correct deficiencies.

Manure and compost were the traditional organic matter applied to improve soil fertility and structure. As both are in short supply, olive oil mill waste is being used successfully; however, only small amounts can be spread because it is rich in potassium and if applied to excess can cause problems of salinization. Studies are underway to determine the maximum amounts that can be used in each soil and climatic situation.

Lime amendments are recommended in acid soils and/or soils that have a poor structure due to lack of calcium, and should be applied in the conventional way.

The application of sludge has been reported to cause major phytotoxic damage to trees on several occasions, both in research trials controlled by technical officers, and in experiments run by growers. Conversely, other crops have not been affected. As knowledge stands now, present-day sludge should not be used in olive orchards.

3.8. SUMMARY

3.8.1. Practices prior to orchard planting and design

- Avoid badly drained soils, or drain them properly beforehand, and consider the possibility of planting on large earth banks to avoid temporary waterlogging, particularly around the trunk of the tree.
- Avoid soils infested with *Verticillium dahliae.* Soils which have been used for a long time to grow sensitive market garden crops or cotton are higher risk in this respect. Sow the ground beforehand with crops which eliminate the pathogen inocula transmitted through the soil, and use them as soil amendments. Studies show that certain cruciferous species and Sudan grass are effective for this purpose.
- Remove stumps and remains of earlier tree species, especially those sensitive to soil-transmitted diseases which also attack olive trees.
- Remove competitive perennial weeds such as *Cynodon dactylon* or *Convolvulus arvensis*. For more effective control, use selective translocated herbicides.
- Break up the soil to a depth, for instance by subsoiling, and remove physical barriers to root development.
- Retain or establish structures or plants to protect the soil from erosion: hedges, dams, terraces, etc.
- Design the orchard and the irrigation system to prevent subsequent concentration of runoff water and to facilitate its disposal through protected channels.

3.8.2. Soil management after planting

Along the middle of the lanes

- Preferably choose systems which maintain plant cover in wide strips along the middle of the orchard lanes. Live cover is recommended on sloping land, provided there is sufficient rainfall.
- Fertilize live cover crops to achieve swift development, good cover and abundant biomass.
- Keep the covers live as long as possible, although this will be limited by the water available for olive production.
- Manage the plant cover by herbicides, mechanical mowing, tillage or grazing to limit competition for water in late winter or spring. In specific years or places with low rainfall, remove the cover early to avoid crop production losses and tree debilitation.

- Avoid soil compaction and flora inversion by using competitive covers with abundant biomass. Rotate covers or change the management system when difficulties arise in weed control. If necessary, break up the soil and promote infiltration by tillage, which should minimize root breakage and prevent circulation of runoff water along the direction of the slope.
- Use complementary practices to soil management if not already employed, and retain existing physical barriers.

Under the tree canopy

- Do not allow the live crop cover to grow to a great height. It can even be done away with to avoid difficulties in harvesting and crop management.

Herbicide use

- View herbicides as an additional tool for managing spontaneous flora and cover crops and for facilitating cultural practices, particularly harvesting.
- Use them as little as possible, on the smallest possible area, and preferably employ alternative management methods. Bear in mind at all times that soil conservation and yields are the top priorities.

Chapter 4 deals with the advantages and risks of herbicide use.

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Herbicide use

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4. Herbicide use

4.1. INTRODUCTION

Herbicides are used optionally in olive growing. Herbicide application often makes for easier soil management and weed control and it is usually cheap; however, herbicide use also entails risks which farmers should evaluate and avoid. This chapter deals with the most important aspects that should be taken into account to ensure safe herbicide use, including the choice of the most suitable products and application machinery.

4.2. HERBICIDES: WHAT THEY ARE

Herbicides are products which help to remove weeds. When intended for agricultural application, they have to be registered as a crop protection herbicide and approved for use on the target crop. The weed-killing substance in the herbicide is known as the active ingredient.

The active ingredients used nowadays are organic substances of varying degrees of complexity, most of which are synthesized from petroleum. Their molecules contain primarily C, O and H atoms; they may also contain others such as P, S, K, Cl or F.

Soil-sterilizing biocides like metham sodium or methyl bromide also have a herbicide effect. Increasing research is being carried out to look for other alternatives based on natural products and micro-organisms capable of destroying weeds; however, as they are not used at present in olive growing, they are not dealt with here.

Active ingredients are not sold as such. They are added a number of substances, some of which make them easier to handle while others, called additives or adjuvants, improve their characteristics and facilitate their application, especially by making them easier to dissolve or disperse in water. The end result is a product formulation or commercial product. Formulations can be liquid or solid: solutions, emulsions, suspensions, flowables, soluble powders, wettable powders, granules or water-dispersible granules. The strength of the commercial product is the proportion of active ingredient it contains, expressed as a percentage (%) of the active ingredient per volume of the commercial product (liquids) or of the weight of the active ingredient per weight of the commercial product (solids). Commercial products are sold in labelled containers which state the active ingredient, strength, rate of application, authorized crop for which they are intended, method of application, target weeds, application hazards and precautions. Before using a herbicide read the label carefully and follow all the instructions closely.

It is frequent for several commercial products to be found with the same active ingredient composition and for the trade names (proprietary names of the commercial products) to vary from country to country. This is why technical advisers recommend a specific dose of active ingredient and why the dose of the commercial product has to be calculated by using the formula:

Dose of commercial product = Dose of active ingredient × 100/strength (%)

Herbicides are usually applied as sprays. Other methods are employed on rare occasions only. First they are diluted or dispersed in a specific volume of water depending on the characteristics of each product. In some cases the product can be applied pure, undiluted, while in others it is applied at volumes of around 1000 l/ha; in olive orchards herbicides are often applied at between 100 and 300 l/ha. It is important to follow the spray volume instructions on the label because the effectiveness of each herbicide depends in part on this factor.

Herbicides can be applied to the soil before the weeds emerge (pre-emergence) or when they are up and growing (postemergence). Some products act through the soil where they are absorbed by the roots or they enter into contact with the plants when they are sprouting; others are absorbed by the leaves and green parts of the plant. Some are dual-action, acting simultaneously through the soil and green parts, and are therefore usually applied at early postemergence of the weeds. When absorption is through the roots it is important for the product to penetrate lightly into the soil to reach the weed roots. When absorption is through the leaves or green parts, it is important for there to be sufficient plant mass to intercept the product. Consequently, the product should not be applied when mechanical mowing or grazing has partially or totally destroyed the target weeds.

Droplet size is very important in spray applications of the soil or green parts of the plant because, at the same volume of spray mixture, small droplets cover a much larger area than large ones. It might be thought that droplets should be really small to ensure the largest possible spread, but this is only true up to a point because of the problem of drift: when the droplets are very small there is greater risk of wind dispersion. Another risk is evaporation. For all these reasons, herbicides cannot be applied when it is windy, i.e. when the wind speed is more than 5 km/hr. Nor can they be applied at high pressures, i.e. over 4-5 bar, because they produce a large proportion of oversmall droplets and there is the risk of wetting the tree. The answer to this problem is generally to add surfactants to the products. The result is medium-sized droplets, which give more coverage.

Some weeds, such as those with thick cuticles, abundant hairs or linear leaves with very little surface area, put up major barriers to herbicide absorption. Young leaves usually absorb herbicides better than old leaves, but because they are less developed they tend to intercept less. Some problems of lack of weed absorption are overcome by adding oil additives to the products which damage the cuticles and enhance penetration of the active ingredients.

Once the herbicide has penetrated the weed it can remain immobile and act through contact (contact herbicide) or it can move inside the weed (translocated herbicide) through the xylem (apoplastic pathway) or phloem (symplastic pathway). Herbicide mobility is very important because it allows the herbicides to reach parts that would otherwise be inaccessible by direct spraying, for instance underground buds; hence, they make control easier by wetting only part of the weeds. The drawback is that if an olive tree is accidentally wetted in the process and the herbicide is absorbed, the whole tree will be damaged.

Each herbicide has a weed-control spectrum, in other words it controls specific species of weed when it is applied at a specific rate and in a specific way. The effectiveness of the treatment depends on the dose in that larger doses are needed to control developed weeds and perennials. Plant susceptibility to herbicides is usually ranked by degrees:

- Resistant – when the weed is not controlled at normal or even higher doses
- Tolerant or moderately resistant
- Moderately or partially susceptible
- Susceptible – when full control is achieved

The choice of herbicide will depend on the weeds growing in each plot. It will be necessary to know the previous weed history of the orchard and to visit the plot to check weed status on the spot. The next step is to consult the data on the effectiveness of each herbicide and to determine which one to apply, when and at what rate.

When a herbicide does not control a particular species it is said to be selective for that species. When growing crops it is essential to make sure that the herbicides are selective so that they do not cause damage. They may be selective because the active ingredient is not capable of damaging the crop concerned (physiological or morphological selectivity) or because of the mode of application (site selectivity). Examples of site selectivity are spraying the weeds with a contact herbicide which does not injure the olive tree if the lower branches are not wetted, or soil application of herbicides which do not reach the roots of the olive tree because they lie deeper down.

It is often advisable to add specific products to the herbicide mix for increased effectiveness, for instance ammonium sulphate or acids to correct the pH of the water. Advisory officers tell farmers what to add and how much.

4.3. MAIN ACTIVE INGREDIENTS

Authorized active ingredients and commercial products can differ in each country. Differences may be purely commercial or based on technical grounds relating to the environmental conditions of each region. Table 1 lists some of the active ingredients used most frequently together with their characteristics.

Extensive information on the mode of action of each product and the species it controls can be found in catalogues, guides and web sites. The most notable characteristics are described here:

- Root-absorbed pre-emergence herbicides: diuron and simazine. These control a large number of annuals, both grasses and broadleaves, and have a lasting effect through the soil.

TABLE 1
Characteristics of active ingredients and timing of application

Active ingredient	Plant absorption	Movement in plant	Persistence of herbicide effect in soil	Timing of application	Type of species controlled	Regrowth of perennials
Simazine	R	A	***	PRE	An	
Diuron	l-R	A	***	PRE-post	An	
Terbuthylazine	L-R	A	**	PRE-POST	An	
Flazasulfuron	L-R	AD	**	PRE-POST	An	
Oxyfluorfen	L	B	**	PRE-POST	An	Quick
Diflufenican	L-r	B	**	PRE-Post	An Br	Quick
Glyphosate	L	AD	0	POST	An-Per	Little or none
Glyphosate trimesium	L	AD	0	POST	An-Per	Little or none
Fluroxypyr	L-r	D	*	pre-POST	An-Per Br	Little
Quizalofop-P	L	AD	*	pre-POST	An-Per Gr	Little
Amitrole	L-r	AD	*	pre-POST	An-Per	Partial
MCPA	L-R	D	*	pre-POST	An-Per Br	Partial
Tribenuron methyl[a]	L-R	D	*	pre-POST	An-Per Br	Partial
Diquat	L	AD	0	POST	An-Per	Quick
Paraquat	L	AD	0	POST	An-Per	Quick
Glufosinate	L	D	0	POST	An-Per	Quick

Plant absorption: root absorption: heavy (R) or light (r); absorption by leaves and green parts of the plant: heavy (L) or light (l).

Movement in plant: ascends greatly (A) or little (a); descends greatly (D) or little (d); barely moves or not at all (B).

Persistence of herbicide effect in the soil: none (0), 0-2 months (*), 3-4 months (**), 5-12 months (***).

Timing of application: pre-emergence (PRE and pre), postemergence (POST and post). Capitals indicate the chief action and small letters indicate the secondary action.

Control: annuals (An), perennials (Per), broadleaves (Br), grasses (Gr).

[a]Tribenuron methyl degrades slowly at low temperatures and in alkaline soils and its persistence may increase to level (**).

- Early pre- and postemergence herbicides: terbuthylazine and flazasulfuron. These are absorbed through the roots and green parts of the leaves and control annuals. They do not have such a long-lasting effect as simazine or diuron.
- Postemergence, high-translocation herbicides which persist in the soil and may act as pre-emergents for several weeks: amitrole, MCPA and tribenuron methyl.
- Postemergence, high-translocation herbicides which do not act through the soil in normal application conditions: glyphosate, glyphosate trimesium, fluroxypyr and quizalofop-P. These are very effective for controlling perennials; however, fluroxypyr only controls broadleaves while quizalofop-P only controls grasses.

- Postemergence contact herbicides: diquat, paraquat and ammonium glufosinate. These act quickly on all kinds of grasses, but regrowth is rapid because the buds that are not wetted will stay alive.
- Special-acting herbicides: oxyfluorfen and diflufenican. These are postemergence contact herbicides but they act as pre-emergents when, after sprouting, the plantlets come into contact with the herbicide deposited on the soil surface. When applied to the soil for pre-emergence effect, the ground should be devoid of dry debris which would prevent the sprouting plantlets from coming into contact with the herbicide.

Herbicides can be classified by group according to their mode of action, i.e. according to the way in which they work inside the plant (Table 2). Herbicides with different modes of action should be used alternately to prevent the appearance of resistant plants.

TABLE 2

Herbicide classification by mode of action issued by the Herbicide Resistance Action Committee (HRAC). The herbicides used most commonly in olive growing are shown in bold.

Group	Mode of Action
A	Inhibition of ACCase: diclofop-methyl**, quizalofop-P**, etc.
B	Inhibition of ALS: **tribenuron-methyl, flazasulfuron,** etc.
C1	Inhibition of photosynthesis at photosystem II: **simazine, terbuthylazine**
C2	Inhibition of photosynthesis at photosystem II: **diuron,** etc.
C3	Inhibition of photosynthesis at photosystem II: bromoxynil
D	Photosystem-I-electron diversion: **diquat, paraquat**
E	Inhibition of protoporphyrinogen oxidase PPO: **oxyfluorfen**, oxadiazon
F1	Bleaching. Inhibition of carotenoids at PDS: **diflufenican,** norflurazon
F2	Bleaching. Inhibition of 4-HPPD
F3	Bleaching. Inhibition of carotenoids (unknown target): **amitrole**
G	Inhibition of EPSP synthase: **glyphosate, glyphosate trimesium**
H	Inhibition of glutamine synthetase: **glufosinate ammonium**
I	Inhibition of DPH synthase
K1	Inhibition of microtubule assembly: oryzalin, pendimethalin, trifluralin
K2	Inhibition of mitosis
K3	Inhibition of cell division
L	Inhibition of cell wall synthesis: isoxaben
M	Uncoupling
N	Inhibition of lipid synthesis (not ACCase)
O	Synthetic auxins: 2,4-D, **MCPA, fluroxipir**
P	Inhibition of auxin transport
Z	Unknown mode of action

Active ingredients are often sold mixed to facilitate control of a large number of species. Commercial products are often mixed for the same reason, but product mixes are not always compatible and farmers should seek specialist advice in every case.

4.4. HAZARDS OF HERBICIDE USE

Herbicides can go through several processes from the time they are applied until they are completely degraded (Fig. 1). Herbicide presence in the environment entails certain hazards which should be known to avoid possible damage to operators, the environment in general, the agrosystem, the crop and the harvest. These can be prevented, in part, through correct product handling; the remaining hazards are inherent to the product itself. Table 3 lists some of the most important parameters which help to evaluate the degree of hazard involved.

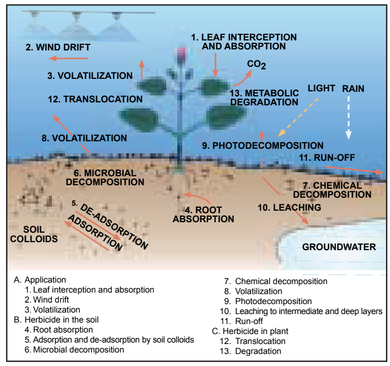

Figure 1. Herbicide behaviour in the soil, plant and environment.

TABLE 3.
Characteristics of active ingredients

Active ingredient	Toxicity LD50 mg/kg	T1/2 Half life days	Solubility mg/l	Koc Adsorption coefficient mg/g	Kow Octanol-water partition coefficient log
Simazine	5,000	60	6.2	90-(130)	2.10
Diuron	3,400	90	36.4	480	2.85
Terbuthylazine	1,700	60	8.5	250	3.21
Flazasulfuron	5,000	38-(7)	2,100	380	-0.06 (-0.6)
Diflufenican	2,000	170-(90)	0.05	2,000	4.9
Oxyfluorfen	5,000	35	0.116	32,000	4.47
Glyphosate	5,600	47	11,600	24,000	-3.4
Glyphosate trimesium	750	3-174-720	4,300,000	-	-4.6 (-2.9)
Fluroxipir	2,405	34-63	91	4,900	-1.24
Quizalofop-P	1,670	60	0.3	510	4.28
Amitrole	1,100	14	280,000	100	-0.97
MCPA	1,000	25	734	20	2.75
Tribenuron methyl	5,000	2-23	2,040	52	0.78
Diquat	231	1,000	700	1,000,000	-4.6
Paraquat	157	1,000	700,000	1,000,000	-0.08
Glufosinate	2,000	7	1,300,000	100	0.1

Values should be taken as guidelines as they may vary according to source and environmental conditions.
Data obtained from different sources.

4.4.1. Hazards to operators

The hazards to operators stem from the toxicity of the product and the form and length of exposure.

Toxicity is the capacity of a substance to cause effects pernicious to human or animal health. Acute toxicity (Table 3) is the amount of product absorbed in 24 hours, capable of killing 50% of the test animals; it is expressed as the lethal dose (LD50). Chronic toxicity is caused by the absorption of small amounts of the substance over a long period. Absorption may occur by contact, inhalation or ingestion. The eyes and mouth are particularly sensitive. Although herbicides are not very toxic in comparison with insecticides, for instance, operators should always take every precaution.

First and foremost, operators should read the label carefully and be absolutely sure about the risks of each product. The label includes symbols or pictograms indicating hazard and signal words referring to the type of hazard and the precautions required; these should be taken into account and followed strictly.

Operators should wear appropriate, special protective equipment including a suitable coverall, apron, goggles, face shield/mask, gloves and footwear. In the European Union all such equipment should be labelled as EC conforming. The type of mask is particularly important, depending on whether powders, liquids or gases are being handled. Operators should never eat, drink or smoke when applying the product. After application, they should remove the protective equipment and then wash.

Sprayers should be kept in perfect condition and correctly calibrated, and they should be handled with care. It is essential to keep equipment clean and in optimal condition for subsequent use. Special attention should be paid to possible leakage or spillage. The environmental conditions, temperature, humidity and wind should be optimal to avoid drift and above all to prevent harm to operators.

If a person is poisoned, call the doctor at once and show them the herbicide label. In the meantime, remove the contaminated clothing from the patient and give them First Aid according to the kind of poisoning involved. Each country has its own protection and safety rules for handling herbicides; follow these strictly. Agricultural and health services run specialized courses for farmers and operators to make them fully conversant with these rules.

4.4.2. Hazards to the environment

The half-life of the product is the time it takes for 50% of the active ingredient to decompose. Substances with long half-lives such as diquat, paraquat, diflufenican or diuron are more hazardous *a priori* than substances like glufosinate which decompose quickly. However, environmental conditions affect these parameters considerably because actual degradation depends on many factors, notably microbial activity, temperature and humidity. Nevertheless, the half-life of some herbicides has to be sufficiently long by necessity. This is the case of soil-acting pre-emergence herbicides because the product has to remain for some time without decomposing so that it can act during weed emergence. As can be seen from Table 3, diuron and simazine have a half-life of 90 and 60 days respectively, which are necessary for the herbicide to act during various months.

The soil adsorption coefficient Koc (Table 3) indicates the risk of water pollution through leaching (Koc= Kd x 1.724 x 100/% of organic matter). If the Koc value is low (< 1000) there is a high risk of polluting groundwater. However, this risk depends in turn on the length of time the product lies on the soil, the half-life and the soil permeability capacity. Products with low Koc values also have a short half-life. Clearly, a product cannot be authorized if it poses a high pollutant risk and it has a long half-life and a low Koc value. The risk in sandy soils is greater than in clay soils.

It is vital to bear these parameters in mind, particularly in special hazard situations.

4.4.3. Hazards to the agrosystem

Herbicides cause important changes in the flora (see section 4.3.) and can also become less effective.

Loss of flora diversity is one of the most visible effects. The species most sensitive to the herbicide applied tend to disappear while the populations of the most tolerant species increase.

Resistance and tolerance. Repeated treatments with the same herbicide lead to the appearance of resistant and tolerant species or ecotypes, which become dominant and harder to control. When problems like this occur, the answer is not to raise the dose but to change the control strategy and even the type of herbicide.

Accelerated degradation. This occurs as a result of specialization of the micro-organisms which break down the herbicide, so shortening its half-life considerably and making the product lose effectiveness through the soil.

To avoid imbalances of this kind it is advisable to alternate herbicides belonging to different groups in terms of their mode of action (see Table 2) and the timing of application (different dates for pre- and postemergence).

4.4.4. Hazards to the crop and harvest

Herbicides must not wet the branches of the olive tree because they can cause phototoxicity. Herbicide risk is greater when the product is absorbed by the leaves and green parts of the plant and it has a high translocation power; this is the case of amitrole, MCPA, glyphosate, etc. Damage can also occur when the herbicide is absorbed through the roots. This is more likely to happen if the herbicide persists for a long time in the soil. Terbuthylazine is one of the herbicides which causes most accidents in this respect.

If the herbicide comes into contact with the olive fruits, the resultant oils may be contaminated. This can occur because it has been absorbed by the tree, because the fruits are wetted during spraying or because of contact on the treated soil. The Kow coefficient helps to estimate the degree of risk posed by the different products because it indicates product affinity for an organic solvent (octanal) compared with water. If the Kow value is high the product will probably remain in the oil; if it is low, it will be removed in the wash water. The products which pose a greater risk from this point of view are diflufenican, oxyfluorfen, quizalofop-P, terbuthylazine, diuron, MCPA and simazine. In contrast, diquat and glyphosate are lower-risk.

4.4.5. Special cases of hazards

Handling near watercourses and wells

Herbicide handling in high-risk situations is frequently responsible for causing pollution. When handling herbicides, keep away from water sources, wells, reservoirs or watercourses. Take extreme care when filling the tank with water to make sure that liquid containing the herbicide is not spilled onto the clean water. One option is to use pumps with an anti-runback device. Add the products carefully to the spray tank. When cleaning spray equipment, do not empty the dirty water into watercourses or urban collecting systems.

Inappropriate cultural practices

After the application of a persistent, soil-acting herbicide the ground should not be worked until the product has been degraded because working it deeply into the soil favours its absorption by the olive tree roots.

Small trees

Maximize precautions when applying foliar-acting herbicides, especially to young trees which can absorb them through the leaves and tender trunk. Be particularly careful if the herbicide is translocated because it will affect the entire plant.

Special climatic conditions: drought–excessive water

In specific circumstances, herbicides with a low Koc level may be absorbed in large amounts through the roots, so causing damage to the olive tree. To give an example, if abundant rainfall occurs after applying this kind of herbicide in drought conditions the herbicide passes into the soil solution and may be quickly absorbed by the tree. Damage of this type has occurred in the case of MCPA treatment at the end of a dry winter.

Water lying on the ground

No herbicide may be applied when water is lying on the ground, for instance after abundant rainfall or when the crop is being irrigated, irrespective of whether irrigation is by surface, sprinkler or drip methods. In these circumstances, the herbicide will very probably penetrate through to deep soil layers or be absorbed by the olive tree. Wait until the water drains away, then apply the herbicide, wait one or two days and water again. If heavy rain is expected, do not apply the herbicide.

Sandy soils with low organic matter content

Soil adsorption of herbicides is low in soils that are sandy and which have a low organic matter content. The herbicide is much more likely to be leached or absorbed by the olive trees than in the case of clay soils containing a large amount of organic matter. For this reason, the authorized doses for sandy soils tend to be lower.

High temperatures

More volatile products like MCPA can produce phytotoxicity if applied at high temperatures. In such conditions products of this type cannot be sprayed over large areas. Instead their use should be confined to patches of specific species which are hard to control by alternative means.

Very persistent herbicides – long-term phytotoxicity

Herbicide-induced phytotoxicity sometimes becomes apparent in the long term, even after a year. Sometimes it occurs with soil-acting herbicides, which are absorbed through the roots, or with translocated herbicides in which case clear-cut symptoms do not occur and growth is merely delayed or halted. It is very important to know about the hazards of each herbicide in each agroclimatic situation and to avoid repeated applications of the most hazardous herbicides in such situations.

Commercial containers

Containers should be rinsed two or three times and the rinse liquid should be added to the tank. They should then be stored in suitable premises for subsequent collection.

4.5. HERBICIDE APPLICATION MACHINERY

Herbicides are normally applied in olive orchards by hydraulic, air induction (hydro-pneumatic) or ultra low volume (ULV) spraying. They can be used over the whole area or part of it, in bands or patches. The type of spraying is decided by how the droplet is produced according to the kind of spray tip (nozzle) used. Spray mix volumes of between 50 and 1000 l/ha can be applied in hydraulic and air induction spraying at pressures normally from 1.5 to 4 bar. ULV spraying involves spraying small, uniformly sized droplets, which can be applied at between 5 and 50 l/ha depending on the speed of the spinning disc (Table 4).

TABLE 4
Droplet size and spray volume applied per hectare according to speed of ULV spinning disc

Disc speed Rpm	Droplet size Microns	Volume applied l/ha
2,000	250	30
3,500	160	15-25
5,000	70-100	4-5

Source: CAP (2003). *Aplicación de Plaguicidas, Nivel Cualificado, Manual y Ejercicios. Cursos Modulares. CAP, Junta de Andalucía.*

Sprayers can be hand-operated or power driven, tractor trailed or mounted. Extensive information on the different types of equipment can be found in Boto and López (1999) and Saavedra and Humanes (1999). The most usual ones are:

Hand-operated sprayers:

- Knapsack (backpack) sprayers (Fig. 2) with a 15-16 litre capacity tank. They can carry spray bars with between one and four hydraulic or air induction spray tips and are lever-operated.
- Battery-operated sprayer with centrifugal spray tips (Fig. 3).

Figure 2. Knapsack sprayer with hand-operated lever.

Figure 3. Battery-operated sprayer with centrifugal spray tip.

Power-drawn sprayers:

- Large sprayers (Fig. 4), fitted with tanks with a capacity of between 500 and 1500 l and booms capable of carrying any type of spray tip, although hydraulic or air induction tips are the most usual ones. They are used for herbicide application over large areas.

Characteristics and parts of power-drawn sprayers

Sprayer parts and materials should be resistant to corrosion and/or abrasion. The sprayer is made up of a tank for holding the water and herbicide which is equipped with an agitation system; a pump capable of reaching a pressure of at least 5 bar, with a return flow system for excess spray mixture; distributor; spray delivery pipes with line filters; opening and shut-off valves; pressure and flow regula-

Figure 4. Power-driven sprayer with large-capacity tank and front and rear booms.

tors; suitably scaled pressure gauge permitting easy distinction between pressures from 0 to 8 bar approximately; and a boom. They may also be fitted with other more sophisticated control devices. Close-ups can be seen in Figure 5.

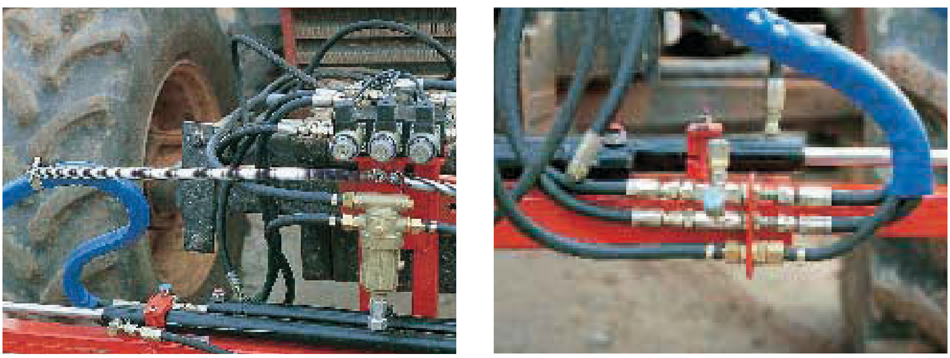

Figure 5. Close-ups of distributor and line filter and boom piping and hydraulics.

Pump

Various types of pump can be used, but it is very important for them to have a low flow rate and to keep a low nozzle pressure. Equipment designed for leaf spraying reaching pressures of up to 20 or 30 bar is often used. In the circumstances in which herbicides are applied, it is not possible to lower the pressure and keep it stable at the required pressure of 1.5-4 bar.

Boom

The boom should be sturdy and fitted with a break-back device to avoid breakage and blows to the olive tree in the event of accidental collision. It should be adjustable to irregularities in the terrain and folding for easy transportation. Total boom length should not be more than 6 m. Longer booms cannot usually be used because there is a risk of wetting the trees due to uneven ground. It advisable to mount the boom in three sections. The two wing or side sections should

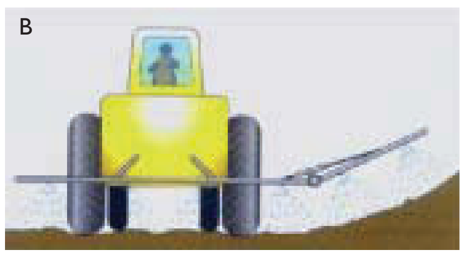

Figure 6. (A) Close-ups of boom sections and end spray tip arrangement. (B) Adaptation to changes in slope.

be mounted at the front of the tractor while the middle section should be set at the rear to avoid running over areas already sprayed (Fig. 6).

Spray tips

Spray tips are the most important part of the sprayer. Many types are found, but manufacturers' catalogues indicate which ones are suitable for herbicide spraying.

The most usual ones are hydraulic flat spray tips (symmetric distribution) and off-centre flat spray tips (asymmetric distribution). These include what are called anti-drift tips because they produce larger, more uniform droplets and they may be of the hydraulic or air induction type. There are also cone spray tips (hollow or full), which are normally used in hand-operated knapsack sprayers.

Spray tip flow rate and filters

The orifice size of the spray tip determines its flow rate (q), which varies with spraying pressure (p) according to:

$$q_1^2/p_1 = q_2^2/p_2$$

TABLE 5

Colour coding according to ISO 10.625:1996 for different spray tip sizes and flow rates delivered at a rated pressure of 3 bar for 50-cm tip spacing according to the forward speed

Reference	Colour	Output at rated pressure of 3 bar (l/min)	Application volume at rated pressure of 3 bar (l/ha)	
			4 km/hr	6 km/hr
01	Orange	0.4	97	65
015	Green	0.6	150	100
02	Yellow	0.8	195	130
03	Blue	1.2	300	200
04	Red	1.6	390	260
05	Brown	2.2	495	330
06	Grey	2.4	600	400
08	White	3.2	750	500

ISO standard 10.625:1996 specifies a colour coding system for spray tip flow rates to which manufacturers are gradually adapting (Table 5). If you buy new tips the colour identification will very probably coincide with the table, but if you are going to use old ones it is best to check the characteristics – do a test if necessary – rather than to judge the flow rate by the colour of the tip. Spray tips get worn with use and the orifice becomes bigger, and sometimes they become clogged owing to precipitation of the herbicide. They should be changed every so often when the variation in the flow rate is more than 10% of the rated flow.

Each spray tip should be fitted with a filter (strainer) to make sure it works properly (Fig. 7). The filtration area should be as wide as possible to prevent clogging and the need for continual cleaning in the field. For this reason top hat-style filters are better than cup filters. Make sure you use the right filter mesh size for the size of the exit orifice; 100 mesh filters are usually used for 01 and 015 orifices and 50 mesh filters for 02 or bigger orifices. Product catalogues specify the right filters for each tip. However, individual spray tip filters are tending to be replaced by

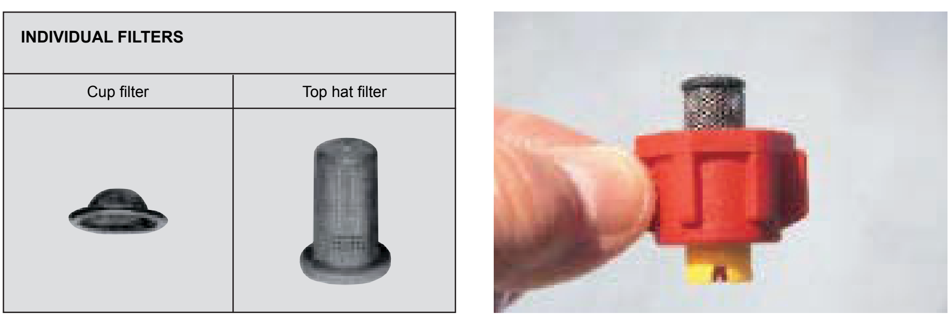

Figure 7. Types of spray tip filters.

line filters with a larger filtration area for 3-5 tips because they avoid clogging and the need for cleaning in the field during application.

Flow distribution

Spray tips can deliver a bell-shaped or uniform flow distribution (Fig. 8). The first type can be mounted in series on the boom so they overlap and give a broad, uniform swath of product. Off-centre spray tips give an asymmetric bell shape and are used for the boom ends as will be seen later on. Conversely, uniform-distribution spray tips cannot be arranged in series on the boom because of incorrect overlapping; however, they are useful for applications in narrow bands, for instance along dripper lines.

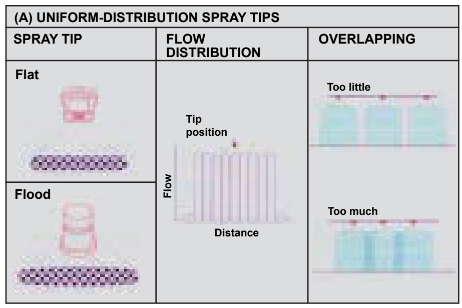

Figure 8. Flow distribution of different types of spray tips.

At a specific spray tip spacing, flow distribution varies according to application height. The spray angle also has an influence and varies according to the type of tip and pressure. The tips normally used for olive orchards have a spray angle of 110° because this allows the spray mixture to be distributed uniformly when spraying at a low height. They are spaced 50 cm apart and positioned at a height of 50 cm above the grass or soil, and pressures of between 2 and 3 bar are usually applied.

Spray tip identification

The model, brand name, spray angle, outlet orifice size (this indicates the flow rate) and material are usually stamped on the tips (Fig. 9).

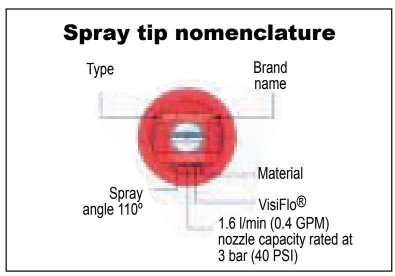

Figure 9. Spray tip identification: type, brand name, spray angle, capacity, material.

Droplet size, drift and operating pressure

Droplets are classified by size as very fine, fine, medium, coarse, very coarse and extremely coarse (ASAE standard S-1572). Fine and very fine droplets are very likely to drift**.** It is important for droplet size to be homogeneous and for the number and volume of very fine droplets to be as low as possible to avoid hazards and damage from product drift. Droplets measuring between 200 and 600 microns are recommended for herbicides, which is relatively large compared with the sizes recommended for insecticides (200-350 microns) or fungicides (100-200 microns). Droplet size is determined by the type of spray tip; the percentage of fine or very fine droplets is very low in some models, which are called anti-drift (Table 6.). Operating pressure affects droplet size in that the higher the pressure, the smaller the droplets and the greater the drift (Table 6). It also affects the spray angle, which is wider at higher pressures. For all these reasons herbicides are applied at low pressures, normally between 1.5 and 4 bar. The pressure should be checked not only at the pump outlet but also just before the tip outlet. Remember that tips are designed to operate at specific pressures. If operated at pressures outside their range they do not work properly.

TABLE 6
Percentage of spray volume of driftable droplets of less than 200 microns at different pressures

Spray tip type	Pressure 1.5 bar	Pressure 3 bar
Standard 110 03	14%	34%
Standard 80 03	2%	23%
Drift guard 110 03	< 1%	20%
Drift guard 80 03	< 1%	16%

Source: Teejet catalogue. Agricultural spray products. Buyer's guide 210-E. Spraying Systems Co.

Spray tip arrangement on the boom

Saavedra and Humanes (1999) discuss various ways of arranging the spray tips on a boom. We will look in detail at the two most frequent arrangements for application in bands along the centre of the orchard lanes and under the tree canopies respectively.

Herbicides are easily applied along the centre of the orchard lanes using flat spray tips (symmetric distribution) (Fig. 10). These should be placed slightly tilted to the vertical plane of the boom to prevent the tips from bumping each other (Fig. 11).

In contrast, herbicide application under the olive canopies poses problems. Boom manoeuvring and visibility are hindered when the trees are large or they have several trunks or low branches. This is why asymmetric-distribution, off-centre flat spray tips are placed at the end of the boom to allow spraying at some distance while symmetric-distribution flat spray tips are placed along the rest of the boom. Figure 12 gives a schematic diagram of spraying. Clearly, a number of conditions has to be met to ensure correct spraying and uniform spray distribution. These conditions, analyzed in detail in Saavedra and Humanes (1999), are now summarized.

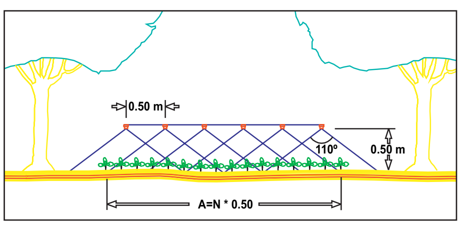

Figure 10. Schematic representation of spraying with flat spray tips (symmetric distribution) for banding along the middle of the orchard lanes.

Because of the way in which it distributes the flow, the end spray tip makes it possible to spray under the tree and beyond the trunk. The same occurs on the other side of the tree, in the next run. After the two runs, spray coverage should be homogeneous. For this to happen, the flow delivered by each tip in its corresponding swath should be as similar as possible. Put differently, at a given pressure, where q_1 is the rated flow of each flat spray tip, d_1 is the distance between the flat spray tips, D is the distance from the last flat spray tip to the tree and q_2 is the rated flow of the off-centre tip, the outputs delivered by each tip in the width they apply should be very similar:

$$q_1 / d_1 \cong q_2 / (D-(d_1/2))$$

Additionally, the range of the off-centre tip should be neither too little nor too much, i.e:

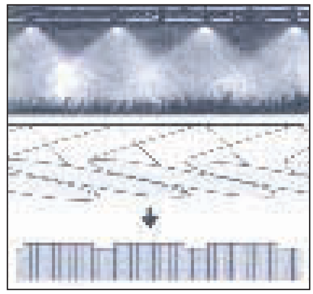

Figure 11. Arrangement of flat spray tips slightly tilted to the vertical plane of the boom.

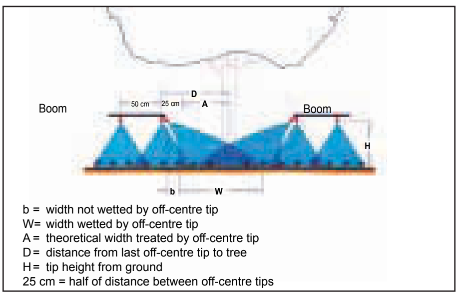

Figure 12. Schematic representation of spraying with flat (symmetric distribution) and off-centre flat spray tips (asymmetric distribution) for banding under the canopies.

- The distance b + W must be greater than the distance between the last flat spray tip and the tree in order for overlapping to occur.
- The distance b + W must be less than or equal to the distance between the last spray tip and the tree to avoid overapplication in the area sprayed by the symmetric-distribution tip.

Table 7 lists the possible combinations calculated for one type of spray tip at a rated pressure of 3 bar.

In addition, flow distribution has to be homogeneous and should be checked once the tips are arranged on the boom, for instance by using a device similar to the one shown in Figure 13 or at centres authorized to check and calibrate agricultural machinery.

Forward speed

It is not easy to apply herbicides at high tractor speeds in olive orchards for several reasons: sloping ground, irregular layouts, short runs and the risk of wetting the trees. Consequently, they are normally applied at between 4 and 6 km/hr. Low volumes of spray mix are not readily applied in conditions like this because they require the use of spray tips with small orifices which clog easily.

The speed should be checked before starting to apply the herbicide. Table 8 shows the time it takes to cover 100 m at different forward speeds.

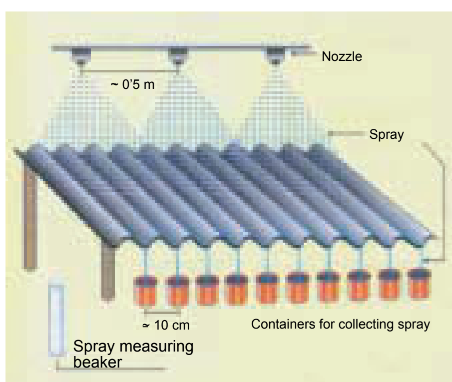

Figure 13. Schematic representation of a simple device for checking the uniformity of spray distribution by a herbicide spray boom.

TABLE 7
Output per metre width of sprayed band delivered by wide angle spray tips spaced at 50 cm and by off-centre spray tips located at the end of the boom according to the distance from the last wide angle spray tip to the tree.

Outputs per minute and metre PRESSURE 3 BAR					Rated outputs/Theoretical width l/m/min — Distance from last off-centre spray tip to tree (cm)						
Asymmetric Distribution	W cm	b cm	W+b cm	Rated output l/min	0.75	100	125	150	175	200	225
TEEJET OC-02	177	45	222	0.79	1.58	1.05	0.79	0.63	0.53	0.45	0.40
TEEJET OC-03	203	40	243	1.18	2.36	1.57	1.18	0.94	0.79	0.67	0.59
TEEJET OC-04	236	30	266	1.58	3.16	2.11	1.58	1.26	1.05	0.90	0.79
TEEJET OC-06	256	30	286	2.37	4.74	3.16	2.37	1.90	1.58	1.35	1.18
TEEJET OC-08	259	30	289	3.16	6.32	4.21	3.16	2.53	2.11	1.80	1.58
TEEJET OC-12	264	30	294	4.74	9.48	6.32	4.74	3.79	3.16	2.71	2.37
TEEJET OC-16	350	25	375	6.32	12.6	8.43	6.32	5.06	4.21	3.61	3.16

Symmetric distribution	Rated output l/min	Rated output/Theoretical width l/m/min
TEEJET 110-015	0.59	1.18
TEEJET 110-02	0.79	1.58
TEEJET 110-03	1.18	2.36
TEEJET 110-04	1.58	3.16

TABLE 8
Time taken to cover 100 m distance at different tractor speeds

Speed km/hr	3	4	5	6	7
Time taken to cover 100 m	2 min	1 min 30 sec	1 min 12 sec	1 min	51 sec

4.6. HERBICIDE SPRAYER CALIBRATION

Sprayer calibration is carried out in three stages (see Boto and López (1999) and Saavedra and Pastor (2002)):

1. The first stage is theoretical and entails establishing the calibration parameters.
2. The next stage is to set the machinery to meet the pre-established theoretical parameters.
3. Next the machinery setting is checked and re-adjusted if necessary.

Calibration parameters

Carefully clean the sprayer and all the sprayer parts. Depending on the characteristics of the target plot, determine a comfortable forward speed for the tractor driver at which they are able to change gear and maintain the engine speed.

Determine the output of all the tips (Q), the working width (a) and the volume of spray mixture for application per hectare (V) at the chosen forward speed (v).

The tips and operating pressure will have been chosen according to the recommendations given in earlier sections.

V (litres/hectare) = 600 x Q (litres/minute) / v (kilometres/hour) x a (metres)

Calculate the amount of product (D) for addition to each tank according to the volume of spray mix to be applied.

If the parameters do not lie inside the desired range, recalculate for other conditions.

Machinery setting

After doing the calculations and determining the correct parameters, check the functioning of the equipment: engine speed, boom height, conduits, regulators, opening and shut-off valves, filters, spray tips (correct type of tip, spacing, slightly tilted positioning, state of filters), fix the pressure and check the flow rate. Do all this with the tank filled with clean water, before adding the herbicide. Correct output distribution can be checked on-farm by using simple devices like the one shown in Figure 13. Then check the tractor forward speed and make sure the mechanisms for extending, opening and folding the boom work properly.

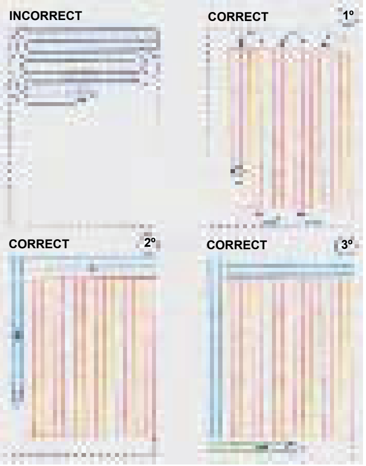

Figure 14. Correct and incorrect ways of turning and applying herbicides along the plot borders.

Application conditions

Make sure the environmental conditions are right for applying the herbicide: no wind, no threat of rain, intermediate temperatures, no mist and no advective conditions. The terrain the machinery has to go over should be even and free from potholes so there is no risk of the tree being wetted when the boom swings.

Plan ahead to avoid unnecessary overlapping and unsprayed areas. Begin by spraying the middle of the plot, then spray the borders where the tractor has had to manoeuvre. Figure 14 shows the correct way of spraying a trapezoidal plot.

When sure that everything is correct, fill the tank with clean water, switch on the agitator and add the herbicide at the calculated rate. Never add the product far in advance of spraying because deterioration and flocculation may occur. If various products have to be mixed, or additives or pH correctors have to be added, do so in the tank unless the product states otherwise. Do not make up mixes in small tubs for later addition to the tank.

Equipment cleaning and maintenance

Filters and spray tips can become clogged during spraying and therefore need cleaning. They should never be cleaned with harsh products; use water and wash them gently. Never put them in your mouth to blow them clean because of the risk involved.

When spraying is completed no spray should be left over if the calculations were done properly. If a small amount *is* left over, do not discharge it into watercourses or sewers but store it in places designed specifically for such products.

The equipment should be cleaned meticulously, depending on the products used:

- Oily products: clean with liquid detergent and rinse with water.
- Hormone herbicides: clean with a 20% ammonium solution and rinse several times, or clean with 100 g of active carbon for every 100 litres for 12 hours.

Detach all the spray tips and filters, empty the conduits and pumps, lubricate all the mechanical parts, release the pressure on the control valve so that the spring is unloaded and repair any damage to the equipment.

Replacement of filters and spray tips

Filters deteriorate with time and the size of the spray tip orifice increases through wear. At times, precipitation may occur and reduce orifice size. The tips should be replaced when flow varies by more than 10% of the rated flow.

4.7. SPRAY GUNS

Spray guns are sometimes used when it is difficult to apply herbicides with boom sprayers. These facilitate access to areas that cannot be reached by conventional equipment, but spraying is frequently done at pressures which are too high. However, herbicides can be applied correctly with spray guns as long as they are applied at low pressure (1-5 bar), they are distributed uniformly and the correct droplet size is employed. To give an example, the off-centre tips placed at the boom end for application under the olive tree canopy can be fitted to a spray gun. Points to remember to make sure the product is properly distributed are that the gun has to be held in the right position, at the correct distance and height, and at a distance from the tree that permits correct overlapping when the herbicide is sprayed on the other side of the tree.

Sprayers with rotary, "cassotti"-type tips are not suitable for applying herbicides to olive because it is difficult to achieve uniform distribution without wetting the tree.

4.8. SAFETY DEVICES

Protective screens are available to facilitate safe applications under the canopy of the olive without wetting the tree. However, in practice, these kinds of screens are usually only used with hand-operated equipment because they catch easily on branches and trunks. They should be designed in materials and shapes adapted to olive growing conditions.

Devices are available to apply herbicides in the planting lines; these allow the operator to get close up to the olive tree, even when it is very small, without the risk of wetting. The sprayer is fitted with a centrifugal tip which applies the herbicide at a very low pressure, and with a mechanism for approaching and moving round the tree, which avoids the risk of wetting the tree while enabling the herbicide to be applied closely to it. This kind of device is very useful for controlling small and medium-sized weeds.

4.9. SUMMARY OF GUIDELINES FOR HERBICIDE APPLICATION

- Inspect the olive orchard, identify the weeds and assess the damage.
- Determine the right time to control the weed or cover crop and choose the appropriate herbicide.
- Other things being equal, choose the least hazardous herbicides but remember there is no zero-risk and that overuse of one single product also entails risk.
- Avoid repeated application of the same active ingredient. Instead, alternate products with different application timings, modes of action and characteristics. Avoid applying the same product to very wide areas at a specific time.
- Read the label carefully and closely follow all the instructions.
- Make sure operators wear special protective clothing, which should be cleaned carefully after each use.
- Use machinery specific for herbicide application. Do not apply herbicides with high-pressure sprayers or sprayers designed for other purposes.
- Keep the sprayer clean and calibrated.
- Choose the spray tips best suited to the type of herbicide and application conditions. Replace worn parts, e.g. tips when the flow varies by more than 10% of the rated output.
- Check the atmospheric, soil and weed conditions. Do not spray if it is windy, if rain is expected or if there is a risk of damage to the olive trees, operators, other crops or the environment. In particular, do not apply herbicides in advance of heavy rain, especially in areas where run-off may occur, or if the herbicide has a high half-life or low adsorption coefficient.
- Fill the tank and handle the herbicide products carefully.

- Do not apply the herbicide to olive fruits intended for harvesting or to the trees, except in the case of applications specially authorized for such purposes.
- Do not apply herbicides with a high Kow to the soil if the olive fruits are expected to be harvested shortly from the ground.
- Spray at low pressures, below 4-5 bar. Note down the environmental conditions of spraying.
- Monitor spray effectiveness and weed or crop cover development and note down as appropriate for subsequent applications.
- If an operator is poisoned, contact a doctor and give them the product label. In the meantime, give the operator First Aid.

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5

Fertilization

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5.1. INTRODUCTION

Fertilization is a common practice in olive growing as it is designed to satisfy the nutritional requirements of trees when the soil does not provide sufficient quantities of nutrients for them to grow. All soils have many characteristics in common, but each one differs considerably in terms of its morphological features and fertility. Similarly, all plants need the same nutrients to grow, but their capacity to take them up from the soil varies from species to species and variety to variety. The requirements of a young olive may differ from those of a mature tree, and the cultivation system may also affect nutrient availability to the tree. Hence, each crop on each orchard poses different problems at different times. It would be illogical, therefore, to issue general recommendations for annual fertilizer applications, even for the same crop in the same locality.

However, repeated fertilization programmes entailing the simultaneous application of several nutrients are customary in many olive-growing areas. A survey of olive fertilization practices in the Mediterranean region conducted in 2001 revealed that 97% of applications were mineral fertilizers. In 77% of cases, the fertilization programme was repeated every year and generally involved applying several mineral elements, which always included nitrogen, although applications did not correspond to the nutritional deficiencies of the olive orchards, which in almost 50% of the cases were not even known. This approach tends to apply more elements than necessary, some of which may already be available to the tree in sufficient amounts to guarantee a good crop. Other possibilities are that it may cause deficiencies because a specific element is not applied in sufficient amounts when required by the crop, or it may lead to the application of excessive amounts of elements. This practice increases growing costs, contributes unnecessarily to soil and water pollution and may have a negative effect on the tree and crop quality.

Rational fertilization has the following objectives:

1. To satisfy the nutritional needs of olive orchards.
2. To minimize the environmental impact of fertilization, particularly in terms of soil, water and air pollution.
3. To obtain a quality crop.
4. To avoid systematic, excessive application of fertilizers.

5. 2. DETERMINING NUTRITIONAL REQUIREMENTS

The olive, like other plants, needs 16 essential elements to complete its growth cycle, namely: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B) and chlorine (Cl). These elements are essential because the plant needs them to complete its life cycle, no element can be replaced by another, and each one is directly involved in plant growth or metabolism.

The first three elements – C, H and O – are non-mineral and account for approximately 95% of the dry weight of an olive tree. However, they are not applied in fertilization because the tree takes them up from the air (CO_2) and from the water (H_2O) in the soil, the combination of which forms carbohydrates through photosynthesis. This explains why water deficit causes such a drastic reduction in crop growth and production. The remaining 13 elements are minerals and are applied through fertilization. Together, they represent approximately 5% of the dry weight of an olive tree, which is why it is easy to apply them in excess. The roots of the olive tree absorb these elements from the soil solution where they are present in the form of ions; once they are taken up by the tree, they must balance each other.

Fertilization has to satisfy the mineral requirements of the tree, but many mineral elements are available in the soil solution in sufficient amounts. Hence, systematic fertilization with a mix of such elements would not be rational. It would not even be rational to fertilize in order to replenish the soil solution with the elements removed by the crop, because this does not take into account luxury consumption, the re-use of nutrients by the tree, the application of elements in irrigation water or rain, mineralization, tree reserves or nutrient dynamics in the soil exchange complex. It is a documented fact that plants do not respond to fertilization when sufficient amounts of an element are available in the soil solution.

Diagnosing the nutritional status of the olive orchard is the only option for determining its nutritional requirements at a specific time. Leaf analysis, i.e. chemical analysis of a sample of leaves, is the most precise diagnostic method. Coupled with details of the soil characteristics and tree appearance or symptoms, leaf analysis helps to diagnose the nutritional status of the olive orchard and to work out fertilization recommendations. Leaf analysis is useful for identifying nutritional disorders, for detecting low nutrient levels before detrimental deficiencies appear, for measuring the response to fertilization programmes and for detecting toxicities caused by elements such as chlorine (Cl), boron (B) and sodium (Na), which should be confirmed by analyzing the soil and, where applicable, the irrigation water.

The *critical level of a nutrient* is defined as the nutrient concentration in the leaf below which plant growth and production rates decrease compared with other plants with higher concentrations. These levels are universal for each species and are valid irrespective of where or how the plants are cultivated. Table 1 gives the critical nutrient levels in olive leaves.

TABLE 1
Interpretation of nutrient levels (dry-weight basis) in olive leaves sampled in July

Element	Deficient	Adequate	Toxic
Nitrogen, N (%)	1.4	1.5-2.0	-
Phosphorus, P (%)	0.05	0.1-0.3	-
Potassium, K (%)	0.4	>0.8	-
Calcium, Ca (%)	0.3	>1	-
Magnesium, Mg (%)	0.08	>0.1	-
Manganese, Mn (ppm)	-	>20	-
Zinc, Zn (ppm)	-	>10	-
Copper, Cu (ppm)	-	>4	-
Boron, B (ppm)	14	19-150	185
Sodium, Na (%)	-	-	>0.2
Chlorine, Cl (%)	-	-	>0.5

Compiled by Fernández-Escobar (2004).

The critical levels as defined earlier correspond to the deficiency values listed in Table 1 for each nutrient. Higher concentrations may indicate levels that are low (between deficient and adequate), adequate, excessive (above adequate levels) or toxic. High values of most nutrients do not cause toxicity as such; however, if they are excessive and lie outside the adequate range they may affect the use of other nutrients or plant metabolism and so trigger negative reactions in the tree. All that needs to be done to determine whether the level of an element is deficient, low, adequate or excessive is to compare the results of the olive leaf analyses with these critical levels, and to take any necessary corrective measures. For the diagnosis to be correct, leaf sampling must be carried out according to strict rules, outlined farther on.

Iron (Fe) is the one exception to what has just been said, because it accumulates in leaves, even under conditions of deficiency. Visual inspection of symptoms, which is always advisable to ensure a good diagnosis, is essential for this element. The characteristic symptoms of iron deficiency are leaf chlorosis, which can vary in intensity although the leaf veins remain green, smaller terminal leaf size and shorter shoot length (see Fig. 6). This deficiency is found frequently in olive orchards growing on very calcareous soils.

5.2.1. Leaf sampling

Olive leaves can be of three different ages: current season, one-year-old or two-year-old. The physiological functions and nutrient content of each kind varies, which means that leaf sampling cannot be carried out totally at random. Additionally, leaf mineral content changes through the year (Fig. 1); as a result, sampling has to be done at the time of year when content changes the least. In any case, leaf sampling has to be performed in the same way as for determining the critical levels shown in Table 1, or else the results will give a wrong diagnosis. The sample must also be representative of the block being studied.

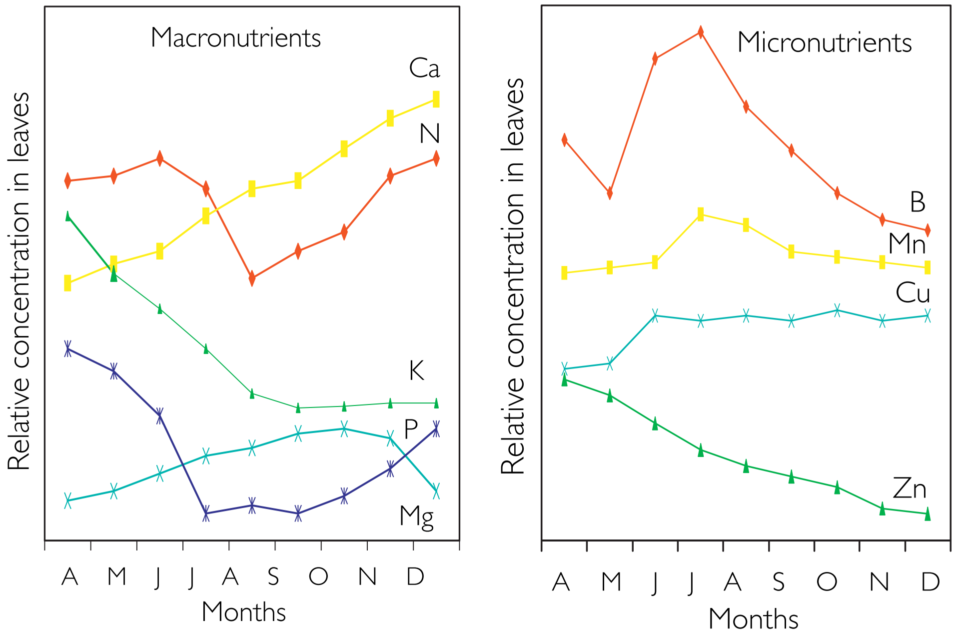

Figure 1. Seasonal changes in nutrient concentration of current-season leaves (from Fernández-Escobar et al.*, 1999).*

The procedure is as follows:

1. Differentiate the blocks by soil type, variety, tree age, cultivation system or any other distinguishing characteristic.
2. Take the samples during the period of summer vegetative rest. This coincides with the month of July – preferably the second fortnight – in the northern hemisphere.
3. Take a sample of approximately 100 leaves from each block. If the block is large, take more samples, at least in the first years.
4. Take the samples from several trees in each block, selected at random along a route through the block in the same way as for soil sampling (see Fig. 3).
5. Take 2-4 leaves per tree. The leaves should be taken from representative shoots located on different sides of the middle section of the canopy. Very vigorous shoots or shoots that show little growth should be avoided, as should those located inside the canopy.
6. Take current-season leaves, 3-5 months old, that are expanded to full size and have a petiole. These are the characteristics of middle-to-basal leaves of current-season shoots in the month of July (Fig. 2).

Figure 2. Bearing shoot in July. The fruitless, apical half represents current-season growth from which the leaves are taken for sampling.

7. Do not take leaves from abnormal or symptomatic trees unless they are collected as a separate sample. Leaves collected for leaf analysis should appear to be symptom-free.
8. Clearly identify each leaf sample and place it in a paper bag, which should be kept in a portable cool box during sampling.
9. Quickly send the samples to the laboratory for analysis, or keep them in a conventional fridge until they are sent.

5.2.2. Analyzing soil fertility

Knowing the soil characteristics is of great help in planning olive fertilization and requires studying the soil profile by digging soil pits in representative parts of the orchard. Soil profile analysis indicates the type and physical, chemical and biological conditions of the soil and gives an idea of the soil limitations for olive growing. Consequently, this type of analysis should be carried out before planting the orchard and it should be borne in mind in any subsequent course of action.

From the fertilization point of view, this knowledge will indicate the amount of nutrients in the soil and nutrient availability to the trees. If the soil of an olive orchard contains a small quantity of a given nutrient, the orchard will be expected to record deficiencies in the nutrient at some point in its lifetime. However, if the soil content is normal, this does not mean that the nutrient is available to the trees whenever they need it because its uptake may be blocked because of the soil characteristics. The calcareous conditions of many Mediterranean soils is a clear example of soils that block the uptake of certain mineral elements. Hence, although very useful in crop management and fertilization, soil analysis is of limited use in determining the nutritional requirements of olive orchards.

Fairly regular soil fertility analyses are useful, however, for the fertilization programme because they reveal changes in the content of available nutrients and they are essential for diagnosing toxicities caused by excess salts, especially those due to excessive concentrations of sodium, chlorine and boron.

5.2.3. Soil sampling

Soil samples should be representative of the volume of soil explored by the roots in the block studied. Because soil nutrient content differs vertically and horizontally, separate samples should be taken of each soil horizon or layer at different points in the sampling block.

Sampling procedure is as follows:

1. Differentiate the blocks by soil type, topography, variety, etc., as for leaf sampling.
2. Establish a route through the block as shown in Figure 3, taking one subsample of each soil layer at each point. Except in special circumstances, it is sufficient to take one sample at a depth of 0-30 cm and another at 30-60 cm. A soil auger or hoe can be used to collect the sample.

3. Take at least 8-20 subsamples of each depth. Make sure the samples from each depth are kept separate and that all the subsamples from each layer contain the same amount of soil.

4. On completing the route, mix all the subsamples of each soil layer as uniformly as possible to form a compound sample. Separate a portion of approximately 0.5 kg for fertility testing.

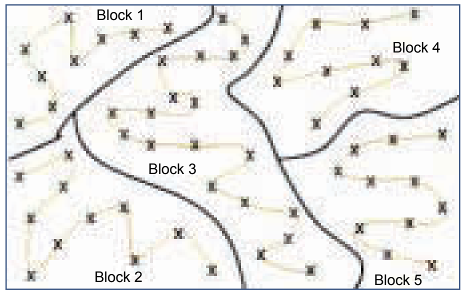

Figure 3. Division of an olive orchard into five blocks and routes for soil sampling.

5. If the subsamples are wet, allow them to dry before mixing them. Air-dry the compound samples, place them in identified plastic bags and send them to the laboratory for analysis.

5.2.4. Interpreting soil fertility analyses

The critical level of a nutrient in the soil is the nutrient concentration above which an increase in fertilization does not lead to greater growth or crop production. This value does not depend solely on the nutrient content in the soil but also depends on other soil characteristics affecting nutrient availability to the crop. The critical level of each nutrient in the soil is not determined specifically for olive; instead, generic data are available for application to many crops. In any case, if a soil nutrient concentration is low or very low, fertilization could be expected to produce a positive response which would not occur if the concentrations are middling or high.

The ***nitrogen*** available in the soil solution is subject to processes of losses and gains, which are sometimes climate-dependent. This means no precise testing procedure can be used to indicate crop nitrogen availability.

The critical ***phosphorus*** level in the soil depends on the testing method employed. The Olsen method is the most appropriate for soils ranging from moderately acid to alkaline and calcareous. Table 2 provides an interpretative guide for a broad range of crops. The critical level can be assumed

TABLE 2
Interpretative guide to soil phosphorus levels

Interpretation	Phosphorus (Olsen method) (ppm)
Very high	>25
High	18-25
Medium	10-17
Low	5-9
Very low	<5

Source: FAO, 1984.

to be not more than 9 ppm for olive because olive orchards do not generally respond to phosphorus fertilization.

The availability of ***potassium, calcium and magnesium*** corresponds to the exchange contents of these nutrients and requires knowledge of the texture or cation exchange capacity (CEC). The levels are interpreted in Table 3 and, as already explained, are not specifically for olive.

TABLE 3
Interpretation of available levels of potassium, calcium and magnesium according to soil texture and CEC

Texture	CEC	Interpretation	K (ppm)	Mg (ppm)	Ca (ppm)
Coarse	Low (<5 $mmol_c$/kg)	Very high	>100	>60	>800
		High	60-100	25-60	500-800
		Medium	30-60	10-25	200-500
		Low	15-30	5-10	100-200
		Very low	<15	<5	<100
Medium	Medium (5-15 $mmol_c$/kg)	Very high	>300	>180	>2400
		High	175-300	80-180	1,600-2,400
		Medium	100-175	40-80	1,000-1,600
		Low	50-100	20-40	500-1,000
		Very low	<50	<20	<500
Fine	High (>15 $mmol_c$/kg)	Very high	>500	>300	>4,000
		High	300-500	120-300	3,000-4,000
		Medium	150-300	60-120	2,000-3,000
		Low	75-150	30-60	1,000-2,000
		Very low	<75	<30	<1,000

Source: FAO, 1984.

When interpreting magnesium values the ratio of potassium to magnesium (K/Mg) must also be taken into account because, if it is over one, potassium-induced magnesium deficiencies may occur.

Iron, manganese, copper and zinc are usually present in the soil, but deficiencies of these minor nutrients may occur, induced by pH, limestone, interactions, etc. Iron deficiency is found particularly in olive orchards growing on calcareous soils. Table 4 gives the critical levels for these nutrients, which seem to fit the levels for olive, particularly for iron.

Soil salinity indicates the presence of excess soluble salts which hinder crop water absorption and may cause toxicity problems. It is measured in terms of the electrical conductivity in a saturated extract (EC_e). A soil is defined as being saline when $EC_e > 4$ dS/m. The olive is considered to be moderately tolerant to salinity and it can stand a higher content of salts than other fruit tree species.

TABLE 4
Critical levels of DTPA-extractable micronutrients in soil

Micronutrient	Critical level (ppm)
Iron (Fe)	3
Manganese (Mn)	1.4
Copper (Cu)	0.2
Zinc (Zn)	0.8

Source: Parra et al., *2003.*

Specific ions that constitute salinity such as ***sodium, chlorine and boron*** can cause toxicity problems by themselves in olive, even at low EC values. Table 5 lists the levels at which these ions can be expected to have a negative effect on the crop.

TABLE 5
Limitations for olive in terms of soil salinity, sodicity, excess boron and excess chlorine

	Degree of limitation		
Type of limitation	Mild	Moderate	Severe
Soil salinity EC_e (dS/m)	4	5	8
Exchangeable sodium percentage (%)		20-40	
Boron toxicity (ppm)	2		
Chloride toxicity (meq/l)	10-15		

Source: Parra et al., *2003.*

5.3. ESTABLISHING THE ANNUAL FERTILIZATION PROGRAMME

For perennials like olive, which have numerous nutrient reserve organs, a good leaf analysis programme will evaluate existing nutritional status and anticipate nutritional requirements for the following season. The strategy is to keep all the nutrients at the adequate levels listed in Table 1 and to fertilize with an element only when levels are deficient because of crop removal or low soil availability. From a rational point of view, nutrients should not be allowed to drop to deficiency levels because this would cause growth to decrease to unacceptable levels. Potassium fertilization is advisable when leaf analysis indicates that K is low, i.e. when the value lies below the adequate range. Although a response to fertilization is not to be expected in such circumstances, potassium uptake tends to be lower if the tree is close to deficiency.

Sometimes a particular nutrient may be low or deficient because another element is lacking or in excess. In such cases, it is enough to apply or eliminate fertilization with the other element in order to return to normality. Although the possible interactions among elements have still to be interpreted to satisfaction, interactions between N and P, P and Zn, and K and Mg are some of the interactions known to occur in many fruit species.

After carrying out the leaf analysis and diagnosing each nutrient, the next step is to establish the fertilization programme for the next season according to the following strategy:

1. If all the nutrients are at adequate levels in the leaves, it is advisable not to fertilize at all the next season and to repeat the analysis the next July to reassess the nutritional status.
2. If a nutrient is low or deficient, a fertilizer rich in the element concerned should be applied, provided it is certain that this is not due to an excess or lack of another nutrient, in which case action should concentrate on the other nutrient.
3. If several elements are low or deficient, it would normally suffice in the majority of cases to apply the one that is most deficient in order to remedy the situation. However, this is not a general rule. It is recommendable, therefore, to seek the advice of an expert. Remember that the application of excessive or unnecessary nutrients at any given time may cause nutritional imbalances in the tree that are not easily corrected afterwards.

5.4. CORRECTING NUTRITIONAL DEFICIENCIES

The olive is a hardy plant capable of growing and bearing fruit even in adverse environmental conditions. Like all perennials, it has nutrient reserve organs and it re-uses nutrients with ease. As a result, it has lower nutritional requirements than other crops.

Nitrogen (N) is the nutrient required in largest amounts by plants, including olive. For this reason it has traditionally been the cornerstone of olive fertilization. Potassium deficiency (K) is the major problem in dry-farming conditions and becomes worse when yields are high. In calcareous soils, iron (Fe) and (B) boron deficiency may occur in addition to potassium deficiency, while calcium (Ca) deficiencies are to be expected in acidic soils. These are the nutritional imbalances that can affect the majority of olive orchards and which it is advisable to monitor through testing. Nevertheless, it is unusual for these imbalances to coincide all at once in the same orchard.

5.4.1. Nitrogen

Nitrogen is a very dynamic element which is lost easily through leaching, volatilization or denitrification, which prevents its uptake by tree roots and contributes to pollution, particularly ground water pollution caused by leaching. For this reason, it has traditionally been considered necessary to apply annual maintenance nitrogen fertilization to offset nitrogen losses. However, studies carried out in different growing conditions have shown that this practice is not effective in maintaining good orchard yields and that it leads to a significant increase in nitrate contamination of water in some areas.

Crop removal of nitrogen is low compared with annuals and can be assessed at around 3–4 g N/kg olive fruits at the most. Besides being applied through fertilization, nitrogen also enters the system through mineralization of the soil organic matter and rainfall, as well as through irrigation water, where applicable. As these amounts are usually disregarded when determining nitrogen fertilization requirements, it is easy to see why olive trees growing on relatively fertile soils have scant nitrogen requirements. Annual nitrogen applications are not necessary in most olive orchards to maintain adequate leaf levels and good levels of yields. On the contrary, a negative effect has been observed on oil quality when nitrogen is over-applied (Fernández-Escobar *et al*., 2006).

Figure 4 shows the symptoms of nitrogen deficiency. When it is diagnosed, it is advisable to apply tentatively 0.5 kg N/tree, without exceeding 150 kg/ha. The optimal dose will depend on the characteristics and management of each olive orchard and it will have to be adjusted by carrying out regular leaf analyses. When correctly interpreted, these will indicate whether it is necessary to increase or decrease the doses applied.

Figure 4a. Olive tree showing symptoms of nitrogen deficiency.

Nitrogen use efficiency (NUE) is defined as the amount of nitrogen absorbed by the plant, divided by the total amount of nitrogen applied. In general, it is estimated to fluctuate between 25 and 50%, which indicates that most of the nitrogen applied is not absorbed by crops. Some of the factors which lower NUE are: (1) the presence of available nitrogen in the soil, which means that when applied through fertilization the tree will absorb less; (2) the application of nitrogen during the period of winter vegetative rest of the tree, because it is incapable of absorbing it in these circumstances; (3) a large crop, as a result of which absorption is greater in 'off' years. In contrast, splitting nitrogen applications favours nitrogen absorption by the tree, increasing NUE. In dry-farmed orchards it is recommendable to divide nitrogen application by applying part to the soil, preferably when rain is anticipated, and part to the leaves. Another possibility is to apply all the nitrogen to the leaves in split applications. In irrigated orchards it is advisable to apply the nitrogen dissolved in the irrigation water. Owing to its characteristics, high-frequency irrigation minimizes nitrogen losses because it allows more splitting of applications.

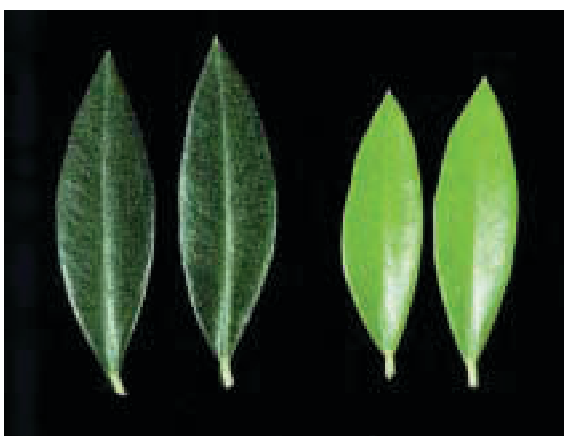

Figure 4b. Generalised leaf chlorosis caused by nitrogen deficiency (right) and normal leaves (left).

5.4.2. Potassium

Potassium is the element removed in largest amounts by the crop, around 4.5 g K/kg olives. This means that potassium is important in olive nutrition, and its importance is magnified by the fact that the growing environment affects potassium availability to the tree.

Low potassium levels or deficiencies are general in many olive orchards. Tree deficiency symptoms include leaf tip necrosis and shoot defoliation, and in "on" years the olive fruits are wrinkled and smaller than normal (Fig. 5). These deficiencies are more pronounced in dry-farmed olive orchards and in dry years because the low soil moisture limits the spread of the potassium ion (K^+) through the soil solution and prevents its absorption by the roots. They are also frequent in soils with a low clay content because the soil has a lower buffer capacity and, as a result, less K is available to the trees.

Figure 5a. Symptoms of potassium deficiency in olive branches.

Figure 5b. Necrotic tips and edges of leaves typical of potassium deficiency.

Potassium deficiency is difficult to correct in olive orchards because the potassium fertilizer is absorbed in smaller amounts by trees suffering from a deficiency. It is advisable, therefore, to check leaf potassium concentration every year in order to apply potassium when values are low, but before they turn into a deficiency. Tentative doses for soil application in such cases are around 1 kg K/tree, provided that soil moisture is not a limiting factor. In dry-farmed olive orchards, between two and four leaf applications of 1%-2% K, depending on K levels, have given satisfactory results, although it is usually necessary to repeat the applications in following seasons until K reaches an adequate level in the leaves. Applications should be done in the spring because young leaves absorb more K than mature leaves. In general, more frequent and more diluted applications of K have proved to be more effective in raising leaf potassium levels than less frequent, more concentrated applications.

Figure 5c. Normal fruits (above) and fruits from potassium-deficient trees (below).

One point to remember when applying potassium to the ground is that, unlike nitrogen, it has a low mobility, particularly if the soil has a high clay content. As a result, the potassium remains on the soil surface unless it is applied close to the root system.

5.4.3. Iron

Iron deficiency, known as *iron chlorosis*, is a nutritional imbalance that can affect olive orchards growing on very calcareous soils with a high pH content. The ion forms of iron are not very soluble in such soils and they are not available to the plants, even when present in sufficient amounts in the soil. Trees suffering from iron chlorosis display a characteristic series of symptoms such as yellow leaves, small shoot growth and lower yield (Fig. 6). Fruits for table production lose commercial value because they tend to be small and to develop a chlorotic appearance. These symptoms are the means of diagnosing iron deficiency as leaf analysis is of no use in such cases because iron accumulates in the leaves even when deficiency occurs.

Figure 6a. Typical symptoms of iron chlorosis in olive leaves.

Iron deficiency is also connected with poor soil aeration because this increases the concentration of the bicarbonate anion in the soil solution, so aggravating iron chlorosis. This is why waterlogging has to be avoided in calcareous soils.

Iron chlorosis is difficult and costly to correct. The best solution for new orchards is to choose a variety that tolerates this anomaly. In established orchards the remedy is to apply iron chelates to the soil, which makes iron available to the plant for a moderately long period in comparison with other products, or to inject iron solutions into the tree trunk, in which case the effects of the injection can last for four years or longer.

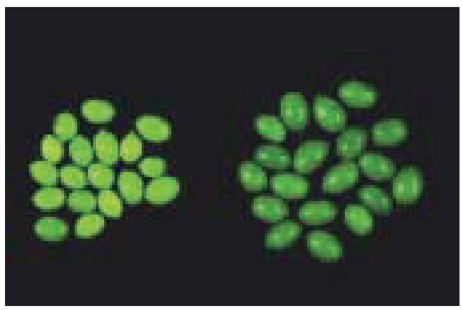

Figure 6b. Chlorotic olives (left) compared with normal fruits (right) in July.

5.4.4. Boron

Olives are considered to have high boron requirements; in fact, they are more tolerant to boron excess in the soil solution than other fruit tree species. Soil availability decreases under drought conditions and at higher soil pH values, particularly in calcareous soils. Boron deficiency symptoms tend to be confused with potassium deficiency symptoms, and boron has sometimes been applied by mistake to correct anomalies caused by potassium, which are more frequent. Leaf analysis is a must prior to any application because boron is toxic to the olive at high concentrations.

If a deficiency is diagnosed, it can be remedied easily by applying boron to the ground at a rate of 25-40 g per tree. In calcareous soils with a pH>8 and in dry-farmed orchards, it is preferable to apply soluble products to the leaves at a concentration of 0.1% boron, prior to flowering. One single application may be enough because plants need only small amounts of boron.

5.4.5. Calcium

Most olive orchards are established on calcareous soils in which large amounts of calcium are available to the trees. Calcium concentrations only decrease to deficiency levels in acidic soils where leaching water has removed most of the exchangeable bases. Such situations call for limestone amendment, i.e. applying calcium carbonate or calcium oxide to neutralize the acidity. The amount required depends on the soil texture and pH and has to be calculated on the basis of soil analysis results.

5.4.6. Other nutrients

The remaining nutrients do not usually pose problems in olive orchards, except in very concrete cases caused by low availability in the soil. ***Phosphorus*** is important for fertilizing annuals, but less important in perennial, woody crops because of the ease with which they re-use this element and the low amounts removed, estimated at around 0.7 g P/kg of olive fruits. Failure to respond to phosphorus fertilization is a general phenomenon in olive growing. Nevertheless, in the event of deficiency, a tentative amount of 0.5 kg P/tree can be applied, which will then have to be adjusted according to the tree response assessed from leaf analyses. ***Magnesium*** tends to be found in large amounts in the soil solution where it behaves in a similar way to calcium. Possible deficiencies in acidic soils can be corrected by trying to neutralize the acidity, as in the case of calcium, by using magnesium carbonate. When deficiencies are observed in neutral, sandy soils, magnesium sulphate may be appropriate treatment. It has to be remembered that magnesium deficiencies may be induced by high concentrations of potassium, calcium and ammonium because these ions compete in the soil solution. If the exchangeable K/exchangeable Mg ratio is over one, such deficiencies can be expected.

The olive needs even smaller amounts of micronutrients than of the other elements and takes them up easily from the soil solution. ***Copper*** tends to be high in olive leaves as it is usually applied as a fungicide in olive growing. Very little is known about ***manganese*** and ***zinc*** in olive because their levels tend to be adequate in olive leaves; any deficiencies must be local in scope. Soil amendments designed to lower the soil pH could make these elements available to the tree. Foliar applications in the form of sulphate or chelates can be tried to correct a possible deficiency that cannot be remedied any other way, although in the case of zinc it has to be made sure that it does not cause phytotoxicity. Zinc could also be applied to the soil in the form of sulphate.

5.5. FERTILIZER APPLICATION

Fertilizers can be applied to trees in three ways: to the soil, to encourage root absorption; to the leaves, to encourage foliar penetration; and to the vascular system, through trunk or branch injections. Each has its pros and cons.

5.5.1. Soil application

This is the traditional way of applying fertilizers to crops. The aim is to enrich the soil solution near the roots to allow them to absorb the nutrients. The fertilizer can be applied to the ground surface or below-ground. Surface applications are more common because they are easier and cheaper and they are suitable for mobile nutrients like nitrogen. Fertilizer can be worked into the soil through surface tillage to prevent the element from volatilizing, or else it can be applied in irrigation water or when rain is anticipated. In surface applications the product must be distributed as uniformly as possible over the whole surface so that the fertilizer is in contact with the largest possible number of absorbent roots, and at non-toxic concentrations. Surface application of fertilizers in drills around the trees would not be appropriate (Fig. 7).

Figure 7. Erroneous surface application of fertilizers.

Deep fertilizer applications are designed to place nutrients such as potassium and iron near the largest possible number of absorbent roots as the former nutrient is not very mobile in the soil while the uptake of the latter is easily blocked. To avoid damaging the tree root system, such applications can be done with a fertilizer lance using soluble products (Fig. 8). Between six and eight injections are required around the tree to ensure correct application.

Figure 8. Fertilizer application by injecting a nutrient solution into the soil.

In overall terms, soil applications have some drawbacks. They will not be effective if the uptake of a nutrient is blocked by a characteristic of the soil. Potassium and iron are clear examples of such nutrients in olive growing as they can cause deficiencies even when present in adequate amounts. Another drawback is the low efficiency when mobile nutrients are applied. Although proper handling of techniques minimizes this problem, ground application of elements like nitrogen does considerably increase water pollution.

5.5.1.1. Fertigation

This is a method where the fertilizer is applied to the soil by dissolving it in the irrigation water. High-frequency, localized irrigation is particularly useful for this kind of application. Consequently, it is advisable to install a fertilizer tank in olive orchards equipped with this system. The advantages are the low cost and effectiveness of fertilizer application because the system positions the nutrients near the absorbent roots distributed in the wetted area. This method allows split application, which is very important in the case of nitrogen because it helps the tree to take up the nutrient when it needs it, and it minimizes leaching losses, so enhancing NUE.

Fertigation does have some disadvantages, however. The first is that it increases the salinity of the irrigation water owing to the dissolution of the fertilizers, which could have a detrimental effect on the trees if the salinity is high. This hazard is attenuated if the application of the nutrients is split. Water-soluble products must be used for fertigation. Care should also be taken when mixing compounds, which is not always necessary, to avoid clogging the dripers owing to precipitation of the products used. It is advisable for the fertilizer solution to have a low acidity and for it to be injected halfway through the irrigation period so that irrigation application begins and ends with clean, fertilizer-free water. In any case, closer attention needs to be paid to the maintenance of the irrigation network, particularly cleaning.

Nitrogen is the element applied the most in olive growing; consequently, it is the nutrient applied most frequently via fertigation. Most nitrogen fertilizers can be applied in this way, but there are differences that should be taken into account. Urea and nitrates move very easily in water whereas ammonium fixes in the soil particles and moves more slowly; however, it quickly turns into nitrate, which moves with greater ease. From the point of view of acidity, ammonium sulphate is more acidifying than the others, which can be an advantage except in acidic soils where its use may be limiting. Irrespective of the type of nitrogen fertilizer used, if nitrogen is left in the irrigation pipes in between water applications this may encourage the proliferation of micro-organisms and lead to blockages in the irrigation network. This can be avoided by cutting off fertilizer application before the end of irrigation, as mentioned earlier; however, irrigation water tends to carry substantial amounts of nitrates, mainly nitrates used for agricultural purposes, which aggravates the problem.

Other nutrients such as potash compounds, particularly nitrate, sulphate and chlorine, are easy to apply through the irrigation water. Conversely, phosphorus fertilizers cause the most clogging because they react with the calcium in the irrigation water, causing precipitates. For this reason, when necessary, it is advisable to employ products prepared specially for fertigation, or to acidify the solution with sulphuric acid. Micronutrients can be applied as sulphates and chelates, although the latter tend to be more soluble.

5.5.2. Foliar fertilization

Foliar fertilization is based on the capacity of the leaves to absorb chemicals (Fig. 9). Compared with ground application, foliar fertilization has the advantage that the product is used more quickly and more effectively. It enables less nitrogen to be applied because it increases NUE, which results in less soil and water pollution. Foliar fertilization is always necessary when soil characteristics block nutrient uptake from the soil.

Foliar fertilization tends to be cheaper when micronutrients are applied because of the small amounts required by the olive. More applications of macronutrients like nitrogen

Figure 9. Foliar application of fertilizers.

and potassium are needed because one single application is not enough for the required amounts of the nutrients to penetrate the leaves and correct the deficiency. Application costs can be lowered by combining nutrient and pesticide treatment in one.

The foremost disadvantage of foliar fertilization is that the product may be leached if moderate rainfall occurs after application. If it rains straight after fertilization, one possibility is to repeat the application when weather conditions are favourable because it can be assumed that little fertilizer managed to penetrate the leaves. On the other hand, if leaching occurs when part of the product has already been absorbed, it is difficult to know exactly how much has been absorbed and whether the application needs to be repeated and how much fertilizer needs to be applied. Another drawback of foliar fertilization is that phytotoxicity may occur at high concentrations. This is an added difficulty when deciding whether to repeat the application when part of the product has already been absorbed. Lastly, foliar fertilization is not effective in the case of certain products, particularly iron compounds. Nonetheless, it is a good technique permitting the split application of macronutrients to dry-farmed olives.

5.5.2.1. Factors affecting leaf nutrient absorption

Leaf nutrient absorption is affected by environmental conditions, notably moisture and temperature. Absorption takes place while the leaf is moist and ceases when it has dried. If all the active ingredient has not penetrated the leaf, it will remain in solid form on the leaf surface and absorption can resume if the leaf is wetted again in amounts that do not cause leaching. Nutrient application is more effective, therefore, if done at night when relative humidity is higher, and less effective on hot days or in the middle of the day when higher temperatures cause a drop in relative humidity. Wetting agents or surfactants increase leaf moistening by lowering the surface tension, so decreasing the angle at which the liquid hits the leaf surface. When used, they enhance leaf absorption of the product applied.

Leaf age is important in absorption. Older leaves are less efficient than younger leaves in terms of nutrient absorption. As a result, foliar fertilizers should be applied when there are young leaves on the tree, which in the northern hemisphere means between April and July.

The chemical formulation and concentration of the product also affect leaf nutrient absorption. A more diluted product is generally absorbed better through the leaves than a more concentrated product, and it reduces the risk of phytotoxicity.

5.5.3. Trunk injections

The third method of tree fertilizer application entails injecting chemicals into the vascular system. This method is less widespread and is used more for pest and disease control than for nutrient application. It is to be recommended for fertilization purposes when soil or foliar applications do not have satisfactory effects, which in the case of the olive limits its use to the treatment of iron chlorosis. Trunk injections do away with air and water pollution because the whole of the product remains inside the tree, which also ensures it is used more effectively.

Numerous injection methods have been developed. However, most have seen little commercial application because they are ineffective or very costly; as a result, this technique is used on a smaller scale. Overall, injection methods are based on two different procedures: infusion and injection. The first takes advantage of the tree transpiration stream to introduce the product into the xylem and comprises two methods employed in olive to apply iron-rich compounds. The first, *bark impregnation*, involves brushing the tree bark with the product to allow it to soak through to the conductive tissue of the tree (Fig. 10). This method is of very limited use because it depends on the solutes being able to move through the bark tissue, which is a strong barrier. The second method entails embedding solid capsules (implants) of the product measuring between 8 and 13 mm in diameter and between 3 and 4 cm in length. The xylem fluids dissolve the embedded material, which is dragged along in the transpiration stream and distributed through the tree. For the treatment to be effective a large number of implants has to be embedded around the trunk to ensure uniform distribution. One of the problems of this method is that the product is dissolved by the xylem fluids while the wound in the xylem is fresh but when the wound heals, the product no longer enters the tree. During the period of cambium activity, cicatrization may be very rapid. With time, the undissolved implants remaining embedded in the wood produce necrotic areas which eventually damage the trunk (Fig. 11).

Figure 10. Bark impregnation with iron compounds.

Figure 11. Damage caused by placing implants in the tree trunk.

The second procedure is injection proper where the product is delivered into the tree in liquid form under pressure, which eliminates the problems associated with the methods just described. Many systems have been developed for this procedure. They can be divided into *high-pressure systems*, which apply the solution at pressures of between 0.7 and 1.4 MPa, and *low-pressure systems*, which do so at pressures below 100 kPa. The latter systems are the most popular because they are easy to use and the product is distributed effectively. Figure 12 shows one of the most popular commercial systems available. It comprises a plastic injector which is placed on the trunk or scaffold branches and a pressurized capsule made of expandable, elastic material, which contains the liquid for injection. When the two parts are connected, the pressure exerted by the capsule enables the product to reach and spread through the transpiration stream of the tree. The number of injections required depends on the size of the tree, but normally ranges from one to three. When treating for iron chlorosis in olive, the effect usually lasts at least four years.

Figure 12. Low-pressure injection.

The main drawback to injection methods is the possible damage from phytotoxicity if the technique is not applied correctly. Risk has been observed to be greatest when the trees are injected in the spring, during the period of leaf expansion. The trees should therefore be injected from mid-June onwards to minimize this risk, or on clear days in winter in evergreen trees like the olive, which is when there is very little risk of phytotoxicity.

5.6. SUMMARY

The list below sets out the do's and don'ts and recommended practices in olive fertilization based on the aspects discussed here and of the guidelines issued for the integrated production of olives by the International Organization for Biological Control of Noxious Animals and Plants (IOBC, 2002).

Do's

1. Determine nutritional requirements by diagnosing the nutritional status of the olive orchard on the basis of leaf analysis carried out as explained in this text. In some cases, diagnosis should be supplemented by inspection of visual symptoms and soil analysis.
2. Collect leaf samples in July in the northern hemisphere. Take fully expanded leaves with petiole from current-season shoots, as explained in this text.
3. Aim for all the mineral elements to lie within the adequate range for leaves.
4. Only apply a nutrient if its concentration is outside the adequate range and lies close to deficiency, provided this is not due to the action of another nutrient, in which case action should concentrate on the latter. Apply potassium when low levels are detected in the leaves.

5. Split nitrogen application, whether to the ground or leaves. When applying it to the ground, bury the nitrogen or incorporate it with irrigation or rain water. When using fertigation, apply the corresponding amount each irrigation day. Do not apply fertilizer after the summer.
6. Split the foliar application of potassium.
7. In the case of ground application, spread the fertilizer across the whole surface, not just underneath the trees, except in fertigation.

Recommended practices

1. Divide the olive orchard into uniform blocks according to soil, age, varieties, cultivation system, etc.
2. Analyze the soil profile, preferably before planting the orchard, to identify any limitations to olive growing.
3. Analyze soil fertility every three or five years, depending on the degree of soil fertility and the intensiveness of cultivation. Perform analyses if high leaf concentrations of sodium, chlorine or boron are detected.
4. Take soil samples at two depths, normally 0–30 cm and 30–60 cm if the soil depth so permits, according to the procedure described in this text.
5. If leaf analysis reveals a nitrogen concentration above or on the upper limits of the adequate range, analyze the irrigation water or find out the reasons for such values.
6. If nutrients are required, begin by applying the tentative doses indicated in this text and then correct the doses in the light of subsequent leaf analyses.
7. Aim foliar nutrient applications for the spring, when the young leaves are still tender. Avoid applying the nutrients in the middle of the day; night applications are advisable in high evaporation conditions. It is recommendable to use wetting agents to promote leaf absorption of the products.
8. For ground applications, apply potassium close to the roots, particularly in clay soils.
9. When carrying out regular soil fertility analyses, check the K/Mg ratio is not more than one to avoid magnesium deficiencies caused by high potassium concentrations.

Don'ts

1. Do not apply nutrients unless justified by leaf diagnosis. The only exception is iron, because leaf analysis is not effective for diagnosing iron deficiency.
2. Do not apply annual maintenance nitrogen fertilization when leaf nitrogen concentration lies inside the adequate range.
3. Do not apply more than 150 kg of nitrogen per hectare.
4. Do not apply all the nitrogen in one go.
5. Do not apply nitrogen during winter rest.
6. Do not carry out foliar applications of iron compounds because they are not effective for remedying this deficiency.
7. Do not inject iron compounds into the vascular system of the trees during the period of leaf expansion.

8. Do not apply compound fertilizers, except in exceptional cases of deficiencies of more than one nutrient, taking into account no interactions between the elements.
9. Do not apply boron to olive orchards on calcareous soils with a pH > 8 or to dry-farmed orchards.

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6

Irrigation

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6. Irrigation

6.1. INTRODUCTION

Irrigation in olive growing has been focused primarily on table olives because oil-olives are traditionally rainfed. Extensive research evidence has revealed that irrigation is a necessary tool for enhancing the quality and volume of crop production.

The resurgence of market interest in olive produce places the onus on operators to supply top quality product and to guarantee the economic sustainability of production, but these objectives are not readily achieved in Mediterranean climatic environments without proper irrigation management.

The olive is a species known for its resistance to water stress. This resistance is due to a series of anatomical adaptations and physiological mechanisms which enable the tree to maintain its vital functions even in conditions of very severe stress. Such features include: the downy underside of the leaves and their high tissue capacitance; the small number of stomata (density of 200-700 mm^{-2}) nestled in the lower surface of the leaves, which help to limit transpiration; the narrow diameter of the xylem vessels, which enable the plant to have a high water-potential transpiration rate; the characteristics of the root system of the olive, which enable it to use water at soil water potential levels below the conventional wilting point; the marked efficiency of the leaves, which display photosynthetic and transpiration activity at leaf water potentials of even -6/-7 MPa; the efficient regulation of stoma activity which helps to modulate gas exchange according to the changes in atmospheric evaporative demand so as to reduce the transpiration rate; a 50% photosynthetic capacity when the moisture available in the soil is at 40% of field capacity; and the marked capacity of the species to increase the root-to-canopy ratio in conditions of water stress, so increasing the volume of soil explored by the root apparatus.

However, these defence mechanisms are activated at considerable expense to the plant in terms of energy. This causes a decrease in crop production and poor vegetative development and may jeopardize both current-season yields and subsequent harvests (Table 1).

Water is a resource in growing demand for civil and industrial use; as a result, water availability for irrigation purposes is constantly declining in most of the Mediterranean region while water supply and distribution costs are tending to rise.

Table 1
Effects of water deficit on olive growth and crop production processes in relation to the timing of deficit.

Phase of vegetative-productive cycle	Period	Effect of water deficit
Vegetative growth	Late summer-autumn	Poor development of flower buds and next season's shoots
Flower bud formation	February-April	Decrease in the number of flowers; pistil abortion
Flowering	May	Decrease in fertile flowers
Fruit set	May-June	Decrease in set fruit (increased alternate bearing)
Initial fruit growth	June-July	Reduction in fruit size (fewer cells/fruit)
Subsequent fruit growth	August-November	Reduction in fruit size (smaller size of fruit cells)
Oil build-up	July-November	Lower oil content/fruit

Source: Adapted from Beede and Goldhamer (1994).

Consequently, it is essential to implement correct irrigation management aimed at:

- avoiding resource wastage;
- improving water use efficiency;
- using suitable distribution systems.

6.2. WATER REQUIREMENTS

Knowing and defining the main soil and climatic parameters are a must for determining water requirements in different olive-growing environments.

To do so, it is essential to put forward easy-to-apply methods for monitoring crop water consumption, which needs to be known for irrigation decision-making.

6.2.1. Adequate water availability

The biennial cycle of the olive has to be taken into account if irrigation is to be managed properly, particularly when deficit irrigation is practised (Fernández and Moreno, 1999).

Shoot growth takes place from February to August in Mediterranean environments and vegetative flush may occur in autumn in good climatic conditions. The inflorescences develop as temperatures rise at the end of winter and flowering subsequently takes place, beginning in spring. If nothing causes late fruit drop a good crop can be obtained even when only 1% of the flowers sets as fruit. Flower and fruit abscission can occur between the fifth and sixth week of full bloom.

The stone (endocarp) of the olive fruit (drupe) starts to lignify (stone hardening) between four and six weeks after fruit set and growth continues for a further three months. Mesocarp (fruit flesh) growth continues through the whole of the summer season, keeping to its characteristic sigmoid pattern. Fruit maturation is complete when the fruit has changed colour entirely, while growth can be considered to be over at the start of colour change.

Following this brief outline of the biology of the olive, it is clear that irrigation planning has to take into account the interaction between water requirements and phenological stages:

1) When vegetative flush occurs it should be ensured that water and nutrients are available to promote vegetative growth, the formation of perfect flowers, flowering and fruit set.

It is important for water deficit not to occur from the start of bud break (vegetative and fruit buds) until flowering because this will affect both the quality and quantity of the flowers and the ensuing number of set fruits. Eighty percent of the fruit cells are formed between the start of fruit growth and stone hardening which is the period when the set fruitlets may undergo marked physiological abscission. Fruit drop is closely correlated with water stress and plant nutritional status. This stage is reported to be the most sensitive in the crop production process, which makes it important to ensure good water and nutritional replenishment. It is also the period when vegetative growth occurs, which is why an adequate leaf surface needs to be maintained to guarantee enough assimilates for the current-season crop and to prepare the productive organs for the next season.

2) According to research results, the olive is less sensitive to water stress during the stone hardening stage. Irrigation volume can therefore be decreased during this period (reduction of ETc percentage), thereby saving a considerable seasonal volume of irrigation water without causing significant negative effects on crop production.

3) The processes of oil formation (triglyceride synthesis) and cell swelling take place during fruit maturation and through to the end of harvest. This is a period when the plant is very sensitive to water stress, especially if there has been a summer water shortage, because it is when final fruit size is determined and the plant accumulates the reserves it will need to ensure an adequate potential crop for the next season.

6.2.2. Soil water availability

Different soil types have clearly defined hydrological characteristics which determine their capacity to allow water to reach the root system. A soil is saturated when the macro and micro-pores are full of water. When all the water contained in the macro-pores has percolated, the soil is at field capacity (FC). In such conditions, crop water availability is at its peak. As a result of water consumption and soil evaporation processes it starts to decrease until it reaches permanent wilting point (PWP) and it gradually displays more resistance to extraction

(Table 2). PWP is reached, therefore, when the water is held so tightly in the soil that the plant cannot extract it.

TABLE 2
Force required to extract water (h) in different soil moisture conditions

h cm water	h MPa	Soil water status
10	-0.01	Straight after irrigation
316	-0.03	Field capacity
800	-0.08	Dry (tensiometer limit)
15,185	-1.5	Permanent wilting point [1]

[1] The value of –1.5 MPa has been fixed by convention, but the olive can actually absorb water beyond the permanent wilting point and maintain leaf activity at around –2.5 MPa (Fernández, 2001).

The difference between FC and PWP is known as the available water content (AWC).

Water content at FC and PWP varies according to the physical characteristics and texture of the soil (clay, silt, sand, loam, etc.), which means that AWC will also differ according to soil type (Table 3). It will be higher in clay soils (greater micro-porosity) than in sandy soils (less micro-porosity).

TABLE 3
Water content at permanent wilting point (PWP; -1.5 MPa), field capacity (FC; -0.03 MPa) and available water content (AWC) of different types of soil

Soil	PWP	FC	AWC
	% volume		
Sand	2	3	1
Sandy loam	4	7	3
Loamy sand	5	9	4
Silt	6	13	6
Silty clay	10	18	8
Medium-textured	14	24	10
Clay loam	36	17	19
Clay	26	46	20

Soil moisture content can be expressed in units of weight ($g\ g^{-1}$) or volume ($g\ cm^{-3}$), or as a percentage by multiplying the volume moisture content by 100.

AWC can be calculated as follows, in mm:

$$AWC = \frac{AWC}{100} Dr = \frac{(FC - PWP)}{100} Dr$$

where:

AWC = available water content (mm);

Dr = depth of soil explored by the roots (mm);

FC = field capacity (% volume);

PWP = permanent wilting point (% volume).

The value of Dr is related to the soil characteristics (texture, depth) and to the depth of the crop root system (plant age and development). Olive water extraction from the soil solution is greatest in the soil layer lying between 0.50 and 1.00 m, and the root system of mature trees growing on deep soils can develop to a depth of as much as 2.00 m (Fernández *et al.*, 1999). However, for the purposes of calculating the water balance, a depth of 1.00 m can be considered for a mature orchard.

The terms for estimating AWC are of key importance in determining the soil characteristics and can easily be ascertained in laboratory tests.

Readily available water (RAW) is the fraction of available water (AWC_{mm}) that can be used by the plant without showing symptoms of water stress. The amount of RAW is a characteristic of the crop (specific capacity of the plant to extract water). In olive, it is believed to range between 65% (Fernández, 2001) and 75 % of the AWC (Orgaz and Fereres, 1997).

Hence, on average:

$$RAW = 0.70\ AWC$$

where:

RAW = readily available water (mm);

AWC = available water (mm).

Several methods can be employed to measure the actual water content of a soil. Some of the most widespread ones are now outlined:

1) Gravimetric method: Soil samples are taken with a soil auger and the water content is measured as the ratio of the soil weight, calculated as the difference between the wet and oven-dried weight (105 °C), to the dry weight. It is converted into volume by multiplying the dry weight by the apparent soil density (t m^{-3}).

This method is time-consuming although the apparatus required is cheap.

$$M\ (\%dw) = \frac{Fw\ -\ Dw}{100}\ 100$$

where:
$M_{\%\ dw}$ = sample moisture (% dry weight);
Fw = fresh weight of the sample;
Dw = dry weight of the sample.

$$M\ (\%vol.) = M\ (\%Dw)\ Ad$$

where:
$M_{\%\ vol}$ = sample moisture (% volume);
Ad = apparent density of the soil.

2) Neutron probe method: The probe consists of a source of fast neutrons and a slow neutron detector. When the fast neutrons collide with hydrogen atoms they are deflected and scattered, losing kinetic energy in the process. The flux of slow neutrons is proportional to the water content and is converted into numerical form by a gauge. The water content of the soil per unit of volume is determined from the gauge reading with the aid of a specific calibration curve for the type of soil.

This method cannot be used on creviced, stony soils, the probes are expensive to buy and maintain, they require skilled staff, and specific authorizations are required in many countries for their possession and use. On the other hand, it can be applied for a wide range of soil moistures.

3) Time domain reflectometry method (TDR): The instrument transmits electromagnetic waves to a probe, which reflects them to a receiver that records the velocity of propagation and amplitude of the signal. The instrument provides a moisture content reading in units of volume.

The instrumentation is quite expensive and specific calibration is required for organic and saline soils. Additionally, special measures have to be taken to install the probes (e.g. by digging trenches) when measuring at depths of more than 50/60 cm, especially in clay soils.

4) Frequency domain method (FD): This precise, automated method measures soil water content by measuring the capacitance and conductivity at a fixed frequency. The instrument is equipped with sensors with a frequency of between 10 and 150 MHz. A sine-wave current is passed through a resistance made up of two electrodes and the soil acts as the dielectric medium. The dielectric properties of the soil are estimated on the basis of the tension measured between two electrodes and the phase difference between the current and the tension. The electrodes may be of various shapes (laminar, ringed or cylindrical). The method is easy to apply, but it is only useful if a large number of sensors is employed.

Irrigation scheduling instruments based on these last two techniques (TDR and FD) have been released on the market in recent years. Some are equipped with computer applications to visualize the data in numerical and graphic mode.

All the methods for determining soil water content will provide reliable estimates if there are numerous measuring points.

6.2.3. Climate and evapotranspiration

Environmental parameters (temperature, relative air humidity, wind, solar radiation, etc.) need to be determined for irrigation scheduling because they influence water transpiration and evaporation by the plant and soil.

Transpiration is the water lost by the plant owing to the effects of weather (temperature, humidity, wind) and the metabolic processes necessary for biomass production. This quantity of water, together with that lost through bare soil evaporation, represents what is known as the maximum crop evapotranspiration under optimal conditions (ETc), which has to be covered by rain and/or irrigation to avoid causing water stress to the plant.

Consequently, irrigation requirements (IR) can be computed if the parameters in the following equation are known:

$$IR = ETc - EP - R \qquad [1]$$

where:
EP = effective precipitation (mm);
R = soil water reserve (mm).

The water reserve (R) is the cumulative amount of water held in the root-explored soil profile which can be consumed by the crop.

To avoid causing stress to the plant, the soil water content should never be less than the readily available water content (RAW), as defined earlier.

$$R\ (mm) = [ETc\ (mm\ day^{-1}) - EP\ (mm\ day^{-1})]\ \text{no days}$$

When in a given period of time ETc < EP, the soil profile reserve is replenished by natural water supply whereas when ETc > EP the reserve decreases.

Effective precipitation (EP) is the rainfall that penetrates the soil and is available to the crop. EP is always lower than total precipitation; it depends on the intensity of rainfall, the hydrological characteristics and slope of the terrain, the soil management techniques applied, which influence water infiltration velocity, and the development of the tree canopy which intercepts a portion of precipitation which will therefore tend to evaporate without reaching the soil. PE can vary between 90% of total precipitation in the case of low-intensity rainfall on sandy, dry, tilled soil and 50% in the case of intense rainfall on non-tilled, wet, clay soil on sloping ground. Many variables affect the estimation of EP; for irrigation scheduling it is generally considered to be 70% of total precipitation in the Mediterranean olive-growing areas. Furthermore, light rainfall in dry, warm periods only wets the surface of the soil and is lost through evaporation before the plant has time to benefit from the water. Consequently, in summer, it is advisable not to compute rainfall of less than 6-10 mm in 24 hours.

The other parameter in equation [1] – ETc – can be calculated according to the FAO method (Doorenbos and Pruitt, 1977; Allen *et al.*, 1998):

$$ETc = ET_0 \ kc \qquad [2]$$

where:
ET_0 = reference crop evapotranspiration (mm);
kc = crop coefficient.

ET_0 is the evapotranspirative demand of the atmosphere irrespective of crop, phenological stage and cultural practices and represents the reference standard.

Direct and indirect methods can be used for estimating ET_0. Direct methods are not easy to apply and will not be discussed here. Indirect methods are easier to use and the most widespread ones are: (1) Class A evaporimeter or Epan method; (2) atmometer method; and (3) models based on measuring climatic variables.

1) The first method of estimation is based on measuring the water that evaporates in a specific period of time in an evaporation pan of a set size and standard manufacturing characteristics. The A class pan is most widespread (Fig. 1) and its manufacturing and installation characteristics are described by Doorenbos and Pruitt (1977).

Figure 1. Class A evaporation pan equipped with sensor for automatic data logging.

According to this approach ET_0 is estimated by:

$$ET_0 = E_{pan} \ kp$$

where:
E_{pan} = pan evaporation (mm);
kp = pan coefficient.

The values of the kp coefficient are dependent on weather and pan site conditions and can also be inferred from the tables reported by Doorenbos and Pruitt (1977).

This widespread method is cheap and gives good results if the pan is positioned and handled in the standard manner. The main drawback is that the kp has to be applied correctly; another disadvantage is the cost of pan maintenance (cleaning, water replenishment, etc.).

2) The modified atmometer (Altenhofen, 1985) is a cheap, easy-to-read instrument that does not require correction factors. Its upkeep is also easy (Fig. 2). It consists of a porous porcelain

Figure 2. Atmometer (from Altenhofen, 1985)

cup (Bellani plate) covered with a green fabric and mounted on a cylindrical water reservoir containing approximately one litre of distilled water; a sight tube is mounted on the outside to indicate the water level. The apparatus simulates the reference crop evapotranspiration (ET_0). Readings may be automated using a data logger.

3) Methods based on measuring climatic variables can use empirical equations but these must be confirmed by experimental data for the area concerned before being applied. The choice of equation depends on the degree of precision required for the estimate, as well as on the frequency of the data and the availability of the type of data.

– The Penman–Monteith model is the most precise method proposed by FAO (Allen *et al.,* 1998) as the international reference method for estimating ET_0. It requires measuring all the chief agrometeorological variables reported in Table 4.

TABLE 4
Climatic and cultural parameters needed to estimate ET_0 using two agrometeorological models

Models for estimating ET_0	Climatic parameters measured	Climatic constants	Cultural parameters
Penman-Monteith	Tm, Urm, VV, Rn, G	Λ, γ	ra, rc
Hargreaves	Tmin, Tmax	Ra	

Tm = mean temperature, Urm = mean daily humidity, VV = wind speed and direction, Rn = net radiation, G = soil heat flux, Λ = vapour pressure γ = psychrometric constant, ra = aerodynamic resistance, rc = stomatic resistance, Tmin = minimum temperature, Tmax = maximum temperature, Ra = extraterrestrial radiation.

The main limitations of this method are the instrument maintenance required (two or three times a month), the calibration and the high cost of the sensors. It can be proposed, therefore, when there is a back-up technical assistance service for collecting, processing and relaying data.

The agricultural weather stations for measuring the variables in the Penman–Monteith model can be automated and fitted with remote reading meter systems, which means that ET_0 can be estimated non-stop (Fig. 3).

Figure 3. Automated weather station

– The Hargreaves equation (1994) is easier to apply and solely requires collecting maximum and minimum temperature data. It is advisable to check the empirical coefficient for the area when applying this method, which provides a good estimate of ET_0. Given the simplicity of the parameter measurements and the low cost of the equipment, it can be used on individual farms:

$$ETo = 0.0023\ Ra\ (Tm + 17.8) \sqrt{Tmax - Tmin}$$

where:

0.0023 = empirical coefficient;

Tm, Tmax, Tmin = mean, maximum and minimum temperature, respectively, during the period considered (°C);

Ra = extraterrestrial radiation (mm day^{-1}), tabulated value according to the latitude and time of year.

In environments characterized by high relative humidity, strong prevailing winds and proximity to the sea, it is recommended replacing the coefficient of 0.0023 by 0.0029 or performing on-site calibrations (Vanderlinden, 1999).

6.2.4. Determination of olive water requirements (ETc) using experimental kc values

To solve equation [2] it is necessary to know the crop coefficient (kc), which quantifies the effect of crop characteristics on water requirements. Hence, the kc coefficient relates the evapotranspiration of a crop that covers the whole soil surface to the reference evapotranspiration (ET_0). The value of kc is empirical; it has to be determined experimentally and it is referred to the crop conditions and environment. In particular, the main factors on which it is dependent are: (a) the time of year; (b) soil and climatic conditions (ET_0, soil type); (c) orchard management characteristics (density, tree age, canopy development and volume).

The kc values reported in the literature for olive in different environments are shown in Table 5. These values range between a minimum and a maximum depending on the time of year; they are highest in spring and autumn and lower in summer.

The kc values given in the table should be viewed as guideline references. Users are referred to the values which have already been determined for specific environments. However, this kind of information is not always available for individual environments. Consequently, when experimental references do not exist, studies are needed to determine this parameter.

The olive is a crop that does not generally cover the whole soil surface in the way that herbaceous crops do. This makes it necessary to insert a reduction coefficient (kr) to allow for this characteristic when estimating ETc. Consequently, equation [2] becomes:

$$ETc = ET_0\ kc\ kr \qquad [3]$$

TABLE 5
Crop coefficient values (kc) obtained and/or adapted in different growing environments

Kc values	Authors	Environments
0.4-0.6	Doorenbos and Kassan, 1988	
0.5-0.6	Milella and Dettori, 1986	Italy (Sardinia)
0.5-0.55	Dettori, 1987	Italy(Sardinia)
0.4-0.64	Deidda *et al.,* 1990	Italy(Sardinia)
0.53-0.72	García Fernández and Berengena, 1993	Spain (Córdoba)
0.45-0.65	Pastor and Orgaz, 1994	Spain (Córdoba)
0.5-0.85	Michelakis *et al.,* 1994	Greece (Crete)
0.55-0.75	Goldhamer *et al.,* 1994	USA (California)
0.5-0.81	Michelakis *et al.,* 1996	Greece (Crete)
0.6-0.65	Patumi *et al.,* 1999	Italy (Campania)
0.5-0.65	Pastor *et al.,* 1999	Spain (Jaén)
0.5-0.7	Fernández, 1999	Spain (Seville)
0.5-0.7	Xiloyannis *et al.,* 1999	Italy (Sardinia)
0.69-0.72	Luna, 2000	Spain (Lleida)
0.63-0.77	Fernández, 2006	Spain (Seville)

The kr coefficient takes into account crop development (soil surface covered by the tree canopy) and ranges between 0 and 1. It is just above 0 in young orchards and 1 in mature, intensive, irrigated orchards where the canopies can cover over 50% of the soil surface. As specific information is not available for olive, good results have been obtained by applying the equation proposed by Fereres *et al*. for almond (1981):

$$Kr = \frac{2\ Sc}{100}$$

where:
Sc = area of soil surface covered by canopy projection.
Sc is computed as follows:

$$Sc = \frac{\pi\ D^2\ N}{400}$$

where:
D = mean canopy diameter (m);
N = planting density (no. olive trees ha^{-1}).

6.2.5. Determination of olive water requirements (ETc) using calculated kc values

Orgaz and Pastor (2005) recently proposed an alternative to the classic method for estimating the crop coefficient, which it has already been explained is the parameter for resolving equation [3].

The proposed methodology is based on the reasoning that the classic method for estimating the crop coefficient (kc) could generate errors, especially in environments characterized by frequent rain and in olive orchards where tree canopy and planting density are low.

The method takes kc to be the product of three component parts:

1) Plant transpiration, which depends on tree size and the time of year.
2) Soil surface evaporation, which depends on solar energy and soil moisture content.
3) Evaporation of the wetted soil surface if a localized irrigation method is employed.

Hence, kc is computed from the following equation:

$$kc = kt + ks + kd \qquad [4]$$

where:
kt = transpiration coefficient;
ks = soil evaporation coefficient;
kd = evaporation coefficient of the soil wetted by the drippers.

The method for calculating each component part is now defined.

Calculating the transpiration coefficient (kt)

To calculate this coefficient the authors (Orgaz and Pastor, 2005) parameterized a simplified model from a complex model (Testi *et al.*, 2006) taking:

$$kt = Q_d \cdot F_1 \cdot F_2 \qquad [5]$$

where:
Q_d = fraction of solar radiation intercepted by the tree canopy, given by:

$$Q_d = 1 - e^{-kr \cdot Vu}$$

where:
Vu = canopy volume per unit of surface ($m^3\ m^{-2}$);
kr = radiation extinction coefficient = 0.52 + 0.00079 N – 0.76 $e^{-1.25\ DI}$;
N = number of trees per hectare;
DI = leaf area density ($m^2\ m^{-3}$) = 2 - (V_0 – 20)/100;
V_0 = canopy volume ($m^3\ pt^{-1}$) = 1/6 π D^2 H;
D = mean canopy diameter (m);
H = canopy height (m).

The value of F_1 and F_2 in [5] differs according to orchard density and time of year. More specifically:

F_1 = adjustment parameter dependent on orchard density;
F_2 = adjustment parameter dependent on the time of year.

Hence:

F_1 = 0.72 if the orchard density < 250 trees per hectare;
F_1 = 0.66 if the orchard density > 250 trees per hectare;
F_2 = tabulated value for the month concerned (Table 10).

Calculating the soil evaporation coefficient (ks)

A simplified model (Orgaz and Pastor, 2005) was also parameterized for this calculation on the basis of papers published by Bonachela *et al.* (1999, 2001) where ks is determined by the following:

$$ks = \left[0.28 - 0.18 \cdot Sc - 0.03 \cdot ET_0 + \frac{3.8 \cdot F \cdot (1 - F)}{ET_0}\right] \cdot (1 - fw)$$

where:
Sc = area of soil surface covered by canopy projection = (π $D^2/4$) (N/10000);
F = frequency of monthly precipitation = no. rainy days/no. days in month;
fw = fraction of soil wetted by drippers = (π $Dd^2/4$) (no. drippers olive tree^{-1} N/10000);
Dd = mean diameter of soil surface wetted by each dripper (m).

The Dd value should be measured experimentally in the field. If this is not possible, the values tabulated according to dripper range and soil texture can be used as a rough approximation (Table 6).

TABLE 6
Mean diameter of the area wetted* at a depth of 30 cm by emitters discharging 4 and 8 L hour^{-1} in relation to soil texture (Orgaz and Pastor, 2005)

Soil texture	4 L h^{-1}	8 L h^{-1}
	cm	
Sandy	75	100
Loamy sand	85	120
Sandy loam	95	130
Loam	110	140
Silt loam	120	150
Clay loam	130	160
Silty clay	135	170
Clay	145	180

** Wetted area = π D^2 / 4*

However, the ks value calculated in this way is not valid when evapotranspiration is high, rain frequency is low and percentage floor cover is high. Such conditions are frequent in the summer months in Mediterranean-climate areas and in mature, intensive olive orchards. In such environments ks values could even be negative, which makes it necessary to set a minimum value (ks_{min})

below which this coefficient cannot be computed from the preceding formula. When this occurs, the following is applied:

$$ks \geq ks_{min} = 0.30/ET_0 \text{ (daily)}$$

Calculating the evaporation coefficient of the soil wetted by the drippers (kd)

The value of the third component part of kc depends on several factors such as tree size, evaporative demand, soil type, dripper position and irrigation frequency.

The authors (Orgaz and Pastor, 2005) again parameterized a simplified model on the basis of papers published by Bonachela *et al.* (1999, 2001) where kd is determined by:

$$kd = \frac{1.4 \cdot e^{-1.6 \cdot Qd} + \left(4.0 \cdot \frac{\sqrt{i-1}}{ET_0}\right)}{i} \cdot fw$$

where:
i = interval between two waterings, measured in days;
ET_0 = daily reference evapotranspiration;
fw = area of soil wetted by the drippers (parameter defined earlier).

When the drippers are placed at a high density (between 0.75 ÷ 1 m) there will be a continuous strip of wetted soil along the lines. In this case, the value of fw can be computed from the following ratio:

$$fw = \frac{l}{L}$$

where:
l = width of the strip wetted by the drippers (m);
L = distance between the rows of trees (m).

Obviously, when no irrigation water is applied, the value of fw is 0.

6.3. SOIL WATER BALANCE AND ESTIMATION OF IRRIGATION REQUIREMENTS

6.3.1. Irrigation scheduling

Information on the parameters described above is needed to determine irrigation frequency (time between two irrigation applications) and volume (mm or m^3 ha^{-1} or L pt^{-1}):

- Physical soil characteristics (FC, PWP, AWC , RAW)
- Depth of root system

- Crop water requirements in different environments and at different phenological stages (kc; kr)
- Water availability (volume and quality)
- Climatic variables (EP; ET_0)
- Aspects of agricultural practices that interact with water consumption (bare or covered soil, type of orchard management and density; pruning system; irrigation system, etc.)

Some examples are now given for calculating the volume of irrigation for an orchard, assuming a planting density of 200 trees ha^{-1}.

The examples simulating the calculation of irrigation requirements are for an environment with a mean annual evapotranspiration (ET_0) of 1,366 mm, a rainfall of 388 mm, a loam-clay soil and a RAW content of 142.5 mm. The orchard concerned (200 trees per hectare) has a mean canopy volume of 8,100 m^3 per hectare. The kc values applied to compute water consumption were taken from the latest relevant literature and from trials conducted in the Seville area (Fernández *et al.*, 2006). The authors state that the kc values reported in earlier papers for the same environment had been estimated when ET_0 was calculated according to the FAO-Penman equation (Doorenbos and Pruitt, 1977) which Mantovani *et al.* (1991) judged to be reliable for this environment. Gavilán and Berengena (2000) have shown that more accurate ET_0 values are obtained in this environment on applying the FAO-56 Penman-Monteith equation (Allen *et al.*, 1998). Hence, the authors propose correcting the kc value when ET_0 is calculated according to this last method, which is currently the international reference method. Consequently, this is taken into account in the following irrigation scheduling examples calculated according to the classic method while a kc = 0.75 has been used as an example for the winter months (November, December, January and February).

A monthly water balance is considered for the sake of simplicity and to allow comparison between the irrigation scheduling examples. Farmers clearly have to adapt water requirement calculations to the irrigation frequency adopted in the specific operating conditions. Frequency will depend on the technical characteristics of the farm and collective distribution facilities, which may differ from those proposed here.

The first example (Table 7) is for a mature, drip-irrigated orchard without limitations in terms of water volume. The full evapotranspiration requirements of the crop can therefore be met, so completely restoring the ETc net of EP. The presence of a usable water reserve in the layer of soil explored by the root system is not considered in this example and total ETc works out at 667 mm. Rainfall exceeds consumption in the first three months, making it unnecessary to irrigate. Consequently, the positive water balance (ΔR) will represent a cumulative reserve in the soil, or, if it is already at FC, it will be lost through percolation. From May, the water balance is negative; therefore, it is necessary to irrigate to replenish plant water consumption net of rainfall. The seasonal irrigation volume (405 mm) is 126 mm greater than seasonal requirements net of precipitation. As a result, the seasonal balance records a surplus, i.e. the quantity of water lost through percolation to the deeper soil layers. This irrigation criterion therefore entails a useless waste of resources and is less efficient.

TABLE 7
Example of monthly irrigation scheduling disregarding the soil water reserve

Month	ET_0 Mm mth^{-1}	kc	kr	ETc	EP	Irr	ΔR
				mm mth^{-1}			
Jan	39	0.75	0.69	20.0	56.1	0	36.1
Feb	52	0.75	0.69	27.0	53	0	26.0
Mar	87	0.76	0.69	45.8	48.3	0	2.5
Apr	109	0.76	0.69	57.2	47.7	10	0.0
May	161	0.76	0.69	84.5	30.2	54	0.0
June	186	0.70	0.69	89.7	0	90	0.0
July	210	0.63	0.69	91.5	0	91	0.0
Aug	207	0.63	0.69	89.8	0	90	0.0
Sept	140	0.72	0.69	69.4	15.7	54	0.0
Oct	90	0.77	0.69	47.8	31.3	16	0.0
Nov	49	0.75	0.69	25.5	55.6	0	30.1
Dec	36	0.75	0.69	18.5	49.8	0	31.3
Yearly total	1,366			667	338	405	126

Hypothesis for calculations:
Mean canopy diameter (D) = 4.7 m
Olive trees/hectare (N) = 200
Clay loam soil
Root depth (Dr) = 1000 mm

Keys:
kc = olive crop coefficient
kr = 2 ((3.14 D^2 N)/400)/100
ETc = ET_0 kc kr
EP = 70% total precipitation
ΔR= Ep + Irr – ETc

The second example is again for an olive orchard planted at a density of 200 trees per hectare, (Table 8) equipped with drip irrigation systems with the following technical characteristics operating a maximum of 6.30 hours per day for an average 25 days a month:

4 drippers per tree at 4 litres per hour = 16 L tree^{-1} hour^{1}

Fixed monthly irrigation volume = 50 mm month^{-1} (to be replenished in 25 working days)

Hence, the system can apply:

2.0 mm day^{-1} = 20.0 m^3 ha^{-1} day^{-1}

and the trees will receive:

$$\frac{20.0\ (m^3 ha^{-1} day^{-1})}{200\ (trees \cdot ha^{-1})} = 0.1\,(m^3 tree^{-1} day^{-1}) = 100\ (L\ tree^{-1} day^{-1})$$

In terms of operating time:

$$\frac{100\ (L\ tree^{-1}\ day^{-1})}{16\ \ (L\ tree^{-1} h^{-1})} \approx 6.30\ hours\ per\ working\ day$$

The calculation proposed in Table 8 gives a seasonal irrigation application of 280 mm. In this case irrigation falls short of consumption because it takes into account the soil water reserve which is consumed during periods of maximum requirements (see "R cum" columns) and is estimated as:

$$R\ cum_t = R\ cum_{(t-1)} + (ETc_t - EP_t - Irr_t)$$

where:

R cum = soil water content at the start (t-1) and at the end (t) of the time period considered.

The soil water reserve will start to increase again when autumn rainfall exceeds consumption (ETc < EP).

TABLE 8

Example of monthly irrigation scheduling using a facility applying a maximum of 50 mm per month (established according to the technical characteristics of the irrigation facility – 4 emitters per plant each applying 4 L h^{-1}) and allowing for the soil water reserve

Month	ET_0 mm mth^{-1}	kc	kr	ETc	EP	Irr	ΔR	R. cum.
				mm mth^{-1}				
Jan	39	0.75	0.69	20.0	56.1	0	36.1	97.6
Feb	52	0.75	0.69	27.0	53	0	26.0	123.6
Mar	87	0.76	0.69	45.8	48.3	0	2.5	126.0
Apr	109	0.76	0.69	57.2	47.7	15	0.0	131.5
May	161	0.76	0.69	84.5	30.2	50	0.0	127.2
June	186	0.70	0.69	89.7	0	50	0.0	87.5
July	210	0.63	0.69	91.5	0	50	0.0	46.0
Aug	207	0.63	0.69	89.8	0	50	0.0	6.3
Sept	140	0.72	0.69	69.4	15.7	50	0.0	2.6
Oct	90	0.77	0.69	47.8	31.3	15	0.0	0.0
Nov	49	0.75	0.69	25.5	55.6	0	30.1	30.2
Dec	36	0.75	0.69	18.5	49.8	0	31.3	61.5
Yearly total	1,366			667	338	280	126	

Hypothesis for calculations:
Mean canopy diameter (D) = 4.7 m
Olive trees/hectare (N) = 200
Clay loam soil
AW = available water = (0.36-0.17)Dr = 190 mm
Readily available water (RAW) =
= 0.75 (0.36 - 0.17) Dr = 142.5 mm
Root depth (Dr) = 1,000 mm

Keys:
kc = olive crop coefficient
kr = 2 ((3.14 D^2 N)/400)/100
ETc = ET_0 kc kr
EP = 70% of total precipitation
Δ R = Ep + Irr - ETc
R cum. = Ep + Irr - ETc + previous month's R cum.

During the irrigation season ET_c was partially satisfied by irrigation (Irr) and partially by the soil water reserve (Racc). This means that in late summer (October: R cum. = 0), the trees will have consumed almost all the reserve, which will be replenished *"for free"* in the winter.

This second strategy entailing use of the soil water reserve has the advantage that it saves irrigation water – 280 mm (Table 8) compared with 405 mm (Table 7) – and allows constant volumes of water to be applied when requirements peak, so making irrigation management easier in practical terms.

Taking the example presented in Table 8 the situation might arise where irrigation is not sufficient to maintain the soil reserve level above the RAW limit. When this occurs the irrigation volumes should be increased to preclude crop water stress. Special care should be taken when determining the contribution of the soil water reserve at the start of the irrigation season, which will have to be brought forward in particularly dry winters. When using localized irrigation methods, it is advisable to start applying irrigation when the limit of 60–70% of the AWC is reached.

When the terrain is sloping a mulch cover can be grown in between the tree rows to reduce erosion and improve the amount of organic matter. In such cases, when computing watering volume, a correction factor has to be applied to the estimate of EP and kc which takes into account the water consumed by the inter-row plant cover while it is present. The following points should be borne in mind in particular:

- EP will be greater than when there is no mulch cover (about 80% of the total), especially in those situations (sloping terrain) where losses occur through run-off;
- The kc coefficient has to be calculated for the "olive cover crop system", according to the following equation:

$$kc_l = \frac{kc_e\, S}{10{,}000} + kc\ (\text{olive tree})\ kr$$

where:
kc_e = crop coefficient of the cover crop;
S = surface area of the cover crop ($m^2\ ha^{-1}$).

To prevent the plant cover competing excessively for water it should be removed by desiccating it, working it into the soil or mowing (see chapter on soil management) when the water balance (ETc – EP) becomes negative.

Table 9 provides an example of the calculations for ETc and watering volume when the soil is covered with a cover crop which is removed in March, and the soil water reserve is taken into account. It shows that the seasonal irrigation volume amounts to 375 mm, which is 95 mm higher than when there is no cover crop in between the rows (Table 8).

If the irrigation system or water supply sources do not impose limitations, irrigation should be more frequent in low water-retention soils (sandy soils) whereas it may be spaced out on clay soils. In clay soils, less frequent irrigation entails applying a larger amount of watering which, if all other

TABLE 9

Example of monthly irrigation scheduling using a facility applying a maximum of 50 mm per month (established according to the technical characteristics of the irrigation facility – 4 emitters per plant each applying 4 L h^{-1}) and allowing for the soil water reserve and with inter-row plant cover

Month	ET_0 mm mth^{-1}	kc_e	Kc_l	ETc	EP	Irr	ΔR	R. cum.
				mm mth^{-1}				
Jan	39	0.50	0.68	26.5	56.1	0	29.6	78.5
Feb	52	0.60	0.72	37.5	53.0	0	15.6	94
Mar	87	0.70	0.76	66.2	48.3	50	32.1	126.1
Apr	109	1.00	0.86	93.6	47.7	50	4.1	130.2
May	161	0.00	0.52	84.5	30.2	50	-4.3	125.9
June	186	0.00	0.48	89.7	0	50	-39.7	86.2
July	210	0.00	0.43	91.5	0	50	-41.5	44.7
Aug	207	0.00	0.43	89.8	0	50	-39.8	5.0
Sept	140	0.00	0.50	69.4	15.7	50	-3.7	1.3
Oct	90	0.30	0.63	56.8	31.3	25	-0.8	-0.1
Nov	49	0.40	0.65	32.0	55.6	0	23.6	23.5
Dec	36	0.50	0.68	24.0	49.8	0	25.4	48.8
Yearly total	1,366			762	338	375		

Hypothesis for calculations:
Mean canopy diameter (D) = 4.7 m
Olive trees/hectare (N) = 200
Clay loam soil
AW = available water = (0.36-0.17)Dr = 190 mm
Readily available water (RAW) =
= 0.75 (0.36 - 0.17) Dr = 142.5 mm
Root depth (Dr) = 1,000 mm

Keys:
kc_e = plant cover crop coefficient
$kc_l = kc_e S\ 10{,}000^{-1}$ + kc (olive) kr
S = 10,000/3 = 3,333.33 $m^2\ ha^{-1}$
$ETc = ET_0\ kc_l$
EP = 70% of total precipitation
Δ R = EP + Irr - ETc
R cum. = EP + Irr - ETc + previous month's R cum.

variables remain the same, could create conditions of asphyxia or moisture losses in soil layers not explored by absorbent roots in sandy soils.

An example of water requirement calculations based on the method proposed by Orgaz and Pastor (2005) is given in Table 10. The simulation can be done using a simple electronic spreadsheet and takes a hypothetical olive orchard featuring the same soil and climatic characteristics as the other examples, and the same agricultural practices.

The monthly ETc values obtained from the model for the kc calculations reported earlier [4] are slightly higher than those computed according to the classic method for this environment.

However, the examples reported provide only a possible methodology for computing irrigation volumes. It must be emphasized that it is important to arrive at accurate estimates of the irrigation

TABLE 10

Example of calculations for ETc using kc values obtained according to the method of Orgaz and Pastor (2005)

Month	ET_0 mm mth^{-1}	kc	F_2	kt	ks	kd	EP mm mth^{-1}	No rainy days	F	ETc mm mth^{-1}
Jan	39	0.79	0.70	0.19	0.59	0.00	56.1	5.0	0.16	30.4
Feb	52	0.71	0.75	0.21	0.50	0.00	53.0	6.0	0.21	37.2
Mar	87	0.59	0.80	0.22	0.37	0.00	48.3	7.0	0.23	51.5
Apr	109	0.50	0.90	0.25	0.25	0.00	47.7	5.0	0.17	54.8
May	161	0.47	1.05	0.29	0.10	0.08	30.2	2.0	0.06	75.9
June	186	0.45	1.23	0.34	0.03	0.08	0	0.0	0.00	83.9
July	210	0.44	1.25	0.35	0.01	0.08	0	0.0	0.00	92.5
Aug	207	0.43	1.20	0.33	0.02	0.08	0	0.0	0.00	88.7
Sept	140	0.51	1.10	0.30	0.12	0.08	15.7	2.0	0.07	70.9
Oct	90	0.66	1.20	0.33	0.25	0.08	31.3	3.0	0.10	59.0
Nov	49	0.86	1.10	0.30	0.55	0.00	55.6	6.0	0.20	42.1
Dec	36	0.82	0.70	0.19	0.63	0.00	49.8	5.0	0.16	29.4
Yearly total	1,366						338			716

Mean canopy diameter (D) = 4.50 m; Mean canopy height (H) = 3.5 m; Canopy volume (Vo) = 40.5 m^3;
Olive tree/hectare (N) = 200; Canopy volume per unit of surface area (Vu) = 0.81 m^3m^{-2}; kr = radiation extinction coefficient = 0.584;
Leaf area density (Dl)= 1.80 m^2m^{-3}; Dl ≤ 2 m^2m^{-3};
Fraction of solar radiation intercepted by canopy (Qd) = 0.383; Fraction of orchard floor covered (Sc)= 0.347^2 m;
No. drippers per olive tree (Ng) = 4; dripper discharge rate 4 L $hour^{-1}$; Mean diameter of wetted area head (Dg) = 1.30 m;
Fraction of soil wetted by drippers (fw) = 0.106; Interval between two irrigations (i) = 1 day;
Monthly frequency of rainy days (F) = no. rainy days / no. days in month.
EP = 70% of total precipitation

parameters for each growing environment. This condition places limitations on both approaches to irrigation scheduling, which depend primarily on correct evaluation of the variables involved in estimating ETc and which must be assessed for each growing environment.

6.3.2. Deficit irrigation

The olive is a species which shows a clear response to irrigation, even when supplied in limited amounts. This makes it possible to implement deficit irrigation strategies where the application of a seasonal volume of irrigation partially satisfies water.

One technique that is becoming quite widespread is known as regulated deficit irrigation. This involves reducing irrigation application during less critical phenological stages for yield while ensuring adequate water supply during the most critical phases. Its application therefore calls for an understanding of the effects of water shortage during the various phenological stages of the crop and the physiological mechanisms correlated with plant response to water stress.

As already explained, flowering, fruit set and cell expansion during fruit growth have been identified as the most critical periods. Conversely, it has been demonstrated that moderate water stress during stone hardening can have a small effect on final fruit size without lowering oil production. Trials conducted in Spain (Catalonia) demonstrated that the application of irrigation volumes representing 75 and 50% of ETc during the stone hardening phase did not cause significant reductions in crop production compared with irrigation covering full requirements, whereas replenishment of only 25 % of ETc led to a 16% fall in production. In terms of saving irrigation water, these trials recorded respective decreases in seasonal irrigation volume of 24, 35 and 47% (Girona, 2001). This irrigation strategy is also very important in reducing the level of competition for water in periods when it is required for other crops or for civil purposes. Implementing this strategy improves water use efficiency because it permits significant decreases in seasonal irrigation volumes.

However, this approach calls for experimental validation checks in different environments from the trial as well as according to the end purpose of the product (for oil or table consumption) and the water stress tolerance of the cultivars grown.

For instance, water stress during stone hardening should be less severe and shorter for table olives than for oil-olives because fruit size at harvest is one of the chief commercial considerations.

In environments where there are limitations on water use during the summer it may be useful to water in winter and at the beginning of spring, so ensuring a good soil water reserve for the critical stages of vegetative flush, flowering and fruit set. This approach will be effective on deep soils with a high water retention. For this reason, it is important to know the hydrological properties of the soil to make sure the right volume of water is applied, so avoiding excessive watering and the ensuing percolation losses. It should be remembered, however, that the crop will presumably consume the water reserve before completing the production cycle. Consequently, it will be necessary to monitor soil water content to determine when to apply supplemental irrigation during the critical crop periods, if possible.

In arid environments and environments where water availability is limited throughout the year only supplemental irrigation can be applied. In such cases it is wise to envisage watering during the most sensitive phenological stages, as described earlier.

The growing body of knowledge on soil–plant–atmosphere relationships will provide helpful information for application in deficit irrigation management. It is a subject area that should be examined in greater depth in the near future, all the more so because of the pressure on the agricultural sector to make rational, sustainable use of water.

6.4. LOCALIZED IRRIGATION

Irrigation water distribution methods differ in terms of their efficiency and uniformity of distribution.

Distribution efficiency (De) is determined by the location of the water in the root system and the absence of water losses during irrigation supply, in other words it is the useful percentage of water that reaches the plant.

$$De = \frac{\text{water supplied to root zone}}{\text{water applied}} 100$$

It follows that if an installation is 90% efficient and 35 mm of water are applied monthly, nine-tenths of the water will be actually available to the plant. The distribution coefficient also varies according to environmental conditions and is taken to be 0.85, 0.90 and 0.95 for arid, temperate and wet climates, respectively.

Good distribution uniformity guarantees that all the trees receive the same amount of water at the same time. Besides being influenced by questions of hydraulics which are dealt with by the installation designer, this is also influenced by the technological features of the emitters.

Localized systems are the most efficient methods available for irrigation water distribution (De > 90%). Traditional methods (flood, furrow, sprinkling, etc.) are not reported because they are less efficient and can only be used in certain conditions.

Localized irrigation responds to the need to reduce watering volumes. Unlike other distribution methods, the whole soil surface is not watered in localized irrigation., so saving water resources which will be available to increase irrigated area or for allocation for other uses.

This irrigation system can be operated automatically and requires little labour for regular maintenance. An additional feature is that the installation can be used to apply nutrients to the trees (fertigation).

6.4.1. Characteristics of localized irrigation systems

- Low working pressure

Emitter working pressures of between 0.10 and 0.25 Mpa are used in localized irrigation. This means that low pump-head stations can be employed compared with other systems, so making considerable savings in terms of investment and operating costs. The plastic material used (pipes, fittings, etc.) is also for low pressures and is therefore cheap.

- Low-flow emitters

This kind of emitter allows long operating times and high frequency watering to meet irrigation needs. These characteristics make it possible:

– to ensure constant moisture in the soil profile and uniform watering of the soil, including soils characterized by low infiltration (clay, loam, non-structured soil) or low water-holding capacity (sand);

– to use small-volume water supplies and small-diameter pipes;
– to use moderately saline water and soils because the salts are pushed out to the edges of the wetted area, which reduces the saline concentration in the area where the water is taken up by the root system.

In contrast, very low-flow drip systems (2–8 L h^{-1}) are ill suited when solely supplemental irrigation or irrigation with high volumes of water at very long intervals are the criteria applied.

- Watering near root system

This makes it possible:

– to apply water and fertilizer to the best position for the absorbing roots;
– to keep the soil at the right degree of moisture for the crop;
– to avoid wetting the entire ground surface, so reducing evaporation-related water losses;
– to avoid wetting the plant, so reducing water losses caused by evaporation of the wetted leaf surface and limiting the onset of fungal diseases;
– to restrain weed development;
– to allow machinery to be manoeuvred and cultural practices to be carried out during irrigation;
– to prevent the negative effect of the wind on the uniformity of water distribution.

The density of the water-absorbing root system will be greatest in the wetted areas; hence, in dry periods, the plant will be very dependent on the water content of this part of the soil. This indirectly leads to one negative aspect of localized irrigation because the volume of soil explored by the roots will be limited and the water it contains will be consumed quickly. This aspect of localized irrigation should be taken into account because incorrect irrigation design or the interruption of irrigation, even accidentally, causes greater stress than in the case of irrigation methods where wider areas of the soil are wetted.

Various types of drippers or sprayers are used as emitters in localized irrigation systems.

6.4.2. Characteristics of emitters

Nominal flow rate

This is the flow rate (generally in litres per hour) declared by the manufacturer.

Laboratory tests assess the technical uniformity of emitter discharge (drippers or sprayers) by estimating the deviation of the flow rate (Qd) and coefficient of variation (CV) of the emitters.

Deviation of flow

This is the percentage difference between the nominal flow and the actual flow, which is the flow measured in a laboratory in a representative sample of emitters.

$$Qd = 100 \frac{Qr - Q_{mean}}{Qr}$$

where:
Qd = deviation from the mean flow rate;
Qr = nominal flow;
Q_{mean} = mean flow rate measured in a representative sample of emitters.

The smaller the difference between the values of the individual emitters and the mean, the greater the uniformity of emission. Qd (%) is usually graded as 0-4, 4-8, 8-12, > 12, which indicate that the emitters are excellent, good, fair or poor, in that order.

Coefficient of variation

This is the statistical evaluation which expresses the variation in emitter flow rate as a percentage of the mean flow rate of a batch of emitters. CV is calculated as:

$$CV = \frac{S}{Q_{mean}}$$

where:
CV = coefficient of variation;
S = standard deviation of the flow rates of a batch of emitters;
Q_{mean} = mean flow rates measured in a representative sample of a batch of emitters.

CV% is usually graded as 0–5, 5–10, 10–15, > 15, which indicate that the emitters are excellent, good, fair or poor, in that order.

Compensation capability

The compensation capability is the effective capacity of the emitters to maintain the actual flow rate unchanged when the working pressure varies. It is calculated by estimating the flow rate deviation (Qd) and the coefficient of variation (CV).

Drippers

Drippers are the devices the water runs through from the pipes to the ground. The water runs through a series of very narrow pathway sections. The flow rates are quite low (generally between 2 and 8 litres h^{-1}) and the working pressure is normally 0.10–0.15 MPa.

– The flow of water inside the dripper can be *laminar, turbulent* or *vortex (whirlpool)*.

In *laminar-flow* drippers the water runs slowly and the water speed is regulated by the friction against the conduit wall. Consequently, the longer and narrower the conduit, the greater the resistance and the smaller the flow. These drippers are simple, cheap devices in which the flow rate varies considerably on changing the working pressure. They also clog easily owing to the low speed of run-through and the small diameter of the conduits, and they are sensitive to the viscosity of the water (i.e. the flow rate varies according to water temperature).

In *turbulent-flow* drippers the water runs quickly and irregularly and the water speed is regulated by the friction against the conduit walls and between the water particles. The internal pathway sections are shorter and broader in diameter than in laminar-flow drippers; hence, there are fewer problems of clogging and they are less sensitive to water viscosity (Figs. 4 and 5).

Figure 4. Inline dripper (Irritol System Europe s.r.l).

In the *vortex* drippers the water rolls inside the emitter to form a whirlpool, with a hollow in the middle. The emission point coincides with the middle of the whirlpool. These emitters are less sensitive to changes in pressure compared with turbulent-flow emitters, but they generally have narrower conduits which become easily blocked.

– Two kinds of dripper can be found on the market in terms of working pressure: standard and self-compensating.

Standard drippers have no flow regulation device, which means the flow changes when the working pressure varies. Consequently, they are used for short lines in flat areas because otherwise the difference in pressure between the start and end of the pipes would cause a low uniformity of water distribution.

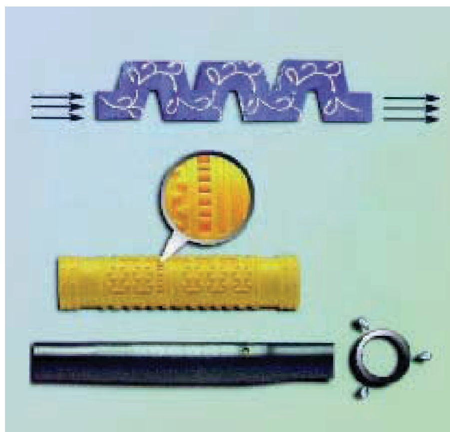

Figure 5. Diagram of a turbulent-flow dripper (Siplast, 2003).

The distinguishing feature of *self-compensating* drippers (Figs. 6 and 7) is that they keep the flow rate constant when the working pressure varies. Water distribution uniformity is therefore good in large systems with long dripper lines and on sloping terrain. The compensating capability is determined by the presence of a membrane (generally silicone) which gives under the pressure of the water, so maintaining the flow constant. These characteristics should be taken into account by designers to ensure distribution uniformity.

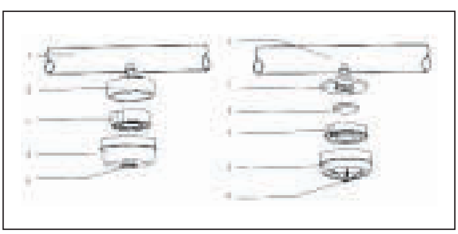

Figure 6. Standard (left) and self-compensating emitter (right). 1) tube; 2) barbed inlet; 3) compensating membrane; 4) internal labyrinth; 5) cap; 6) outlet hole (from Guidoboni, 1990).

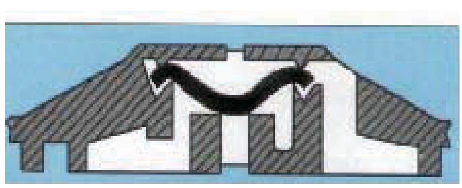

Figure 7. Diagram showing how the membrane works in a self-compensating dripper (Irritol System Europe s.r.l).

– Two kinds of dripper can be singled out in terms of their position on the piping: "online" or "inline"

Drippers are said to be *"online"* when they are mounted on feeder tubes along the dripline and *"inline"* when they are moulded into the dripline tubing. The first kind are generally used for hanging dripper lines whereas the second can also be laid on the ground. In the case of pre-assembled lines, the distance between inline drippers is determined before the tubing is extruded.

– Drippers can be take-apart or integral: The first type can be opened to remove solid particles blocking the water outlet. They are not advisable in the case of self-compensating drippers because opening can alter the characteristics of the membrane with the ensuing risk of modifying the flow rate (Fig. 8).

– Drippers with anti-drip device:

The problem of system emptying at the end of watering can be resolved by using drippers fitted with a special manufacturing feature that blocks dripping at system shut-down. This has the advantage that irrigation volume is measured more easily and more accurately.

Figure 8. Take-apart dripper (Irritol System Europe s.r.l - Euro-Key classic type).

– Self-flushing drippers:

Some of the drippers available on the marketplace adapt better than others to the use of low quality water. The self-flushing mode operates by modulating the working pressure of the system accordingly.

Sprayers

Sprayers have higher flow rates than drippers and can be divided into micro-sprayers with a discharge rate of between 30 and 150 litres $hour^{-1}$ and mini-sprayers with a discharge rate of between 150 and 350 litres $hour^{-1}$.

They can be further divided into *static* (Fig. 9) and *dynamic* (Fig. 10) emitters. The first kind have no moving parts; depending on the type and shape of the outlet holes, they can wet different sections of the ground (circles or strips). The second are equipped with moving parts (rotating) which give a circular shape to the wetted area.

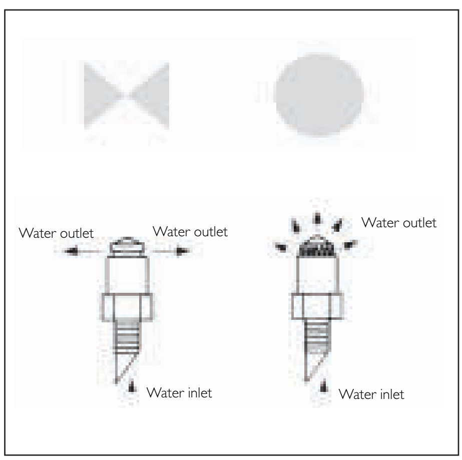

Figure 9. Static sprayer (ERSAM, 2001).

Several commercial models are available but it has to be remembered that water spraying performance varies according to both the working pressure and the height from the ground. The sprayers can be mounted directly onto the tubing but this is not advisable because it means that the emitter cannot be kept perpendicular to the ground because of the moving and twisting of the piping caused by the changes in temperature. This distorts the areas wetted by the emitters.

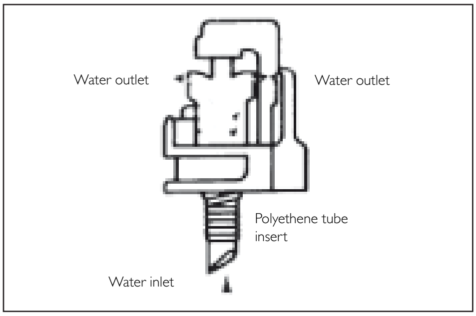

Figure 10. Dynamic sprayer (ERSAM, 2001).

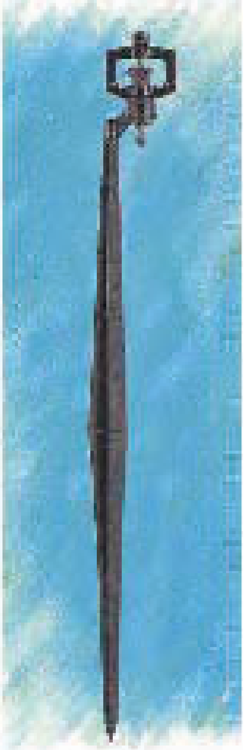

Figure 11. Mini-sprinkler mounted on a spike (Irritol System Europe s.r.l).

Several solutions have been found to overcome this drawback. The most widespread ones are now outlined:

– The sprayer can be mounted on a spike dug into the ground near the tree and connected to the supply pipe via a micro-tube. As a result, the spray pattern is not affected by the hose movements. In this case the supply pipe can be laid directly on the ground, buried underneath along the row or hung along supports or on the tree itself (Fig. 11).
– In aerial lines, some types of sprayer can be mounted head downwards and connected to the supply pipe by a flexible mini-tube. Sometimes a stiff plastic tube needs to be inserted in the connecting tube to make sure the sprayer stays perpendicular to the ground.

The advantage of the first system is that the position of the sprayer can be altered to suit tree requirements. For instance, the system can be shifted small distances to suit the irrigation needs of the trees as they develop over the years (young orchards). However, the spikes are an obstacle to tillage along the rows; the choice of system will therefore be based on the type of orchard management.

The position of the sprayers is particularly important because if the water wets the tree trunk, this will encourage the appearance of fungal diseases in the collar and trunk (Fig. 12).

6.4.3. Number and position of emitters

Choosing the right number of emitters according to soil type, orchard density and irrigation volume is an important decision to avoid losing the advantages of localized irrigation.

Figure 12. Mini-sprinkler in operation in olive orchard. Wetting the trunk encourages the onset of diseases.

One point to remember from the agronomic standpoint is that the water delivered by a dripper creates a wetting front which varies depending on the hydrological characteristics of the soil and the speed of emission (see Table 6). The water in the soil is subjected to forces of gravity (downwards) and capillarity (in an external radial direction) which give a characteristic water distribution model for each type of soil (Fig. 13).

The number and position of the delivery points therefore have to be established on the basis of the type of soil, which makes it important to know its characteristics. Some guidelines are now provided:

– Permeability is low in clay soils and water first tends to expand on the surface (laterally) and then downwards. A large volume of soil is wetted, which means that a small number of emitters can be installed compared with other types of soil.

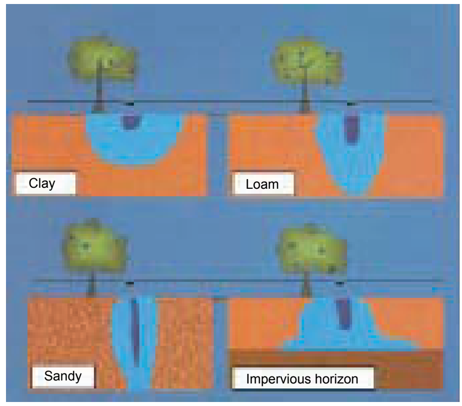

Figure 13. Dripper wetting pattern on clay, loam and sandy soil and in the presence of an impervious horizon (ERSAM, 2001).

– In medium type soils, the forces of gravity and capillarity are more balanced and the water is distributed more uniformly at a depth. To avoid water losses through deep percolation (below the absorbent zone) it is necessary to increase the number of emitters as well as to reduce the volume of irrigation and increase the frequency of watering.

– In sandy or gravel soils (permeable) the gravity and low capillarity cause rapid deep percolation of the water. The wetted area is narrow and elongated in shape. The right ratio between wetted soil and roots is achieved by positioning a large number of emitters and by irrigating frequently in small volumes.

The number of drippers along the lines has to be tailored to the climate, tree requirements and soil type. Not only is this aspect important to satisfy crop irrigation requirements, it also affects investment costs (diameter of piping, number of drippers, size of pump stations, etc.). Table 11 provides some examples that give an idea of dripper spacing on different soils according to their discharge rate. Easy-to-use computer applications are also available.

When using sprayers, the wetting radius and the shape of the wetted area have to be taken into account. Manufacturers' catalogues give details of the area wetted by sprayers; in any case, dynamic sprayers generally wet a round-shaped area of between 1 and 5 m. Users are recommended to position the sprayers at a distance from the trees equal to twice the length of the spray throw, irrespective of the type of soil.

TABLE 11
Number of drippers per tree, distance on each side of trunk and mean rainfall in relation to type of soil texture and dripper discharge rate

	Dripper discharge rate									
	4 litres per hour					8 litres per hour				
Soil type	Drippers per tree $^{-1}$	Distance from trunk			Rainfall	Drippers per tree $^{-1}$	Distance from trunk			Rainfall
	n.pt $^{-1}$	cm			mm h $^{-1}$	n.pt $^{-1}$	cm			mm h $^{-1}$
		I	II	III			I	II	III	
Sand	6	59	118	178	0.49	6	59	118	178	0.98
Loam	6	62	125	188	0.49	6	62	125	188	0.98
Clay	4	145	218	-----	0.33	4	145	218	-----	0.65

Irrigation needs increase as the tree grows. One way of satisfying the increasing irrigation requirements of the crop over time is to install the amount of tubing the orchard will need when it is mature and to add on drippers as the development of the trees increases their irrigation needs.

6.4.4. Subsurface irrigation

Inline dripper lines can be buried under the soil surface, in which case the system is known as subsurface irrigation.

This method has a number of advantages over surface drip irrigation which can be worthwhile in arid-climate environments. Notably, recent research has reported that:

– evaporation- and wind-induced water losses are smaller (wind-induced losses occur in hanging dripper lines);
– fertigation is more efficient because the fertilizers are well distributed in the area explored by the root system;
– keeping soil moisture below the vegetation helps to reduce fungal diseases and above all to curb the development of weeds;
– it facilitates the use of recycled water with a high microbial count;
– burying the dripper lines underground protects them from damage by ultraviolet rays and temperature extremes;
– buried dripper lines have less impact on the landscape and are not vandalized;
– it is easier for machinery to manoeuvre, so making it possible to mechanize cultural practices because the dripper lines are not suspended or on the ground.

This system does have some drawbacks owing to the risk of the water outlet orifices being clogged by roots and soil.

One effective way of preventing soil blockages is to avoid system pressure lowering at the end of watering. This 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. This problem will be more evident in sloping terrain where additional air relief valves can be installed on ridges. It is also advisable to use self-flushing, turbulent-flow drippers. To attenuate the problem of root hairs getting into the emitters, one possibility is to use drippers (available commercially) incorporating a small amount of herbicide (trifluralin) which is released non-stop in small amounts that are not pernicious for the environment. The trifluralin is not leached because it is heavily adsorbed by the soil and it diverts root elongation.

For guidance purposes, in intensive olive orchards two dripper lines can be envisaged per row, buried at a depth of around 35 cm at a distance of 120–140 cm from the row and fitted with drippers positioned at 1-m intervals and delivering between 2 and 4 litres of water per hr^{1} .

As in the case of surface irrigation systems it is always wise to hire a professional to design the facility and to define its agronomic and engineering characteristics.

6.5. WATER QUALITY

Irrigation water comes from several sources (rivers, lakes, canals, reservoirs, wells, urban and industrial waste, etc.) which have a bearing on its quality. It is important to know the quality characteristics of irrigation water because of its effects on the trees, soil and system maintenance (Table 12).

The indicators characterizing water quality can be grouped into three categories:

1) Physical indicators: temperature, suspended solids, natural organic matter.
2) Biological indicators: pathogenic micro-organisms (coliform, streptococcal, faecal, etc.), algae, fungi, actinomycetes.
3) Chemical indicators: pH, salinity, sodium adsorption ratio (SAR), presence of chlorides, sulphates, boron, trace elements (heavy metals) and trace compounds (surfactants, solvents, dyes, etc.).

Physical indicators

High temperatures occurring in tubing when the system is shut down can be involved in some chemical reactions (conversion of calcium bicarbonate into insoluble carbonate, with the resultant deposits and blockages) and lead to the development of micro-organisms. Also, the occurrence of organic and inorganic suspended solids causes problems of emitter clogging, filter blockages, etc. As a rule, the suspended solids concentration should not be more than 50 mg L^{-1}. Surface water and wastewater are the most contaminated from this point of view.

Biological indicators

Besides the hazard that some bacteria pose for human health, the presence of micro-organisms can generate proliferations of bacterial slime which causes blockages and problems of water distribution uniformity. In addition, algae, actinomycetes and fungi can grow on the surfaces of tanks and collecting basins that are exposed to light.

TABLE 12
Analytical determinations required to assess water quality for irrigation purposes (Ayers and Westcot, 1994)

Analytical parameters	Symbol	Unit of measurement [1]	Normal values
SALINITY			
Electrical conductivity	ECw	$dS\ m^{-1}$	0 – 3
Total solids in solution	TDS	$mg\ L^{-1}$	0 – 2,000
CATIONS and ANIONS			
Calcium	Ca^{++}	$meq\ L^{-1}$	0 – 20
Magnesium	Mg^{++}	$meq\ L^{-1}$	0 – 5
Sodium	Na^{+}	$meq\ L^{-1}$	0 – 40
Carbonates	CO_3^{--}	$meq\ L^{-1}$	0 – 1
Bicarbonates	HCO_3^{-}	$meq\ L^{-1}$	0 – 10
Chlorine	Cl^{-}	$meq\ L^{-1}$	0 – 30
Sulphates	SO_4^{--}	$meq\ L^{-1}$	0 – 20
NUTRIENTS			
Nitrates-Nitrogen [2]	NO_3 - N	$mg\ L^{-1}$	0 – 10
Ammonium-Nitrogen [2]	NH_4 - N	$mg\ L^{-1}$	0 – 5
Phosphates-Phosphorus [2]	PO_4 -P	$mg\ L^{-1}$	0 – 2
Potassium	K^{+}	$mg\ L^{-1}$	0 – 2
OTHER			
Boron	B	$mg\ L^{-1}$	0 – 2
Acidity/Basicity	pH	1 - 14	6.0 – 8.5
Sodium adsorption ratio	SAR	$meq\ L^{-1}$	0 - 15

[1] $dS\ m^{-1}$ = decisiemens metre-1 (equivalent to 1 mmho cm^{-1} = 1 millimmho $centimetre^{-1}$)
$mg\ L^{-1}$ = milligrammes per litre = parts per millionth (ppm)
$meq\ L^{-1}$ = milliequivalents per litre ($mg\ L^{-1}$ ÷ equivalent weight = $meq\ L^{-1}$)
[2] Laboratories generally give the quantity of NO_3-- in chemical equivalents of nitrogen; the same applies to ammonium and phosphates

Chemical indicators

The optimal pH of water lies between 6.5 and 7.5. When pH values > 8 special attention should be paid to the presence of Ca^{++}, Fe^{++}, Fe^{+++} and PO_4^{-} ions because calcium precipitates, iron oxides, phosphate compounds, etc. can cause clogging of the emitters.

Another chemical aspect that should be taken into account when evaluating irrigation water is the quantity and quality of the soluble salts (salinity) because of their effects on the soil and plant.

Several indicators can be applied to define water salinity: one of the most widely used is electrical conductivity (ECw), generally expressed in $dS\ m^{-1}$.

The higher the value of the ECw, the greater the quantity of soluble salts in the water. Other conditions being the same, this raises the osmotic pressure of the soil solution, which decreases the water available to the crop.

ECw only provides a quantitative evaluation of the salts. If the aim is to estimate the specific phytotoxic effects of some ions (boron, chlorine and sodium) and the effects of other solutes (sodium, calcium, magnesium, carbonates, etc.) on the chemical and physical nature of the soil it is necessary to carry out qualitative analytical assessments.

Several indicators are used to evaluate the risk of soil sodification and the ensuing deterioration in physical characteristics. One of the indicators in greatest use is the sodium adsorption ratio or SAR, which takes into account the quality of the salts that influence colloidal adsorption and therefore affect soil structure:

$$SAR = Na^+ \Big/ \sqrt{\frac{Ca^{++} + Mg^{++}}{2}}$$

where the ion concentrations (Na^+, Ca^{++}, Mg^{++}) are expressed in milliequivalents per litre (meq L^{-1}).

It is of key importance to determine the ECw, SAR and the quantity of certain toxic ions in order to decide whether the water can be employed for irrigation purposes (Tables 12 and 13).

TABLE 13

General indications for assessing water intended for irrigation purposes.

Potential problems during irrigation	Index / Ion	Unit of measurement	Limitation on use: none	moderate	severe
Salinity	ECw	dS m^{-1}	< 0.7	0.7 – 3.0	> 3.0
Decrease in speed of water infiltration into soil	SAR	for: 0<SAR<3 and ECw →	> 0.7	0.7 – 0.2	< 0.2
		for: 0<SAR<6 and ECw →	> 1.2	1.2 – 0.3	< 0.3
		for: 0<SAR<12 and ECw →	> 1.9	1.9 – 0.5	< 0.5
		for: 0<SAR<20 and ECw →	> 2.9	2.9 – 1.3	< 1.3
		for: 0<SAR<40 and ECw →	> 5.0	5.0 – 2.9	< 2.9
Effects of toxicity on sensitive crops	sodium (Na^+)	mg L-1	< 69	> 69	
	chlorine (CL^-)	mg L-1	140	140 – 350	> 350
	boron (B)	mg L^{-1}	< 0.5	0.5 - 1	> 1
	other elements	(see Table 11)			
Misc. effects on sensitive crops	Nitric nitrogen (NO_3^-)	mg L-1	< 0.5	5 – 30	>30
	Bicarbonate (HCO_3^-)	meq L-1	< 1.5	1.5 – 8.5	> 8.5
	pH		between 6.5 and 8.4		

Source: Adapted from Ayers and Westcot, 1995

6.5.1. Water treatment

The emitters used for delivering water in localized irrigation have small orifices which can easily become blocked. This makes it necessary to know the quality characteristics of the water, which will have a bearing on the choice of filtration system.

Water can be treated in two ways:

PHYSICAL = to eliminate suspended solids (organic and inorganic)
CHEMICAL = to eliminate substances dissolved in the water (carbonate, iron, etc.)

– Various types of physical treatment can be used depending on the type of material present in the water. The main methods use sedimentation tanks, hydrocyclone filters, gravel filters, sand filters, screen filters and disc filters. Different types of filter can be coupled together.

Sedimentation tanks

Sedimentation tanks are used to decrease the amount of suspended solids in the water. Owing to the force of gravity, the heavier suspended particles in the water sink to the bottom of the tanks. The speed with which they are deposited depends on the type of suspended solid and on the manufacturing characteristics of the tank. As they generally involve high investment and maintenance costs they are only used in specific cases.

Centrifugal or hydrocyclone filters

The hydrocyclone or centrifugal separator (Fig. 14) is used primarily to filter sand and particles that are heavier than water. The centrifugal force generated by the funnel shape of the filter throws the impurities against the walls and pushes them down to the collecting tank. Centrifugal separators are often installed ahead of the pumps to reduce wear and tear (Fig. 15). When necessary, the filter is cleaned by opening discharge valves and the sediment is removed by the flow of water; some types are self-cleaning. Pressure losses induced by the centrifugal force are high (0.50–0.80 MPa), particularly in the types mounted ahead of the pumps. The filter is generally made of galvanized steel and the inside walls are covered with epoxy materials that reduce abrasion.

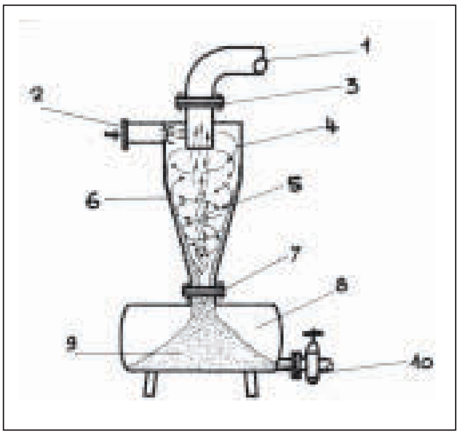

Figure 14. Operating diagram of a hydrocyclone filter 1) delivery pipe; 2) inlet pipe; 3) outlet pipe coupling; 4) movement of water; 5) direction of rising water; 6) galvanized wall; 7) coupling between filter and sand collection chamber; 8) sand collection chamber; 9) sand; 10) discharge valve (from Guidoboni, 1990).

Sand or gravel filters

Gravel filters (Fig. 16) use granite or crushed silica of varying sizes depending on

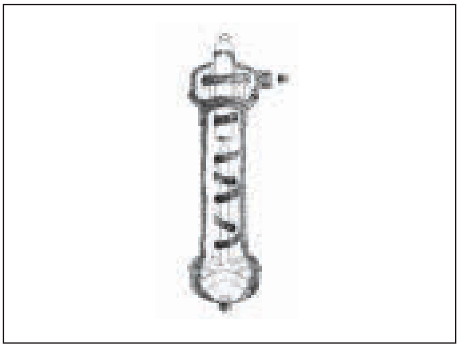

Figure 15. Operating diagram of a sand separator (from Boswell, 1993).

filtration requirements and the size of the emitter orifices (Table 14). The tank may hold layers of coarser gravel at the top of the filter, and finer layers closer to the outlet. The water runs into the gravel tank through an opening at the top, with the jet facing upwards. The water is thus distributed evenly over the surface of the gravel; as it runs through the layers it is cleaned of algae, organic debris, soil particles and other coarse particles. The impurities that build up limit filtration power. To clean the filter (by hand or automatically) the water flow has to be reversed; the water is run through the outlet and the dirty water is removed through a passageway. Backwashing is carried out whenever the pressure drops by around 0.03–0.08 MPa with respect to normal values.

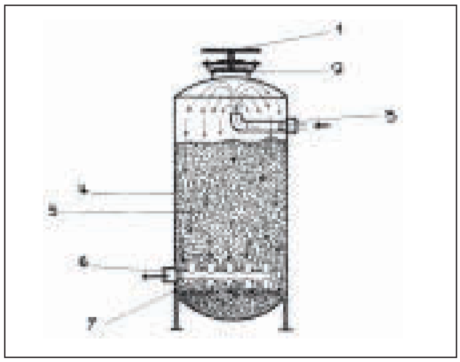

Figure 16. Operating diagram of a gravel filter 1) cover with handle; 2) cover gasket; 3) water inlet 4) filter wall; 5) filter medium; 6) water outlet; 7) collection chamber (from Guidoboni, 1990).

Screen filters

Screen filters (Fig. 17) consist of a cylindrical plastic or galvanized steel container with an airtight lid; inside there are one or more fine-meshed screens which are the filter medium. These kinds of filters are employed to retain sand or other coarse particules. The size of the screen mesh (expressed in number of mesh wires per square inch) depends on the quality of the water being treated and the size of the emitter outlet holes (Table 14). This kind of filter can be used on its own; however, it is more usual for it to be mounted in battery after a gravel filter or hydrocyclone.

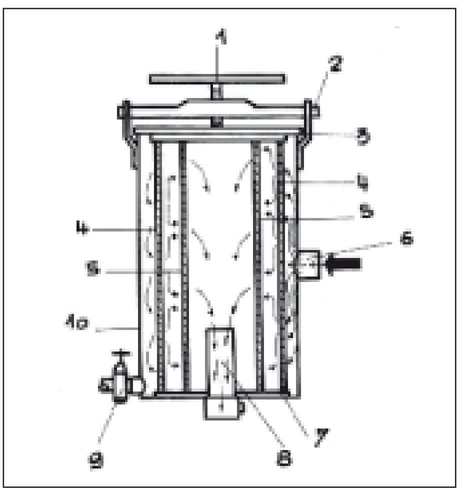

Figure 17. Operating diagram of a screen filter 1) seal; 2) cover; 3) gasket; 4) outer filter cartridge; 5) inner filter cartridge; 6) water inlet; 7) gasket; 8) collection outlet; 9) bleed valve; 10) filter housing (from Guidoboni, 1990).

The water entering the filter runs through the screen, which holds back the impurities. Plugging is detected owing to the larger than usual difference between the pressure measured by manometers placed at the filter inlet and outlet. As a rule, the filter screens are replaced after the irrigation season. As this kind of filter is cheap, it is recommended to install several at various points along the system.

TABLE 14
Tentative choice of filters according to diameter of emitter holes – drippers and sprayers (ERSAM, 2001)

Diameter of emitter orifices (mm)	Diameter of sand or gravel (mm)		Screen mesh (mesh)	
	Drippers	Sprayers	Drippers	Sprayers
< 0.4	0.6		270	
0.4 – 0.5	0.7		230	
0.5 – 0.6	0.8		200	
0.6 – 0.7	1.0		170	
0.7 – 0.8	1.1	1.1	140	140
0.8 – 1.0	1.4	1.4	120	120
1.0 – 1.2	1.7	1.7	100	100
1.2 – 1.4	1.7	2.0	100	80
1.4 – 1.6	1.7	2.3	100	70
1.6 – 1.8	1.8	2.5	100	70
1.8 – 2.0	1.8	2.5	100	60
2.0 – 2.3	1.8	2.5	100	60

Disc filters

A disc filter (Fig. 18) consists of a very resistant plastic housing containing a stack of round, bumpy discs. When stacked on top of each other with the aid of a spring or bolt, they form an effective filter surface. The discs are different colours and each colour corresponds to a degree of filtration, generally varying between 40 and 200 mesh.

The filters are washed by removing and washing the discs; self-cleaning models are currently available on the marketplace.

With regard to the quantity and quality of suspended solids (organic and inorganic) different filter types can be mounted in battery.

Chemical treatment is necessary when testing reveals the presence of substances in the water that could plug the outlet holes (Table 15) and entails adding products which prevent the formation of precipitates.

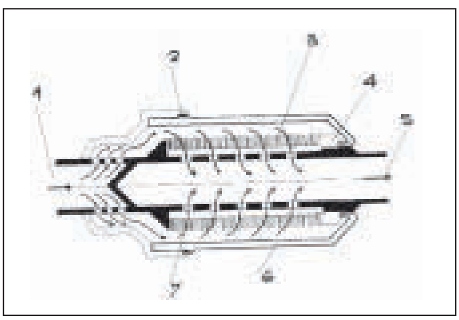

Figure 18. Operating diagram of a disc filter 1) water inlet; 2 and 6) gasket; 3) filtration ring; 4) ring closure nut; 5) water outlet (from Guidoboni, 1990).

The iron in groundwater is in solution, but after pumping it may easily be oxidized through the action of oxidizing micro-organisms. In such cases the recommendation is to add acidifying products like chlorine (sodium hypochlorite is usually used) to the water. Chlorination can be continuous (at a concentration of 1 mg of chlorine for every 0.7 mg L^{-1} of iron). It can also be applied successfully in the presence of calcium salts which can form insoluble precipitates in the drippers or feeder lines.

TABLE 15

Concentrations at which the chief chemical agents found in irrigation water can cause problems of dripper blockage (Nakayama and Bucks, 1981)

Chemical agent	Extent of problem		
	none	medium	serious
		mg L^{-1}	
Iron	0 - 0.1	0.1 - 0.4	> 0.4
Manganese	0 - 0.2	0.2 - 0.4	> 0.4
Sulphates	0 - 0.1	0.1 - 0.2	> 0.2
pH	< 7	7.0 - 8.0	> 8

To prevent algal growth in the collecting tank or light-free bacterial growth in the lines or other parts of the irrigation system (high risk at 50,000 bacteria per mL) the water can also be acidified intermittently at chlorine concentrations varying between 10 and 20 mg L^{-1} for approximately one hour (Guidoboni, 1990). Other acids like phosphoric acid, hydrochloric acid and sulphuric acid can also be used intermittently as long as the aerial part of the tree is not wetted.

All the acids have to be employed with care, making sure to add the acid to the water as opposed to vice versa.

Acidification constitutes normal maintenance work at the end of the irrigation season and the start of the next season.

It is not often feasible to treat the water chemically because of the high cost of the systems; in such instances a specific evaluation is required.

Figure 19. Scaling caused by iron in the water (from Guidoboni, 1990).

6.5.2. Irrigating with saline water

The olive is considered to be moderately tolerant of salinity. It starts to damage crops (Freeman and Hartman, 1994) when the irrigation water has an ECw value of between 2.5 and 4 dS m^{-1} and becomes significant at values above 5.5 dS m^{-1} (Table 16). The conductivity of the soil-saturated extract (ECe), which has a direct influence on crop performance, causes a 10% drop in yields if values reach 4–5 dS m^{-1} , a 25% decrease at values of between 5 and 7.5 dS m^{-1} and a 50% drop at values of more than 8 dS m^{-1} (Mass and Hoffman, 1977). The same authors have calculated nil yields at ECe values over 14 dS m^{-1}.

TABLE 16

Risk levels of electrical conductivity of irrigation water (ECw) and electrical conductivity of soil saturated extract (ECe) for olive

	Extent of problem		
	none	medium	severe
		dS m^{-1}	
Salinity of irrigation water	< 2	2.5 - 4	> 5.5
Salinity of soil	< 4	5 - 8	> 8

The chief, typical symptoms of salt stress include a reduction in the number of flowers, decreased shoot and root growth, decreased leaf surface and fruit size, changes in plant tissue composition and in oil fatty acid composition, increased dry matter, decreased fruit moisture and lower yields.

Cultivars respond differently to salt stress. A recent review provides a rating of the most widespread cultivars although the authors do point out that most of the trials were carried out on plants bred in a controlled environment.

Boron toxicity can also occur in olive and boron levels in irrigated water should not exceed 2.5 ppm.

The water analysis should be interpreted to determine the risk of salts building up in the parts of the soil explored by the root apparatus. As a rule, the quantity of elements relative to the water quality reported in Table 13 should be taken into account and any changes in electrical conductivity (ECw) should be monitored through the year.

Some general rules can be applied, particularly if the ECw level exceeds 2.5 dS m^{-1}:

- Make sure the ECw is not lower than the soil level.
- Apply localized irrigation frequently so as to maintain constant moisture over time. This will concentrate the salts in the peripheral area of the wetted circle, so lowering the electrical conductivity of the middle part (Fig. 20).
- Irrigate even when rainfall occurs to curb the redistribution of the salts concentrated in the peripheral part of the wetted area (which eliminates the advantages of localized irrigation).
- Ensure good soil drainage to stimulate removal of the salts carried to a depth through leaching.

- Leach preferably when evaporation is low.
- If the soils are calcareous, acidify the water (with sulphuric acid) to make the calcium salts soluble; these facilitate the leaching of the sodium salts and improve the permeability of this type of soil.
- If the soils are not calcareous and lack Ca^{++} e Mg^{++} add these salts to the soil to stimulate leaching of the sodium salts.
- Alter the fertilization programme to give preference to fertilizers containing potassium and calcium because sodium and chloride compete with each other to absorb these ions.
- If the water has an ECw value of more than 4 dS m^{-1} and a boron content of more than 2.5 ppm (or mg L^{-1}) it might be advisable not to irrigate.
- Apply higher irrigation volumes than necessary, using water with an ECw value below that of the soil, to remove the most soluble salts (NaCl) from the area explored by the roots (leaching).

Calculating the leaching fraction

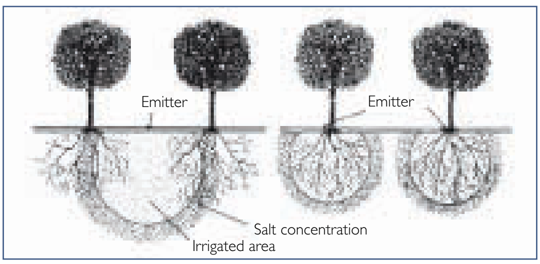

Figure 20. Position of drippers in relation to movement of soil salts (from Boswell, 1993).

Leaching is generally recommended to remove excess soluble salts and entails increasing the amount of irrigation water to push the salts outside the root zone. There are many methods for estimating the leaching fraction. Two approaches that can be put forward in different situations are now outlined.

The amount of water that has to be applied when using spray methods (static or dynamic sprayers) can be calculated as follows (Ayers and Westcot, 1995):

$$\text{Vol. irr.} = ET\ (1 - LF)^{-1}$$

where:

Vol. irr. = irrigation required when using saline water

ET = irrigation required when using good-quality water

LF = leaching fraction, given by:

$$LF = \frac{ECw}{5ECe - ECw}$$

where:

ECw = electrical conductivity of the irrigation water (dS m^{-1})

ECe = value of the electrical conductivity of the soil at which yields do not start to drop (dS m^{-1}).

According to Mass and Hoffman (1977), salinity causes olive yields to start to decrease at an ECe value of 2.7 dS m^{-1}.

When drip irrigation is employed, the leaching fraction can be estimated as follows (Ayers and Westcot, 1995):

$$LF = \frac{ECw}{2(\max ECe)}$$

where:
max ECe = maximum electrical conductivity (dS m^{-1}) at which crop yield decreases by 100%.

CONCLUSIONS

The olive shows a clear, positive response to irrigation. This enables the application of irrigation strategies tailored to differing soil and climatic conditions. Irrigation to meet full needs gives the best results in terms of yields, but the high cost of water, and its scarcity, particularly in Mediterranean environments, makes it necessary to employ irrigation strategies aimed at lowering seasonal irrigation volume while maintaining a high standard of quality and yields. Correct irrigation management helps to ensure more stable crop production, with all the ensuing social and economic implications.

Recommendations for estimating irrigation volume

- When drawing up an irrigation management programme it is of key importance to know the soil characteristics and to estimate the climatic variables. This will provide the basis for determining irrigation frequency and volume. The hydrological characteristics of the soil indicate the amount of water that can accumulated in the root zone, which will be taken into account for estimating the irrigation volume. It is thus possible to estimate the contribution of the soil water reserve and to take it into account for calculating the watering volume. Climatic parameters will help to give a good estimation of crop water consumption in order to determine the volume to be applied through irrigation.
- In conditions where water is not a limiting factor it is advisable to replenish crop water consumption in full, taking into account the soil water reserve. Several methods can be used for this purpose, some of which employ complex, costly equipment. The agrometeorological approach described in this text can be an easy-to-apply irrigation scheduling option for producers and extension services as it fulfils cost requirements, it is simple to use, it makes efficient use of water resources and it gives good results. Two methods are described in this text; one is the classic method and the other is a method proposed by Orgaz and Pastor (2005). The first method starts from the assumption that the crop coefficients (kc) are known for each environment and the reduction coefficients (kr) are known for each olive orchard while the second provides a methodology for directly determining kc.
- If water availability is a limiting factor it is advisable to apply techniques that save water resources without causing an excessive drop in productivity. Irrigation volumes can be reduced in some stages of the crop cycle or by applying water in periods when it is available cheaply and at a low environmental impact. In the first case irrigation volume can be cut by up to 50% during the stone hardening stage; in the second, irrigation can be applied in winter and spring

when the soils are deep and have a good water retention. A water reserve sufficient to avoid stress will thus be available to the crop during the critical stages of flowering, fruit set and early fruit development. It will then be advisable to irrigate when the soil reserve has been used up or, if this is not possible, to apply supplemental irrigation during the cell expansion stage.

Recommendations for choosing the water distribution method

- Localised water distribution methods are recommended because of their high efficiency. Drip irrigation methods save the greatest amount of water resources; however, if water is available at low cost and in sufficient amounts, under-canopy sprayers can also be used.
- Drip emitters should have low coefficients of flow variation. Generally speaking, self-compensating drippers are preferable because they maintain a constant flow rate over quite a wide range of working pressures. The same characteristic warrants their use in areas where the ground is not flat.
- To avoid problems of blockages the choice of water filters should be based on the quality of water available:

  – In the case of the physical treatment of the irrigation water, hydrocyclone or screen filters are to be preferred when the water contains sand or solid particles heavier than water, and gravel filters when the water contains algae and organic debris. Filtration power will depend on water quality.
  – Generally speaking, it is difficult and costly to treat irrigation water chemically. As a rule, the presence of Ca^{++}, Fe^{++}, Fe^{+++} and PO_4^{--} ions can cause clogging of the emitters because of the formation of calcium precipitates, iron oxides and phosphate compounds, etc. The addition of acidifying agents is recommended in such instances. This practice is also advised at the end of the irrigation season to prevent the growth of algae and bacteria in the equipment.

Recommendations for using saline water

- The risk entailed in using saline water is medium when the ECw values lie between 2.5 and 4 dS m^{-1} and high when they are over 5.5 dS m^{-1} . The electrical conductivity of the soil-saturated extract (ECe) causes a 10% drop in yields if values reach 4-5 dS m^{-1}; a 25% decrease at values of between 5 and 7.5 dS m^{-1}; a 50% drop at values of more than 8 dS m^{-1} and a 100% drop at ECe values of over 14 dS m^{-1}. These values are guidelines as long-term trials have not been carried out and tolerant cultivars may be able to adapt to conditions of greater salinity.
- Leaching can be carried out on deep, well drained soils, in periods of low evaporation and when the electrical conductivity of the water is less than that of the soil.

SUMMARY

The text outlines the chief parameters for determining olive water requirements and concisely defines the main soil characteristics and certain hydrological parameters for determining available water content and the water readily available to the crop. In addition, it provides guidelines for using some

of the chief instruments for determining soil moisture content and outlines the pros and cons of each method. Examples are given for calculating irrigation volume and timing which, if properly adapted to environmental and orchard management conditions, can be employed as guidelines for irrigation scheduling. Irrigation planning in different environmental conditions is discussed and the principles for improving water efficiency use in olive growing are highlighted together with possible strategies to lower irrigation volume in terms of seasonal volumes and the number of applications. Particular reference is made to regulated deficit irrigation, which partially satisfies irrigation requirements, and to possible solutions for reducing competition for water use at times of year when water resources are in heavy demand for other purposes. The second section discusses the most efficient methods of water distribution – drip, spray, subsurface – and the operating principles of the main equipment available, complete with a concise evaluation of the advantages and disadvantages of their functional characteristics. Owing to the fact the irrigation water is becoming increasingly poorer in quality, which is considered to be one of the key factors in lower crop yields, the fundaments of using saline water in olive growing are discussed. The critical levels for the use of saline water are provided along with two possible approaches for calculating leaching requirements when spray or drip irrigation is employed.

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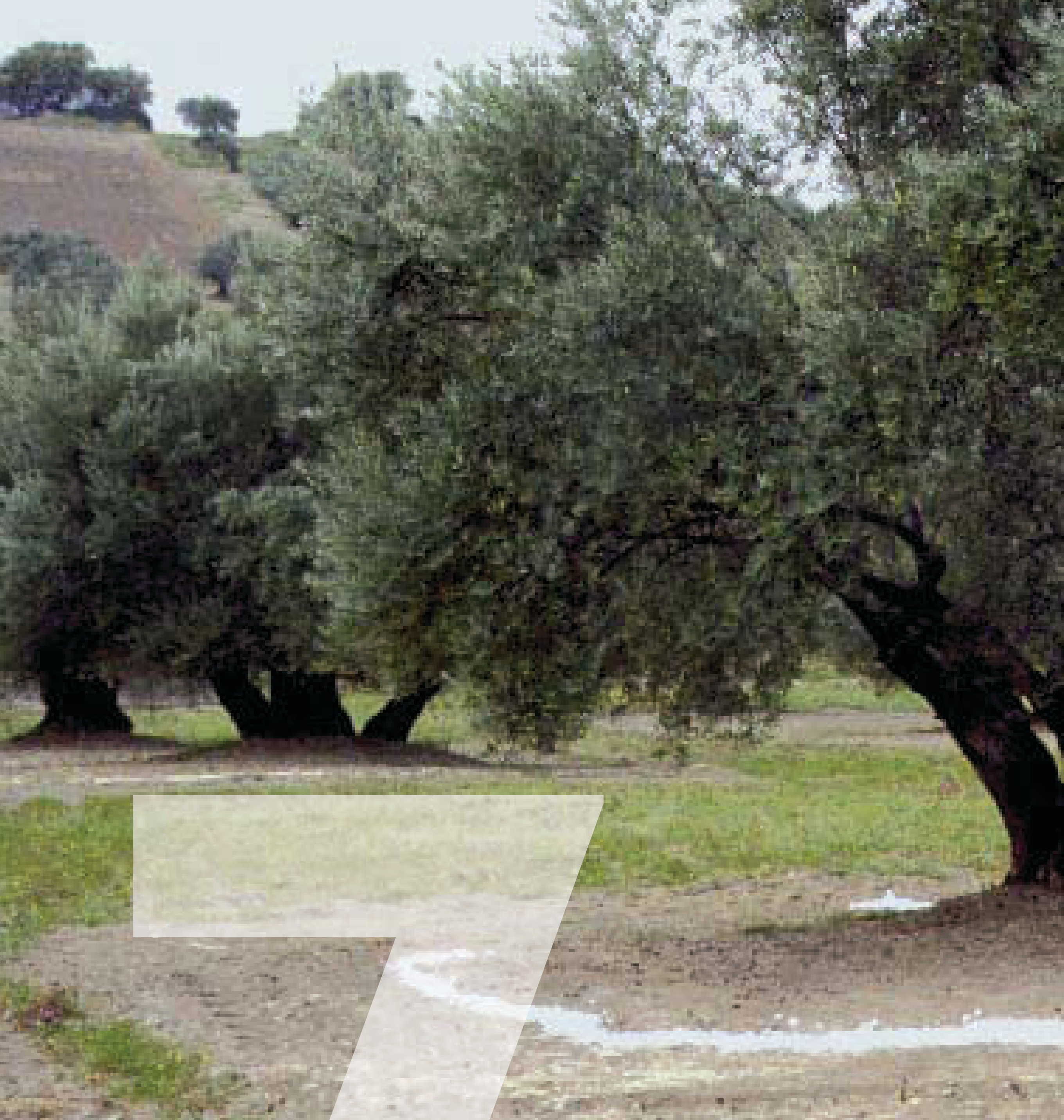

7

Plant health protection

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Plant health protection

7. Plant health protection

7.I. INTRODUCTION

Firmly established in the ancestral traditions of the Mediterranean peoples, the olive tree is gaining increasing socio-economic and environmental importance in the majority of the olive-growing countries.

Since the late 1980s, the documented dietary benefits of olive oil have led to a surge of fresh interest in olive growing in most of the Mediterranean producing countries and further afield, also stimulated by the major technical and technological progress in plant propagation, olive orchard management and olive oil extraction.

The drive to raise orchard yields by restructuring olive orchards and above all by expanding olive crop area through the application of modern, intensive-oriented methods has generated a substantial increase in world production. In the process, however, problems have arisen concerning marketing (competition) and final product quality as well as the conservation of natural resources and environmental equilibrium.

Set against this backdrop, plant health aspects are at the forefront of the factors of production affecting olive and olive oil quality and natural resources management. This is particularly so in an international context where food security is a growing concern and is governed by international standards which are becoming more and more restrictive on the use of agricultural chemicals.

Over the last thirty years, plant health protection methods have seen continuous change and have gone through several stages (IOBC, 1977), moving from blind chemical control (calendar-based) to advice-based and specific chemical control and then to integrated plant protection, which scientists 20 years ago considered to be the ultimate and best.

However, according to new, recently developed approaches to natural resources management summed up in "integrated production" (IOBC, 1993) and "organic production" (EEC, 1991), plant health protection cannot be separated from cultural practices overall and should be incorporated into the system of production (IOBC, 1993, 1998, 1999, 2002).

Unfortunately, these very rapid changes in the concepts of natural resources management have not been followed up on the ground by large-scale, practical implementation, not even in integrated management.

The fact is that, despite advances in research and the availability of techniques, many countries, particularly in the southern Mediterranean region although also in the northern Mediterranean, do not have sufficient expertise in controlling or treating phytosanitary problems.

This manual will be a valuable tool for extension officers and producers. The objective is to achieve sustainable production of top quality product by placing priority on natural regulatory mechanisms of noxious populations and by minimizing the use and side effects of pesticides (useless or wrongly applied treatments, risk of transfer of active matter to the environment, problem of residues in the end product, imbalances in fauna,…).

It is presented in a very simple format accessible to both extension officers and olive growers, and pays close attention to practical aspects.

After this brief introduction highlighting the increasing importance placed on olive plant health protection in response to changing world public opinion about food quality and safety and the sustainable management of natural resources, the main harmful species will now be presented according to the symptoms they cause in the plant organs. The presentation will keep to the usual systematic classification system beginning with the higher order insects and ending with the lower orders of insects and diseases. This information will be amplified by information on their geographical distribution and economic importance in the olive-growing regions.

The next section deals with management strategies, notably the fundaments of "integrated management" in sustainable farming, and the strategy recommended for each target species, with the emphasis on those species of economic importance in most of the regions or in localized areas of certain countries.

Clearly, owing to the continuing changes in crop protection tools and the constant advances in science, the details provided on techniques and products are merely guidelines and will require updating whenever necessary.

Close attention is paid to the effectiveness and environmental impact of the means and methods of treatment.

Lastly, all the information on good practices has been summarized in tabulated form for quick, easy reference.

7.2. MAIN NOXIOUS SPECIES

7.2.1. Systematic position, geographical distribution and organs attacked

TABLE I
Classification of insect pests

Order	Species	Geographical distribution	Organs attacked
Lepidoptera	**Olive moth:** *Prays oleae* BERN. = *Prays oleaellus* (STAINTON, 1867)	Throughout the Mediterranean region, and as far as Russia (shores of the Black Sea: Crimea and Georgia).	Leaves, terminal buds, flowers and fruits.
	Leopard moth: *Zeuzera pyrina* L. = *Zeuzera aesculi* L.	Northern and southern Europe, North Africa, Near and Middle East, Iran, China, Japan.	Leaf petioles, young twigs, twigs, branches, trunk.
	Jasmine moth: *Margaronia* (*Palpita* = *Glyphodes*) *unionalis* HÜBN.	Mediterranean, Near East, Canary Islands and Madeira, Japan, tropical countries of America.	Leaves, terminal buds and fruits.
	Pyralid moth: *Euzophera pinguis* HAW. (= *Euzophera neliella* RAG.)	Whole of the Mediterranean region, most of Europe: Denmark, France, central Europe, Portugal.	Branches and trunk.
	Zelleria oleastrella MILL. (= *Tinea oleastrella* MILL.)	Spain, Italy, France.	Parenchyma of the upper surface of leaves, leaflets on end of suckers.
	Parectopa latifoliella MILL. (= *Oecophyllembius neglectus* SILV.)	Throughout the Mediterranean olive-growing region.	Leaves (upper surface).
	***Gymnoscelis pumilata* HÜBN** (= *Eupithecia pumilata* HÜBN = *Tephrochystia pumilata* HÜBN.)	From Ireland across Europe, North Africa and as far as Turkistan.	Flower buds.

TABLE I
Classification of insect pests (contd)

Order	Species	Geographical distribution	Organs attacked
Diptera	**Olive fruit fly:** *Bactrocera oleae* GMEL. (= *Dacus oleae, Musca* oleae, *Daculus oleae*)	Throughout the Mediterranean region, Canary Islands, Near East, India, North, East and South Africa.	Olive fruits.
	Olive leaf gall midge: *Dasineura oleae* F. LOEW. (= *Perrisia* oleae, = *Perrisia lathieri)*	Eastern Mediterranean region, Croatia, Italy.	Leaves, vegetative buds, flower stalks and stems.
	Olive bark midge: *Resselliella oleisuga* (= *Diplosis* = *clinodiplosis* = *Thomasiniana oleisuga*) (TARGIONI-TOZZETI)	Traditional olive-growing areas (Spain, France, Greece, Italy, Montenegro, Yugoslavia, Lebanon, Syria, Jordan, Morocco, Tunisia).	Woody stems, bark.
	Olive mites: *Prolasioptera berlesiana* PAOLI (= *Lasioptera brevicornis* = *L. carpophila*)	Most of the Mediterranean olive-growing region.	Olive fruits.
Homoptera	**Black scale:** *Saissetia oleae* OLIVIER	Throughout the Mediterranean region.	Leaves, twigs, inflorescences.
	Olive psyllid: *Euphyllura olivina* COSTA (= *Thrips olivina, Psylla oleae, Psylla olivina, Euphyllura oleae*)	Throughout the Mediterranean olive-growing region.	Leaves, buds, young shoots, stems, inflorescences and fruiting shoots.
	Philippia follicularis TARGIONI – TOZZETTI (= *Euphilippia olivina* BERLESE & SILVESTRI)	Mediterranean region.	Leaves, twigs.
	Lichtensia viburni *SIGNORET (= Philippia oleae COSTA)*	Throughout the Mediterranean region.	Leaves, twigs.
	Pollinia pollini *COSTA* *(= Coccus pollinii COSTA)*	Throughout the Mediterranean region, Argentina.	Leaves, twigs, fruit stems.

TABLE I
Classification of insect pests (contd)

Order	Species	Geographical distribution	Organs attacked
Homoptera (contd)	**Oleander scale:** *Aspidiotus nerii* BOUCHE (=*A. hederae* VALLOT)	Throughout the southern Palearctic region (countries bordering the Mediterranean).	Leaves, fruits.
	Olive scale: *Parlatoria oleae* COLVEE (= *P. Calianthina* BERL.& LEON = *P. affinis* NEWST)	Throughout the Mediterranean region, United States (California, Arizona, Maryland), Asia, Europe, North Africa, Middle East.	Leaves, woody parts, fruits.
	Oystershell scale: *Lepidosaphes ulmi* L. (= *L. pomorum* BOUCHE = *L. juglandis* FITH = *L. oleae* LEONARDI)	Vast geographical distribution: whole Palearctic region, introduced in America, reported in Asia, South Africa, Australia.	Leaves, twigs, fruits.
	***Lepidosaphes destefanii* LEON** (= *L. conchyformis* KORONES)	Mediterranean region (from Spain to the Middle East), former USSR, California.	Females: twigs, trunk of young trees with smooth bark. Males: edges of leaves, sometimes of shoots.
	***Leucaspis riccae* TARG.** (= *L. ephedrae* MARCHAL)	Mediterranean species; it does not appear to exist in Western Europe (France, Spain) or certain countries of North Africa (Morocco, Algeria).	Leaves, twigs, branches and fruits.
	***Quadraspidiotus maleti* VAYSS.**	Localized species in Morocco.	Leaves, fruits (stem base).
	***Quadraspidiotus lenticularis* LIND.**	Throughout the Palearctic region.	Leaves, fruits.
	California red scale: *Aonidiella aurantii* MESK. (=*Aspidiotus citri* COMSTOCK)	All the tropical and subtropical regions suited to citrus growing.	Trunk, branches, twigs, leaves and fruits.

TABLE I
Classification of insect pests (contd)

Order	Species	Geographical distribution	Organs attacked
Homoptera (contd)	**Cicadas:** - *Cicada orni* L. - *Tibicen plebejus Scop.* - *Cicadetta brullei Fieb.*	Reported in Italy.	Young twigs.
	- *Psalmocharias plagifera. Schum.*	Reported in Tunisia (South-west region).	Young twigs.
Coleoptera	**Olive beetle:** *Phloeotribus scarabaeoides* BERN, (*P. oleae* LATREILLE)	Throughout the Mediterranean region, North Africa, Near and Middle East as far as Iran.	Twigs, flower clusters and above all fruiting clusters, pruning wood, trunk, branches and twigs of trees suffering from dieback.
	Olive borer: *Hylesinus oleiperda* FABR. (= *H. terranio* DANTHOINE = *H. suturalis* REDT. = *H. esau* GREDLER)	Throughout the Mediterranean region as far as the Near and Middle East (Iran), northern Europe (Belgium, England, Denmark), Chile, Argentina.	Trunk and branches.
	Weevils: *Otiorrhynchus cribricollis* GYLL. (= *O. terrestris* MARSEUL)	Throughout the Mediterranean region. Adventive species in California, Australia, New Zealand	Leaves.
	Rhynchites cribripennis DESBR. (= *R. ruber* Shilsky NON FAIRM)	Eastern Mediterranean region, southern tip of Russia, Turkey, Greece, Italy, north eastern, central and southern Yugoslavia, islands (Malta, Sicily, Sardinia, Corsica).	Leaves, fruits.
	White grubs: *Melolontha sp.*	Spain, Tunisia.	Roots, crown.
Thysanoptera	**Olive thrips:** *Liothrips oleae* COSTA (= *Thrips oleae*, *Phloeothrips oleae*, *Leurothrips linearis*)	All the Mediterranean, olive-growing areas.	Leaves, young stems, terminal shoots, fruits.

TABLE I
Classification of insect pests (contd)

Order	Species	Geographical distribution	Organs attacked
Acarina	***Aceria oleae* NAL.**	All the Mediterranean areas.	Leaves, buds, shoots, flower clusters, fruits.
	***Oxycenus maxwelli* VEIFER**	Mediterranean olive-growing areas, California.	Leaves (upper surface), young shoots, flower clusters.
	Aceria olivi and Oxycenus niloticus (ZAHER & ABOU AWAD)	Egypt (El Fayoum).	Leaves (lower and upper surface).
	Aculus olearius CASTAGNOLI	Italy.	Flower buds and young fruits.
	Aculops benakii	Reported in Greece.	Young leaves, young shoots, flower buds and fruits.
	Tegolophus hassani	Reported in Greece, Egypt, Italy and Portugal.	Young leaves, flower clusters.
	Dytrimacus athiasellus	Reported in Italy, Greece, Portugal and Algeria.	Young leaves, axis of flower clusters and flower stalks.
Nematodes	***Pratylenchus vulnus*** and other ***Pratylenchus***	Mediterranean region, USA.	Roots.
	Tylenchulus semipenetrans	Mediterranean region, USA.	
	Meloidogyne sp.	Spain, Greece, Italy, Portugal.	

TABLE II
Classification of diseases (fungi, bacteria, viruses)

Order/group	Species	Geographical distribution	Organs attacked
G. Hyphomycetes	**Olive leaf spot:** *Cycloconium oleaginum* (= *Spilocaea oleaginea* FRIES)	Mediterranean olive-growing regions, California, Chile, South Africa.	Leaves especially; fruits and young twigs very occasionally.
	Verticillium wilt: *Verticillium dahliae* KLEB	Numerous Mediterranean olive-growing countries, USA.	Vascular disease causing wilting of attacked parts.
	Cercospora cladosporioides SACC.	Certain Mediterranean olive-growing countries (Italy, Portugal, Greece, Spain, Algeria, Tunisia…), California, Australia.	Leaves and fruits.
G. Coelomycetes	**Olive anthracnose:** *Gloeosporium olivarum* ALM.	Most of the Mediterranean olive-growing areas, Argentina, Russia, Japan, Uruguay.	Leaves, twigs, flowers and fruits.
	Macrophoma (= Sphaeropsis dalmatica THUM)	Most of the Mediterranean olive-growing areas.	Fruits.
G. Hyphomycetes	**Sooty mould:** *Capnodium meridionale*, *Capnodium oleae*, Genera *Towba*, *Triposporium*, *Brachysporium*, *Alternaria*, *Cladosporium*.	All the Mediterranean olive-growing regions.	Leaves, flowers, fruits, twigs, branches.

Root rot fungi			
O. Agaricales	***Armillaria mellea*** (= *Armillariella*)	Reported in certain olive-growing countries: Italy, Spain, Syria, Tunisia,…	Roots.
G. Agonomycetes	***Macrophomina phaseoli*** (= *Rhizoctonia bataticola*)	Several Mediterranean countries.	Roots of plants in nurseries and young orchards.

TABLE II
Classification of diseases (fungi, bacteria, viruses) (contd)

Order/group	Species	Geographical distribution	Organs attacked
G. Hyphomycetes	***Fusarium oxysporum, F. solani***	Several Mediterranean countries.	Roots of plants in nurseries and young orchards.
O. Xilariales	***Rosellinea necatrix***	Spain, Argentina.	Roots of plants in nurseries and young orchards.
O. Ceratoba-sidiales	***Corticium solani***	Italy, Tunisia.	Roots of nursery plants.
O. Pythiales	***Phytophtora sp.***	Several Mediterranean countries.	Roots of young plants.
G. Agonomycetes	***Sclerotium rolfsii***	Several Mediterranean countries.	Roots of young plants.
Pseudomona bacteria	**Olive knot:** *Pseudomonas syringae* PV. *savastanoi* SMITH	Throughout the Mediterranean olive-growing region, Central Europe, Asia Minor, Australia, South Africa, Argentina, California, Peru.	Twigs, branches, trunk, leaves.
Eubacteria	**Crown gall:** *Agrobacterium tumefasciens* Smith & Townsend	Jordan, Tunisia.	Crown, roots.
Viruses*	Several species.	Spain, Greece, Italy, Portugal, …	Leaves, buds, flowers.

*Very little information is available.

7.2.2. Keys to recognizing and identifying main noxious species

TABLE III
Keys to recognizing noxious species

Organs attacked/Symptoms	Causal agent
I. ROOTS Small nicks on root bark near trunk base of irrigated trees and presence of characteristic white grubs of scarab coleopterans.	White grubs: *Melolontha melonlontha*, *Melolontha papposa*, …
– Longitudinal cracking of root cortex; tissue underneath is darkened and necrotic.	Nematodes: *Pratylenchus vulnus.*
– Gelatinous coating (nests) on roots, produced by females; destruction of root hairs.	Nematodes: Citrus nematode *Tylenchulus semi penetrans.*
– Numerous galls on roots (cell hypertrophy).	Nematodes: Meloidogynes.
– Small patches of rotted bark, generally on the aspect least exposed to sunlight (North–North East), and whitish down on infested roots and nearby soil.	Root rot fungus: *Armillaria mellea.*
– Root excrescences near trunk (knots): crown gall.	Crown gall: *Agrobacterium tumefasciens.*
Rotting bark on small roots and necrotic secondary roots.	Several fungi species which have to be isolated and identified in the laboratory: *Fusarium* sp., *Phytophtora* sp., *Rhizoctonia bataticola.*
II. TRUNK, BRANCHES, TWIGS, PRUNED WOOD	
– Entry holes and sawdust on bark or small holes in pruned wood or in trunk/branches of trees suffering from dieback.	Olive beetle: *Phloeotribus scarabaeoïdes.*
– Cavities on small flowering or fruit-bearing shoots, empty or housing small black coleopterans (with sawdust).	Olive beetle: *Phloeotribus scarabaeoïdes.*

TABLE III
Keys to recognizing noxious species (contd)

Organs attacked/Symptoms	Causal agent
– Pruned wood with large exit holes approximately 5 mm in diameter, burrowed at an angle to the lengthwise axis of the wood.	Cerambycid: *Xylotrechus smei.*
– Chlorotic branches and leaf drop. Cracks and fissures in bark in infested areas and frass on outside of trunk crown or crotches of scaffold branches (or secondary branches).	Pyralid moth: *Euzophera pinguis.*
– Trunk and scaffold branches with reddish patches on bark and borer entry holes, or cracked bark and exit holes larger than the size of the borer. All or part of the tree may look chlorotic and leaf drop may occur in the event of heavy attack.	Olive borer: *Hylesinus oleiperda.*
– Galleries in twigs, branches or trunks, with/without beige or brown frass at entry; can be wide in diameter (6-7 mm) in large branches or the trunk and may or may not house a larva. – Pupa near gallery towards end of winter or beginning of spring.	Leopard moth: *Zeuzera pyrina.*
– Withered or dying shoots with reddish fissures or cracks in the bark. Pink larvae under the bark, arranged in series along the lengthwise axis of the twig.	Olive bark midge: *Resseliella oleisuga.*
– Comma-shaped scales on twigs or small branches.	Oystershell scale: *Lepidosaphes ulmi.*
– Round or rectangular grey or white scales on twigs.	Olive scale: *Parlatoria oleae.*
– Blackish brown scales marked with an 'H' on branches or small branches; plant is sometimes darkened due to a fungal complex (sooty mould).	Black scale: *Saissetia oleae*, possibly in conjunction with sooty mould.

TABLE III
Keys to recognizing noxious species (contd)

Organs attacked/Symptoms	Causal agent
– Partial or total dieback of primary or secondary branches. Wood turns violet and xylem of the infested branches tends to turn brown (this is not systematic in olive, unlike in other fruit tree species). The leaves on the infested part gradually fade in colour and roll longitudinally towards the lower surface. They turn grey, then brownish yellow and light yellow and eventually wither, without dropping off. Symptoms are observed in two periods: late spring and late summer–autumn (September–October).	Verticillium wilt: *Verticillium dahliae.*
– Differently sized necrotic excrescences or galls, single or in clusters, on twigs, small branches and scaffold branches.	Olive knot: *Pseudomonas savastanoï.*
III. LEAVES AND YOUNG SHOOTS	
– Saw-like bites along the edges of the leaves. Leaves and buds almost eaten away on young shoots.	'A' weevil: *Otiorrhynchus cribricollis.*
– Edges of young shoots eaten away; lower surface of leaves nibbled, leaving epidermis intact, or partly or completely eaten away. Light green, translucent caterpillars may be present.	Jasmine moth: *Margaronia unionalis.*
– Leaves nibbled on lower surface, leaving the epidermis intact; deformed, with large holes.	*Rhynchites cribripennis.*
– Leaves with varying degrees of deformation depending on leaf age and yellowish white blotches due to bites. Leaves curl if bites are close to main nervature.	Olive thrips: *Liothrips oleae.*
– Different shapes and sizes of scales, yellow, yellowish orange or brownish yellow in colour, and white egg sacks on lower surfaces of leaves and twigs.	Vibirnum cushion scale *Lichtensia viburni* (=*Philippia oleae*).

TABLE III
Keys to recognizing noxious species (contd)

Organs attacked/Symptoms	Causal agent
– Deformed leaves with light green hollows on lower surface, devoid of trichomes, and corresponding chlorotic bumps on upper surface. Leaf deformations on buds and young shoots similar to those caused by thrips.	Acarids: *Aceria oleae.*
– Deformed leaves with light yellow hollows on upper surface and small corresponding bumps on lower surface.	Acarids: *Aculops benakii, Oxycenus maxwelli.*
– Galleries of varying shapes and sizes burrowed in the parenchyma depending on the stage of the caterpillar, or large gallery tunnelled in lower surface of leaf leaving only the upper epidermis untouched and making the leaf transparent.	Olive moth, *Prays oleae*: phyllophagous generation.
– Leaf galls caused by localized, visible swelling of the blade on both sides; leaves sometimes heavily deformed in spiral or twisted shapes.	Olive leaf gall midge: *Dasineura oleae.*
– Wide gallery under the epidermis of the leaves, very visible on the upper surface.	*Oecophyllembius neglectus.*
– White, cottony mass with honeydew and wax on young shoots and buds.	Olive psyllid: *Euphyllura olivina*
– Parenchyma on upper surface of old leaves eaten away; leaflets at end of suckers and blades nibbled.	*Zelleria oleastrella.*
– Oval, elongated scales on lower surface of leaves, of differing sizes and ranging in colour from light amber to blackish brown.	Black scale: *Saissetia oleae.*
– Circular or subcircular, slightly dome-shaped scales, uniform, matt, light beige colour, of differing sizes, located on lower or upper surface of leaves. Yellow larvae under scale.	Oleander scale: *Aspidiotus nerii.*
– Comma-shaped scale, mytliform or narrowly pyriform, straight or wavy, domed, uniform, shiny dark brown colour.	Oystershell scale: *Lepidosaphes ulmi.*
– Oval, rectangular, arched shields on leaves, ash grey to dirty grey in colour. Brown, off-centre larval exuviae. Live female, dark violet in colour.	Olive scale: *Parlatoria oleae.*
– Small necrotic galls on leaf blade or petiole.	Olive knot: *Pseudomonas savastanoï.*

TABLE III
Keys to recognizing noxious species (contd)

Organs attacked/Symptoms	Causal agent
– Concentric, circular stains, yellow, brown, black or green in colour, of varying size, on upper surface of leaves. Blackish blotches on lower surface along nervature.	Olive leaf spot: *Cycloconium oleaginum.*
– Greyish blotches on lower surface of leaves and corresponding yellow blotches on upper surface, which turn brown at leaf drop.	*Cercospora cladosporioides.*
– Partial drying of leaf tips, greyish in colour, followed by withering of young nursery plants.	Soil fungi *(Fusarium oxysporum* and *Rhizoctonia bataticola).*
IV. INFLORESCENCES AND BUDS – Flower buds with holes, destroyed partially or fully (flower pistil severed), possible presence of larva; petals connected by silk threads forming a brown mass at the end of flowering, and possible presence of pupae in silky cocoon.	Olive moth: *Prays oleae* (anthophagous generation).
– Terminal buds eaten away; presence of frass and silk threads.	Olive moth: *Prays oleae* (phyllophagous generation).
– Inflorescences and terminal buds covered with white cottony mass, with reddish or brownish yellow larvae underneath. Withered flower clusters in event of heavy attack.	Olive psyllid *Euphyllura olivina.*
– Holes plugged with sawdust at flower cluster insertion point in shoot; withered clusters.	Olive beetle (*Phloeotribus scarabaeoïdes*): feeding bites.
– Swollen flower stalks and stems, twisted into spiral shapes.	Olive leaf gall midge: *Dasineura oleae.*
– Flower buds with hole housing a looper caterpillar clearly eating the flower and petals.	*Gymnocelis pumilata.*
– Inflorescences partially or totally withered or wilted; premature flower bud and inflorescence drop in event of heavy attack.	Acarids: several species.

TABLE III
Keys to recognizing noxious species (contd)

Organs attacked/Symptoms	Causal agent
– Withered inflorescences on specific section of tree.	Verticillium wilt: *Verticillium dahliae*.
– Withered inflorescences all over the tree (especially in young irrigated trees).	Root fungi.
V. FRUITS	
– Green olives in summer with one or more necrotic bites on epidermis.	Olive fruit fly (*Bactrocera oleae*): bites by summer generations.
– Green olives, flesh partially eaten, sagging epidermis, reddish brown colour in the infested area, possibly showing larval exit hole. Olives deformed by cicatrization of eaten part of fruit (winding galleries in flesh).	Olive fruit fly: damage by summer generations.
– Violet or ripe olives exuding oil, with maggot in flesh or partial sagging of epidermis and exit hole at tip of infested part.	Olive fruit fly: autumn/winter generations; even spring generation.
– Fruit drop (green olives) from end of summer until early autumn, with or without holes at fruit stem insertion point.	Olive moth (*Prays oleae*): autumn fruit drop due to carpophagous generation.
– Massive summer drop of young set fruitlets (May-July).	Physiological fruit drop in majority of varieties (small sized and oil varieties) and partially due to *Prays oleae* (carpophagous generation).
– Drop of fruit-bearing shoots in summer and autumn.	Olive beetle: *Phloeotribus scarabaeoïdes* (feeding stage).
– Fruits with whitish, circular or oval shields covering all or part of the fruit surface. Fruits deformed to varying degrees, with violet blotches.	Oleander scale: *Aspidiotus nerii.*

TABLE III
Keys to recognizing noxious species (contd)

Organs attacked/Symptoms	Causal agent
– Fruits with comma-shaped scales.	Oystershell scale: *Lepidosaphes ulmi.*
– Fruits with circular, elongated shields, ash grey to dirty grey in colour, with discoloured or darkened blotches and malformations.	Olive scale: *Parlatoria oleae.*
– More or less pronounced fruit deformations with deep hollows in ripe olives.	Olive thrips: *Liothrips oleae.*
– Brown, circular or irregular spots on apex of ripe fruits; isolated at first, then spreading to rest of the olive. The olives wither and drop.	Olive anthracnose: *Gloeosporium olivarum.*
– Sagging, isolated brown spots.	*Macrophoma (=Sphaeropsis) dalmatica.*
– Olives with adult bites and larval exit holes.	*Rynchites cribripennis.*
– Green olives with flesh eaten partially to the stone and frass.	Jasmine moth: *Margaronia unionalis.*

7.3. PROTECTION STRATEGIES

In Europe, the International Organization for Biological Control of Noxious Animals and Plants (IOBC) plays an important role in developing crop protection techniques.

In 1977, it published a document on the changes in protection strategies, defined as follows:

7.3.1. Blind chemical control (or according to a pre-established calendar):

This is based on systematic, routine applications of the chemicals available, possibly seeking advice from pesticide manufacturers.

Unfortunately, this strategy is still occasionally applied in a few olive producing countries.

7.3.2. Advice-based chemical control

This entails the application of a wide range of pesticides after consultation with an official phytosanitary advisory service.

Many growers continue to apply this strategy in a number of olive-producing regions.

7.3.3. Specific control

This is a transitional stage in the move towards integrated management because it incorporates three important new features of management strategy:

– Economic threshold levels;
– Choice of pesticides without negative environmental side-effects;
- Protection of natural enemies of pests.

This management concept is widely followed in many olive-growing countries although it often tends to be mixed up with a more developed strategy known as "integrated protection".

7.3.4. Integrated plant protection or management

This is similar to the preceding strategy; however, in addition, it incorporates biological and biotechnical methods and good agricultural practice. Chemical control is limited to what is strictly necessary.

For the last ten years or so this concept has been gaining ground on a large scale in certain olive-growing countries, particularly countries in the northern Mediterranean area with well organized facilities (Spain, Italy, Greece, France) or in rare cases where plant protection (alerts and treatment) is still in State hands (Tunisia).

However, since the end of the 1980s and early 1990s, the emergence of new management approaches in sustainable farming has led to several interpretations of "integrated plant protection". These have eventually resulted in a new, more modern concept of "integrated production" in which phytosanitary aspects are an integral part of the production system and the agro-ecosystem is the key element where priority is placed on mechanisms of natural regulation.

7.3.5. Integrated production

Besides the concepts embodied in integrated plant protection, this management method is based on the integration and exploitation of all the factors in the agro-ecosystem which have a positive impact on the quality and volume of production according to ecological principles.

This approaches prioritizes preventive protection measures (or indirect measures). Monitoring and forecasting of noxious populations is the second important factor, which determines the final decision in the last stage of the strategy, i.e. direct management measures. In such conditions, pesticides are the last resort if preventive measures are inadequate.

7.4. INTEGRATED OLIVE PRODUCTION IN SUSTAINABLE FARMING

7.4.1. Objectives

- To promote a model of olive growing which is economically feasible, environmentally friendly and which allows the crop to perform its social, cultural and ecological roles to the full.
- To achieve the sustainable production of olives and olive oil of top quality from the food and health points of view with a minimum of residues or virtually none at all.
- To protect growers and agricultural workers from the risks of handling agricultural chemicals.
- To guarantee the continuing stability and equilibrium of the ecosystem while striving to preserve and develop biodiversity.
- To place priority on natural regulatory mechanisms.

7.4.2. Fundaments

In the context of sustainable development and the conservation of natural resources, the new approach to the concept of integrated production views the agro-ecosystem as the prime, fundamental element in protection strategy. Starting from this principle, this strategy is based on the following three elements, listed by order of importance: preventive measures, monitoring and forecasting of the risk of damage from harmful populations, and application of direct management measures.

7.4.2.1. Prophylactic or preventive measures

Absolute priority is placed on preventive measures both when working in existing orchards and establishing new orchards.

These measures are based on a series of principles:

Optimal use of natural resources when establishing a new orchard:

- The varieties chosen should be adapted to environmental conditions, i.e. the varieties or clones should be resistant to/tolerant of pests and diseases.
- Plants and soil should be free from insects, pathogens and nematodes.
- Soils in which crops sensitive to certain diseases were grown beforehand should be avoided.
- Intercropping of market garden crops sensitive to diseases (verticillium, *Fusarium*, etc.) is not recommended.
- The soil should be properly prepared and fertilized (good soil aeration and filtration, balanced manuring – organic manures are highly recommended).

- Planting timing and density should be appropriate (very high densities which impede tree aeration and penetration of sunlight are not recommended).
- Appropriate irrigation systems and techniques should be applied (avoid irrigating too close to the trunk, irrigate regularly, avoid excess watering,…).
- Avoid excessive intensification (densities of more than 300 trees/ha).

Application of cultural practices without negative side-effects on the agro-ecosystem and particularly unfavourable to the development and propagation of noxious species:

This encompasses all the cultural practices concerning tree management (training, pruning for fruit production, rejuvenation pruning, maintenance of pruning implements, management of pruning by-products, chemical treatments, …) and soil management (tillage, fertilization, irrigation, water and soil conservation, weed control, …) which help to maintain the stability of the agro-ecosystem (diversity of flora and auxiliary fauna), to ensure dissuasive conditions for the development of harmful species and to encourage the role of natural antagonists.

The following should be singled out amongst the techniques of importance in preventing phytosanitary problems:

– Pruning allows air and sunlight into the tree canopy by removing wood or thinning branches and shoots and eliminating suckers. As such, it is a relatively effective way of reducing the numbers of many harmful species (insects, acarids and diseases) or of making conditions non-conducive to their development, particularly olive leaf spot, scales, olive psyllid, xylophagous insects (olive borer, olive beetle, pyralid moth, leopard moth, …) and olive moth (third generation).
– Pruning implements must be disinfected to avoid spreading olive knot. Growers are also strongly recommended to heal pruning wounds, which are an entry point for pathogens (fungi, bacteria) and wood-eating larvae (pyralid moth, leopard moth).
– Pruning by-products (wood, twigs) should be treated or incorporated into the soil to improve soil fertility or removed from the orchard after using them as an attractant for olive beetle.
– Nitrogen should not be applied to excess to prevent the development of scales, olive psyllid, mites and olive leaf spot. Generally, nutrients should be applied on the basis of leaf and soil analyses.
– In intensive farming, water should not be applied in excess or near the trunk. Any water stagnation or hindrance to water infiltration could cause the onset of root rot.
– Soil management should be adapted to the soil and climatic conditions of the crop in order to avoid soil erosion and compaction, to control competition from weeds and to ensure optimal utilization of rainwater, particularly in semi-arid and arid regions.
– The olive fruits should be harvested at the right time (quite early) to guarantee good oil quality and to avoid olive fruit fly infestations.
– Plant health treatments (choice and method of product application, release or introduction–acclimatization of auxiliary fauna) and any other practices (conservation of flora and relay plants, growing of hedges as shelter for natural enemies, …) aimed at protecting and enhancing the role of natural antagonists are highly recommended.

It should be stressed that preventive measures are based on a good understanding of the natural environment and all its soil, climatic, agronomic, biological and social component parts and interactions.

7.4.2.2. Monitoring of noxious populations, damage risk forecasting and estimation

Monitoring of noxious species and determination of their harmfulness threshold are the second important facet of the strategy because it provides the necessary information to decide whether or not to apply a treatment.

Objectives

- To detect the presence of the noxious species and to estimate the numbers involved (adult populations, pre-imaginal stages per unit of measurement, contamination rate,…) in an orchard or set of uniform holdings.
- To demarcate, if possible, their area of geographical distribution (primary and secondary outbreak sites,…).
- To ascertain the risk of economic damage (harmfulness threshold) taking into account all the environmental factors (plant-host, climate, auxiliary fauna, orchard management techniques).
- To determine the optimal time for treatment in the light of the vulnerable stage(s) of the noxious species.

Tools and measures

Adult trapping:

- Different types of traps are used: sex pheromone, food, colour, light, natural attractants (pruning wood), etc.
- The conditions in which the different types of traps are used are important for interpreting the capture counts: density of traps/ha, position on tree and location in orchard, precautions, frequency of counts.

Sampling:

- Objectives: To estimate the extent of infestation and the potential risk of damage and to monitor the developmental status of the harmful species (pre-imaginal stages) in order to decide whether and when to apply a treatment.
- Arrangements: Collection of samples of plant organs (roots, shoots, stems, leaves, flowers, fruits, bark) or on-site inspection.

Sampling frequency varies according to the target species and to the type of information for collection. It is generally done every week or every ten days during the period of reproductive activity of the species. The size of the sample (quantity of organs, number of control trees) varies according to the target species and population density.

- Sample inspection: This is based on cards tailored to the species and kind of information being collected.
- Processing of sampling data: Data computerization facilitates sample processing and analysis and data pooling when the data from several stations or several olive-growing areas are to be centralized.

Other monitoring parameters:

- Laboratory examination and analysis to identify pathogens.
- Monitoring of host plant phenology (reference stages) and of female fertility in the case of the olive fruit fly.
- Monitoring of climatic data (particularly temperature extremes and rainfall).
- Scraping the bark or counting the entry/exit holes in the case of wood-eating species (olive beetle, olive borer, leopard moth, pyralid moth, etc.).

Implementation of monitoring system:

Monitoring stations can be set up on an individual scale (in an orchard or a holding) or they can serve holdings organized into associations or cooperatives in an olive-growing locality or area as part of a network of stations supported by one or more weather stations.

In the latter case, the zone is divided into sufficiently uniform micro-areas (relief, orchard status, production system and management techniques) where the number of stations varies according to the degree of homogeneity of the olive holdings. The general rule is one station for every 500-1,000 ha. Each station has a variable number of observation plots according to the heterogeneity of the environment where the traps are installed (3-5 traps/plot) and the samples are collected.

7.4.2.3. Direct control measures

Principles:

- Direct control is only undertaken if the population levels reach the harmfulness threshold.
- Priority is placed on natural, cultural, biological and biotechnical measures and methods and on specific protection techniques, and the use of pesticides is kept to an absolute minimum.
- The pesticides chosen are the formulations which are most selective, least toxic in general or which are the least persistent and have minimum effects on humans, game, livestock and the environment in general.

Methods and techniques:

- Several cultural techniques can be employed as direct control measures: pruning and sucker removal to combat numerous noxious species; use of natural attractants (olive beetle); trapping ('A' weevil); direct adult captures; mechanical control, pruning and burning of infested organs; and soil management (tillage, hoeing under the trunk and canopy) to control weeds or soil-borne insects (olive moth, olive fruit fly, white grubs, 'A' weevil, cicada larvae, etc).
- The use of specific, selective products is highly recommended, particularly bacterial formulations such as *Bacillus thuringiensis* or *Saccharopolyspora spinosa* (Spinosad) or fungi to combat lepidopteran caterpillars (olive moth, jasmine moth, pyralid moth, leopard moth, etc.) or even dipteran larvae (olive fruit fly).
- All the techniques entailing the combination of an attractant (food, pheromone, etc.) and the local application of an insecticide to a small area of the tree are highly recommended.

- Biotechnical methods based on mass trapping or mating disruption should be encouraged (olive fruit fly, olive moth, jasmine moth, pyralid moth, etc.).
- Releases of auxiliary agents (parasitoids, predators) are recommended, particularly to control scales, in conjunction with cultural measures.
- Lastly, sulphur-based pesticide formulations (against mites) or lime mixed with copper products are an alternative to using synthesis insecticides.

Pesticide selection and conditions of application

Basic criteria for choosing pesticides:

- Only approved formulations are authorized and should be applied in stringent compliance with the instructions.
- Pesticides are classified according to the following criteria:

• Toxicity vis-à-vis humans, natural enemies, game and animals
• Extent to which they pollute the soil and water
• Capacity to induce the development of other noxious species
• Selectivity
• Length of time they remain in the environment and their solubility in oil
• Risk of causing the development of resistance phenomena in the target species

Non-selective products which are persistent and highly volatile should be banned.

Taking these criteria as a basis, the following is recommended:

• Avoid blanket treatments with pyrethroids
• Avoid using certain toxic, highly persistent herbicides (diquat, paraquat,etc.)
• Rationalize the use of certain insecticides and fungicides (doses and number of applications/ha/year): broad spectrum organophosphorus products, carabamates, copper-based products,…
• Comply with the specified length of time between product application and harvest to minimize or guarantee the absence of traces of residues in the olive fruits and olive oil

Application metholds and equipment:

The application of phytosanitary treatments should meet the following requirements:

- It should be sufficiently effective to keep the population levels of the target species below the economic tolerance threshold.
- The volume of product sprayed should be limited to the amount of active matter strictly needed per hectare or per tree taking into account tree size. Any product loss on the soil or through drift should be kept to an absolute minimum.
- The product should be distributed uniformly in a fine spray at the right pressure (about 6 bars) and should be targeted at the parts of the tree where the noxious species can be reached.
- It should have minimum side effects on the auxiliary fauna and the natural environment in general.
- Spraying should be automated to avoid handling errors to the maximum.

Recommendations

– Aerial spraying should be banned owing to its extremely negative environmental repercussions.

It should only be tolerated when ground application is impossible or scientific studies have proved it has a limited ecological impact. In any event, blanket aerial spraying cannot be authorized.

– Sprayers should be regulated and calibrated regularly before starting applications, particularly to check pressure and nozzles.
– Semi- or totally automated equipment is recommended.
– Products should not be applied when it is windy or very hot.
– Localized applications employing a poisoned lure (insecticide + food or pheromone attractant) are highly recommended to combat olive fruit fly. The same applies for the localized treatments on the trunk and/or scaffold branches to control wood-eating species (olive beetle, olive pyralid moth and possibly leopard moth).

7.4.3. Main noxious species and recommended methods of management

7.4.3.1. Insect pests

Order: Diptera

OLIVE FRUIT FLY: *BACTROCERA OLEAE* GMEL (DIPTERA, *F. TEPHRITIDAE*)

Common names

Olive fruit fly (English); Mouche de l'olive (French); Mosca del olivo (Spanish); Mosca dell' olivo (Italian); Mosca da azeitona (Portuguese); Dhoubabet azzaitoun (Arabic).

Geographical distribution

This species is found throughout the Mediterranean region, further afield as far as India, and in the United States (California). It has a major economic impact in the majority of the olive producing countries.

Host plant

Cultivated olive tree and oleaster.

Description

– *Adult*: 5 mm long, brown abdomen with black markings along the sides although the colouring varies greatly. Females have an ovipositor (Fig. 1).

Figure 1. Olive fruit fly adults.

– *Egg:* white, elongated, 0.8 mm long (Fig. 2).
– *Larva*: three larval instars and one pupal stage.

Life cycle

Several generations (4-5) occur through the year. The actual number is closely linked to the climate and to the availability of olive fruits.

– Adults and larvae (maggots) overwinter in fruit on the tree while the pupae do so in the soil.
– The start of the first summer generation depends on fruit susceptibility and temperature conditions. It is early (June) in hot coastal areas (southern Mediterranean) and later (July–August) in northern Mediterranean and mountainous regions.
– Between three and four generations can occur from early autumn until winter.

Symptoms and damage

– Puncture marks or 'stings' on the olive fruits (Fig. 3).
– Premature drop of olive fruits attacked by the summer generation(s) or later in autumn.
– Loss of fruit weight (part of the flesh eaten by the larvae) and consequently of oil yield (later attacks in autumn and/or winter) (Fig. 4).
– Deterioration of oil quality.

Regulatory factors

– *Climate*

Excessively high summer temperatures (above 35 °C) and low winter temperatures curb the fly ovipositional (egg-laying) activity.

Figure 2. Egg laid in a green olive, sticking out of the flesh.

Figure 3. Traces of puncture marks on olive fruits in early summer.

Figure 4. Fruit flesh partly eaten by olive fruit fly larvae (summer attack).

– *Fruit susceptibility*

Large, fleshy olive fruits (with a high fruit-to-stone ratio) are more susceptible and are the first to be infested.

– *Auxiliary fauna*

The auxiliary fauna is relatively large and varied in number (birds, Myriapods and especially insects) but does not often provide sufficient control, particularly when olive fruit fly populations are high. The most important parasites include *Opius concolor* (Hymenoptera, Braconidae), *Eupelmus urozonus* (Hym. Eupelmidae), *Eurytoma martelli* (Hym. Eurytomidae) and *Pnigalio mediterraneus* (Hym. Eulophidae).

Monitoring and risk prevention

Several complementary methods are employed for monitoring.

Adult trapping

Types of trap

- McPhail food traps baited with protein hydrolyzate, ammonium bicarbonate or 3% diammonium phosphate (Figs. 5 and 6); these are more effective in hot regions.

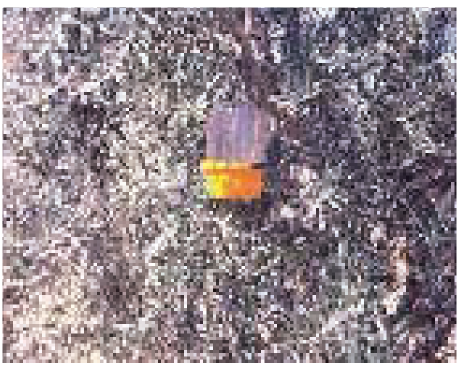

Figure 5. Plastic McPhail trap.

Figure 6. Glass McPhail trap baited with diammonium phosphate.

- Yellow sticky traps, which can be spiked with a sex pheromone capsule (spiroacetate). Rebell-type cross boards (Fig. 7) or single panels are available (Fig. 8).

Application

The traps are placed in the tree canopy at the height of a person and at a density of 2-3 traps per hectare. Fly capture counts should be taken between once and twice a week.

Capture rates are not correlated with the extent of infestation. Consequently, it is necessary to take additional measures such as:

- Monitoring of female fertility by dissecting around 50 females per week from the start of the first summer generation (from May in hot regions) and noting down ovary status, the number of ripe eggs per ovary and the percentage of mature females.

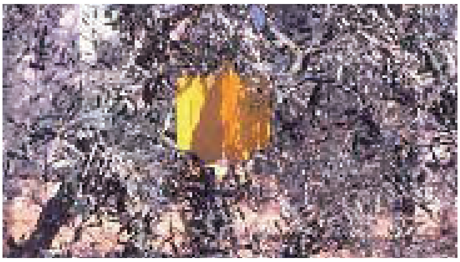

Figure 7. Rebell-type cross-board trap.

- Fruit sampling to estimate insect ovipositional activity by collecting around ten fruits per tree from a minimum of 20 trees and calculating the percentage of fruits with one or more eggs and/or larvae.
- Monitoring of climatic data (especially maximum temperatures).

Figure 8. Single panel yellow sticky trap with pheromone.

Methods of management

Cultural practices

– Turning over the soil under the canopies (to a depth of 15-20 cm) in autumn and winter, and even in early spring to bury the pupae.
– Speeding up olive harvesting if autumn attacks break out.

Biotechnical methods

Mass adult trapping at the start of the season: one trap every one or two trees (this is effective above all when the populations are small to moderate).

Types of trap

McPhail trap baited with protein hydrolyzate, ammonium bicarbonate or diammonium phosphate (DAP); sticky plastic panel or wooden board (25 x 17 cm) impregnated with Decis (Deltamethrine) and baited with a sachet of ammonium bicarbonate or DAP and a pheromone capsule (80 mg of spiroacetate); Ecotrap (Fig. 9), which gives fairly satisfactory results; water or milk bottles baited with an attractant (3% DAP) and punctured at the top to let the flies in.

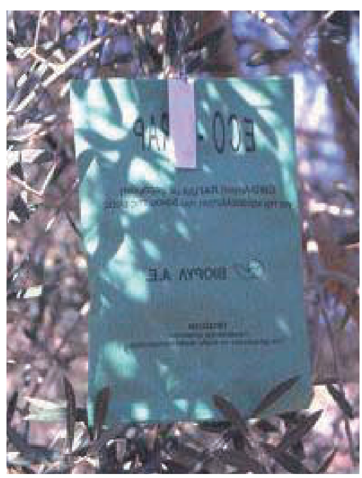

Figure 9. Ecotrap.

Chemical control

– Localized treatment with poisoned bait to kill the adults before or on the appearance of the first punctures.

Conditions

- Early action at the start of the season before massive proliferation of the populations. The capture threshold per trap and day varies according to region and population level; the same applies to the number of treatments.
- Mixture of insecticide (0.3–0.6 litres of Decis-dimethoate,…) and one litre of protein hydrolyzate in 100 litres of water. The hydrolyzate can be replaced by olive fruit fly pheromone.
- Application to a number of trees in the olive orchard or to part of the trees at a rate of 250 cc–2 litres/tree (according to canopy volume).

– Localized application of Bordeaux mixture to kill the adults (tested in Italy): mixture of 1 kg of copper sulphate with 2.5 kg of lime in 100 litres of water, Spinosad or tracer 240.
– Control of larvae and adults.

- Treatment threshold: 10–15% fruit infested with eggs and/or larvae when the olives are intended for oil production and 1–2% when they are intended for table olive production.
- Products: systemic organophosphorus products.
- Ground spraying of the entire tree.

NB: The latest date for applying chemical treatments is around late September–early October.

Biological management

Mass release of *Opius concolor* (500-1,000 parasites/tree); however, this parasite is only effective in early summer when the populations are low to medium.

GALL MIDGES *(DIPTERA, CECIDOMYIDAE)*: OLIVE LEAF GALL MIDGE: *DASINEURA OLEAE* F. LOEW

Common names

Olive leaf gall midge (English); Cecidomyie des feuilles de l'olivier – Cecidomyie des feuilles et des pédoncules floraux de l'olivier (French); Mosquito de la hoja del olivo (Spanish); Cecidomia dell'olivo (Italian); Dhoubabet Aourak azzaitoun (Arabic).

Geographical distribution

This species is found mainly in the Eastern Mediterranean region (Syria, Lebanon, Jordan, Palestine, Israel, Cyprus, Greece) although it has also been reported in Croatia, Italy and Istria.

Host plant

Olea europaea.

Description

– *Adult*: 2.25–2.50 mm long, yellow in colour with reddish abdomen (females); very short-lived. Female fertility: approx. 100 eggs (Fig. 1).
– *Egg*: elongated, slightly tapering at each end, pale yellow in colour turning to red at both ends.
– *Larva*: yellow, with dark brown bilobate sternal plate.
– *Pupa:* orange red.

Figure 1. Adult olive leaf gall midge (from Arambourg, 1986).

Life cycle

Two generations occur annually:

– Adult emergence: end of February–May.
– Oviposition: on young leaves, buds or flower buds straight after adult emergence.
– Larval and pupal development.

As the newly-hatched larvae feed inside the plant organs they create plant growths called galls.

- Development on leaves (phyllophagous generation): The second-instar larvae go into diapause at the end of summer and only metamorphose into pupae in late winter.
- Development on flower clusters (anthophagous generation): Larval development is concluded in April–May. The adults which emerged in May lay eggs on the leaves while the second-instar larvae go into post-summer diapause.

Symptoms and damage

– Appearance of galls on the leaves and inflorescences.
– Leaf and inflorescence deformation and inflorescence drop.

Monitoring

Sampling the plant organs is the only way of checking for the presence of larvae on the leaves and inflorescences.

Management strategy

Generally, the insect does not cause sufficient damage to merit treatment. Nevertheless, in the event of heavy infestations of flower clusters (this has occurred in Syria), it may be necessary to apply low doses of systemic products to control the first larval instar in the spring.

OLIVE BARK MIDGE: *RESSELIELLA OLEISUGA* TARGIONI - TOZZETI

Synonyms

Diplosis oleisuga; *Clinodiplosis oleisuga*; *Thomasiniana oleisuga.*

Common names

Olive bark midge (English); Cecidomyie de l'écorce de l'olivier (French); Mosquito de la corteza del olivo (Spanish); Cecidomia suggiscorza dell'olivo (Italian); Dhoubabet Kichrat Azzaitoun or Dhoubabet Kelf Aghsan Azzaitoun (Arabic).

Geographical distribution

This species has been reported in most of the Mediterranean olive-growing countries (North Africa, Middle East, Spain, Greece, Italy, France, former Yugoslavia). It tends to develop in intensive olive orchards.

Host plant

Although the larvae only develop on the bark of the olive tree, they can also live under the bark of other genera of the *Oleaceae* family (*Phillyrea*, *Fraxinus*).

Description

– *Adult:* 3 mm long, black, with orange (female) and greyish (male) abdominal segments (Fig. 1).
– *Egg*: 0.25-0.30 mm long, elliptic, elongated; initially transparent, turning to yellow prior to hatching.
– *Larva*: 3-4 mm long, initially transparent, later turning whitish and then orange in later stages.
– *Pupa*: 1.5-2.2 mm long, dark yellow or orangish.

Figure 1. Olive bark midge adult (from Arambourg, 1986).

Life cycle

Two generations occur annually in spring and summer, except in Crete where there is only one generation.

– Overwintering: as summer-generation larvae.
– Pupation: end of winter.
– Adult emergence: beginning of spring.

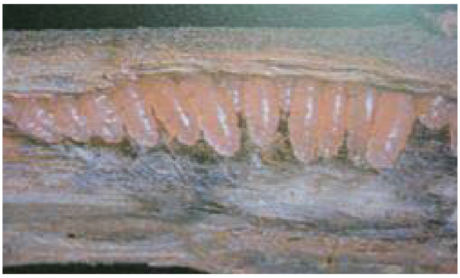

Figure 2. Clusters of eggs laid on a twig.

– Oviposition: small clusters of 10-30 eggs are laid under the bark (raised by natural injuries or injuries caused by man or insects) (Fig. 2).
– Larval and pupal development: the young larvae dig parallel cells in the cambium under the bark (Fig. 2). When fully developed, they abandon the bark and pupate in the ground.

Symptoms and damage

Attacks are often observed at the base of young shoots growing from old rejuvenated trees or in young, irrigated olive orchards.

Symptoms

- Necrosis of the bark around the ovipositional site, with the formation of hollows or cracks, and change in colour to reddish yellow (Fig. 3).
- Withering of the part of the twig above the ovipositional site (Fig. 4).

Figure 3. Cracked twig.

Figure 4. Withered shoot.

Regulatory factors

Abiotic factors

- High relative humidity, abundant rainfall and irrigation are conducive to the development of this insect.
- Bark injuries of any type (caused by man, wind, insects, frost, hail, etc.) are favourable for midge ovipositional activity.
- Aridity associated with harsh heat limits its development and appears to affect larval survival in summer.

Biotic factors

- An ectoparasite *Eupelmus hartigi* has been reported in addition to a predatory mite belonging to the genus *Pyemotes*.

Monitoring

Monitoring is by visual observation of symptoms of attacks on twigs.

Management strategy (valid for organic growing)

Management focuses primarily on cultural practices:

– Prophylactic measures:

- Application of cicatrizants to pruning wounds and removal of parts injured by the wind or harvesting
- Prevention of machinery damage

– Direct control by removing and burning infested twigs and branches.

Order: Lepidoptera

OLIVE MOTH: *PRAYS OLEAE* BERN. *(LEPIDOPTERA, F. HYPONOMEUTIDAE)*

Common names

Olive moth or olive kernel borer; Teigne de l'olivier (French); Polilla del olivo (Spanish); Tignola dell'olivo (Italian); Traça de oliveira (Portuguese); Al Itha (Arabic).

Geographical distribution

Throughout the Mediterranean region and as far as Russia.

Description

– *Adult*: micro-lepidopteran, 6-7 mm long with a wingspan of 13-14 mm (Fig. 1).
– *Egg:* sub-ovate, convex, very reticular. White when recently laid, then turning yellowish as it develops. Sensitive to increases in temperature and decreases in humidity (Fig. 2).
– *Larva*: five larval instars.
– *Pupa*: enclosed in a dirty white, loosely knit silk cocoon.

Figure 1. Olive moth adult.

Life cycle

Three generations occur annually.

– The moth overwinters as leaf-mining larvae.

First generation (anthophagous): Adult flight occurs in early March (hot regions) and early April (northern Mediterranean). The females lay their eggs on the calyx of the flower buds which is only susceptible at stage D (Fig. 2).

– The larvae develop on the stamens and pistil (Fig. 3) and the pupae develop on the flower clusters (Fig. 4).

Second generation (carpophagous): Adult flight takes place in early May-early June. The females lay their eggs on the calyx of the young fruits (Fig. 5). The larvae burrow into the olive fruits and feed on the kernel (Fig. 6). When fully developed, they abandon the fruit by digging an exit hole at the calyx, dropping to the ground where they pupate (Figs. 7 and 8).

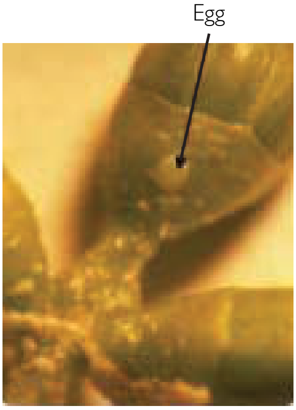

Figure 2. Eggs laid on flower bud.

Figure 3. Later-instar caterpillar eating flower buds.

Figure 4. Damage to flower clusters (note pupation).

Third generation (phyllophagous): The flight of the 2nd-generation adults starts in September–October. The females lay their eggs on the upper surface of the leaves. The leaf-mining larvae dig galleries characteristic of each instar. Pupation takes place between two leaves or in cracks in the scaffold branches and trunk.

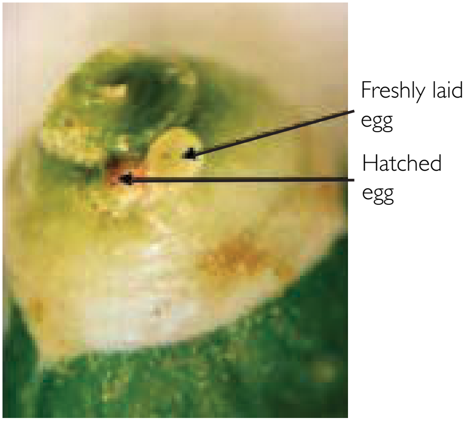

Figure 5. Eggs laid on calyx of young fruit (carpophagous generation).

Symptoms and damage

Anthophagous generation

This generation can destroy a fairly large proportion of the flower buds, causing decreased fruit set (Figs. 3 and 4).

Carpophagous generation

- This generation causes summer fruit drop (larval penetration), which can be mistaken for natural fruit drop.
- It causes autumn fruit drop (larval exit), which causes the real damage (Figs. 7, 8 and 9).

Figure 6. Olive kernel eaten by older larva.

Figure 7. Fully developed larva emerging from the fruit.

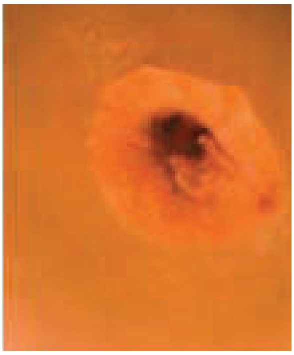

Figure 8. Fruit orifice after larval exit.

Phyllophagous generation

This generation burrows galleries in the leaves which differ in shape according to the larval instar. When heavy infestation occurs the terminal buds are sometimes eaten (Figs. 10, 11 and 12).

Figure 9. Autumn fruit drop induced by olive moth.

Regulatory factors

– *Climate*

Temperature and humidity determine the geographical location of the species, which is confined to coastal areas or mild, damp regions owing to the sensitivity of the eggs to air dryness. High spring and summer temperatures (above 30 °C and close to 35 °C) combined with a decrease in humidity have a drastic impact on the survival of the eggs and young larvae inside the fruits (carpophagous generation).

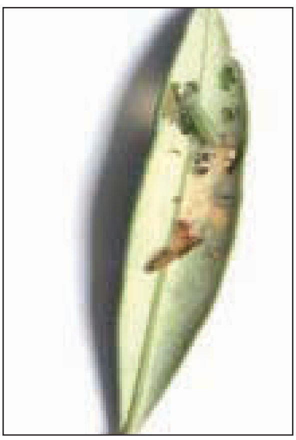

Figure 10. Gallery and L-3 instar.

Figure 11. Different sizes of galleries mined in leaves.

Figure 12. Infested terminal bud.

– *Tree*

The tree is a regulatory factor in three ways, particularly of the carpophagous generation:

- Fruit thinning drop in early summer eliminates a substantial number of eggs and larvae.
- Multiple eggs are laid on the fruits when the crop load is low to medium. This helps to reduce the number of supernumerary eggs because only one larva can develop per fruit.
- Olive fruit response to larval penetration associated with high temperatures contributes to high mortality of the young penetrating larvae.

– *Natural enemies*

There is a wide, diversified range of auxiliary fauna made up of around 40 parasites and predator species in the northern Mediterranean regions and fewer in the southern regions (about ten species in Tunisia).

Natural enemies play an important part, particularly in combating the 2nd generation by eating the eggs (up to 80%) and larval eggs and larvae (over 60%).This role appears to be linked to host density.

Monitoring and prevention

Adult control

Delta pheromone traps (Fig. 13): 2-3 traps/ha (50-70 m between traps).

- The traps are placed at shoulder height.

First generation: from late February (hot regions) to late March (cold regions)

Second generation: from late April to late May

Third generation: early September

- The pheromone capsule is changed at the end of each generation and the glued card is replaced whenever necessary (big catches, sandy winds).

Average catches/trap and maximum catches/ seven days/trap can indicate the potential risk of inflorescence and fruit infestation. In addition, the levels of first generation captures enable forecasting of the second generation.

Figure 13. Delta pheromone trap.

Sampling

Anthophagous generation: 50-100 flower clusters/tree are collected from approximately ten trees when flowering is about to start (% of infested clusters and density of hatched eggs/100 clusters).

Carpophagous generation: depending on the extent of infestation,10-30 fruits/tree are collected from 10 trees every 7 days from fruit set (% infested fruit, density of hatched eggs/100 fruits).

Phyllophagous generation: leaf samples are collected once (100 leaves/tree from 10 trees) at the last mature larval instar–start of pupation (late January-late February): larval density/100 leaves.

Management strategy

Cultural measures

– Suitable pruning at the end of winter to reduce the phyllophagous generations.

– Turning over of the soil under the tree canopies in autumn to reduce the adult populations of the 2^{nd} generation.

Direct control (remedial)

– Treatment thresholds: 4-5% infested clusters; 20-30% infested olives (small oil-olives); lower thresholds (10%) for table olive varieties.

– Management methods:

- Microbiological control by spraying the trees with *Bacillus thuringiensis* or *Saccharopolyspora spinosa* (Spinosad-Tracer) to combat the first generation as soon as the first flowers open. The same methods may be applied exceptionally to the third generation in the event of heavy larval density on the leaves.
- Chemical control of the 2^{nd} generation by employing a systemic product (dimethoate) when the egg hatching rate exceeds 50% and approaches 75%.

LEOPARD MOTH: *ZEUZERA PYRINA* L. *(LEPIDOPTERA, F. COSSIDAE)*

Common names

Leopard moth; Zeuzère (French); Taladro del olivo (Spanish); Perdilegno bianco/Perdilegno giallo (Italian); Broca (Portuguese); Hoffar essak (Arabic).

Geographical distribution

The leopard moth is spread across northern and southern Europe, North Africa, the whole of the Near and Middle East, Iran, reaching as far as China and Japan.

It is found in olive above all in the eastern countries of the Mediterranean (Syria, Lebanon, Egypt, Israel, Jordan, Cyprus, Turkey, etc.), but rarely in the western Mediterranean although it has been reported in Italy (Sicily).

Host plant

The leopard moth is highly polyphagous and attacks numerous species of tree and shrub, notably apple, pear, plum, cherry, fig, olive and even pomegranate.

Description

– *Adult*: wingspan of 50-70 mm for the female and 40-50 mm for the male. White, sprinkled with numerous large dark blue spots on the fore wings and lighter dots on the hind wings (Fig. 1).

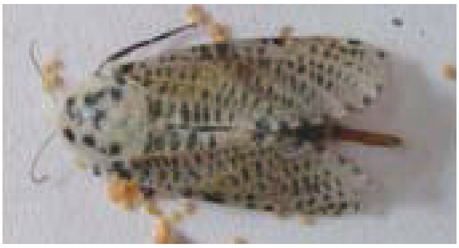

Figure 1. Leopard moth female.

Moth gender is easily distinguished by size (the female is larger) and by the shape of the antennae (filiform in the female and bipectinate in the male).

– *Egg:* approx. 1 mm, oval, subelliptic in shape and yellow-to-salmon in colour. The eggs are often laid in clusters in bark cracks or in old galleries.

– *Larva:* five larval instars, followed by a pupal stage. After the egg hatches, the pale yellow L_1 larva is 1 mm long. By the end of development (L_5) the larva can be 50-60 mm long (Fig. 2).

– *Pupa:* 35 mm long, yellowish brown in colour. Pupation takes place at the entrance to the larval gallery, which is plugged with sawdust (Fig. 3).

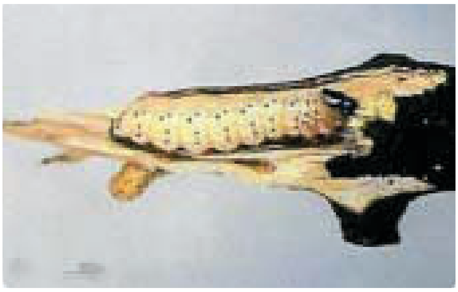

Figure 2. Leopard moth larva (from Guario et al., *2002).*

Figure 3. Cast skin of leopard moth pupa (from Guario et al., *2002).*

Life cycle

The cycle is annual in northern Europe and in the Mediterranean olive-growing region more generally. In rare cases, it may be every two years.

– *Adult flight*

The flight period varies according to geographical location. It runs from May until the end of August, and even until November (Italy) with one or two peaks in June and August. In Syria it runs from late August until October, peaking around the end of September.

– *Oviposition*

The leopard moth lays its eggs in bark crevices or cracks or in old larval galleries a few days after the start of adult flight.

– *Larval development*

After hatching, the L_1 larvae remain clustered together for some time before dispersing to young shoots or suckers which they penetrate by burrowing an ascending gallery. As they tunnel, they push the frass to the outside of the entry hole where a reddish pile of sawdust accumulates (Fig. 4).

Figure 4. Pile of sawdust after larval penetration (from Guario et al., *2002)*

A few weeks later, the older larval instars attack 1-4 year-old branches, and even older branches or the scaffold branches.

The large 4^{th} and 5^{th} instar larvae migrate to the large branches or trunk where they overwinter in galleries.

– *Pupation*

When fully developed towards the beginning of spring, the last instar stage returns to its gallery and moves towards the entry hole where it pupates, sealing the hole with a protective characteristic plug of sawdust.

Figure 5. Withered shoots after migration of young larvae (from Guario et al., 2002).

Symptoms and damage

The leopard moth is considered a primary pest in the Middle East where it can cause significant damage to young orchards and mature trees. The larval gallery weakens and may wither the part of the plant above the entry hole (case of young shoots or twigs) (Fig. 5).

Economic tolerance threshold

– 5 larvae/tree in 8-year-old trees
– 5– 5 larvae/tree in 20-year-old trees
– 20–30 larvae/tree in 20+ trees

Monitoring

Determination of adult flight period

Light traps or pheromone traps are employed to catch adult leopard moths. Males are caught primarily because the females are too heavy to fly.

Estimation of infestation level

- In late summer, weekly counts are taken of the infested (withering) young shoots of around 20 trees, after migration of the L_1 larvae.
- In winter–early spring, tree trunks and scaffold branches are checked for traces of the presence of mature larvae.

Control methods

Control is made difficult by the fact that the flight and ovipositional periods are staggered.

Currently, a combination of methods is used for leopard moth control:

– Cultural methods:

- Frequent pruning of young twigs showing signs of infestation by young larvae
- Removal and burning of debilitated, heavily infested branches to eliminate larvae
- Maintenance of suckers and watersprouts during the autumn–winter period as preferential sites for the first larval migration and subsequent removal and burning

– Mechanical methods:

- Insertion of wires in the galleries to kill the mature larvae
- Plugging of the larval galleries with modelling clay or cotton wool impregnated with toxic products
- Collection of the females during the flight period

– Biotechnical methods:

Adult mass trapping (males especially) by placing 10-20 light or pheromone traps/ha (Fig. 6).

– Biological methods:

- Injection of microbiological products (*Bacillus thuringiensis*, *Saccharopolyspora spinosa*) into the galleries and plugging of the holes to combat the young larvae migrating to shoots and twigs or mature larvae in winter-early spring

Figure 6. Light trap for trapping leopard moth adults (from Guario et al.*, 2002).*

PYRALID MOTH: *EUZOPHERA PINGUIS* HAW. *(LEPIDOPTERA, F. PYRALIDAE)*

Common names:

Pyralid moth; Pyrale de l'olivier (French); Barrenador de la rama or Agusanado del olivo (Spanish); Piralide dell'olivo or Perforatore dei rami (Italian); Farachet Kelf Azzaitoun (Arabic).

Figure 1. Pyralid moth adult (from Arambourg, 1986).

Geographical distribution

Although present throughout the Mediterranean region and most of Europe, the pyralid moth is only reported in olive in Spain, Tunisia, Morocco and occasionally Italy.

Host plant

Fraxinus excelsior in the northern Mediterranean, *Olea europaea* in the southern Mediterranean.

Description

– *Adult*: moth 12-14 mm long with a wingspan of 20-25 mm, beige to dark brown in colour. Forewings are marked with two pale zig zag lines (Fig. 1).

– *Egg*: flattened oval shape like an onion bulb (1 mm x 0.8 mm) with a finely reticulated chorion (Fig. 2).

– *Larva and pupa*: five larval stages followed by a pupal stage.

First instar larva: 1-2 mm long, pink.
Fifth instar larva: 20-25 mm, yellowish white.
Pupa: 10-12 mm, dark brown, enclosed in a silk cocoon.

Life cycle

In Spain and Tunisia there are two generations a year. The first is in the spring–summer and lasts approximately four months and the second is in the autumn-winter and lasts seven months (Fig. 3).

Figure 2. Pyralid moth eggs.

- Overwintering: as larvae in galleries tunnelled under the bark of the trunk and branches.
- Pupation: from March– early April until the end of May.
- Adult flight: from March–April until the end of June.
- Oviposition: second fortnight of April. The eggs are laid singly or in clusters of five or six. Larval development takes place from the end of April until August.
- Pupation: first fortnight of August.
- Flight of 1st generation adults: August–October.
- Oviposition and larval development: autumn, winter and early spring of the following year.

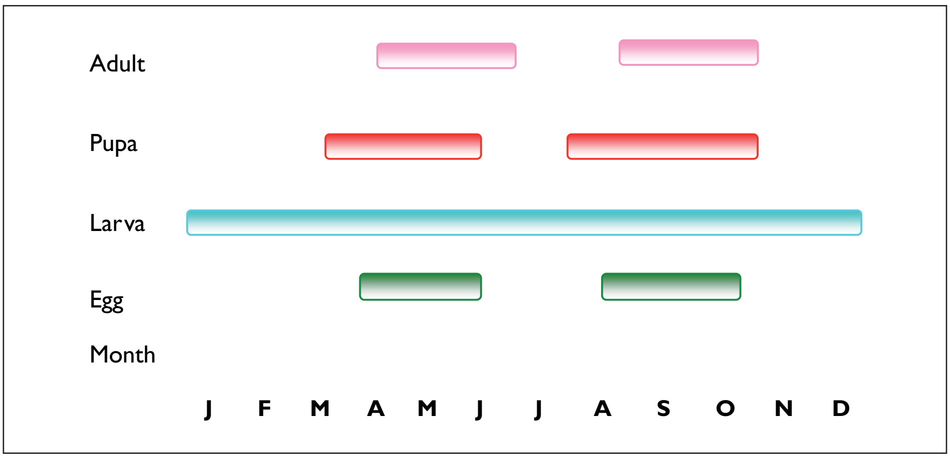

Figure 3. Pyralid moth life cycle (Spain – Tunisia).

Symptoms and damage

The pyralid moth is a primary pest which attacks vigorous trees. The galleries burrowed by the caterpillars at the base of the trunk or in crotches of the scaffold branches (Fig. 4) hinder sap circulation and lead to debilitation of the part of the plant located above the infestation site.

In young orchards, the presence of a few larvae can cause the death of the tree (Fig. 5).

Monitoring

This entails monitoring adult flights, checking the pre-imaginal stages per tree and visually inspecting the trees for symptoms of withering and traces of sawdust on the trunk and branches.

Pile of sawdust

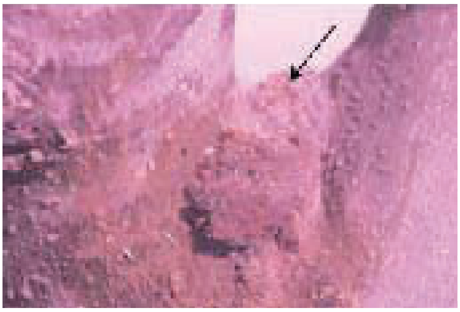

Figure 4. Larval gallery in the crotch of a scaffold branch, identifiable from the presence of sawdust.

Figure 5. Debilitation and withering of the parts above the infested zone (from Civantos, 1999).

– Monitoring of adult flights:

- Light traps: These are very effective in determining whether adults are present (Fig. 6), but the level of catches does not provide information on the potential risk of infestation.
- Pheromone traps
- Food traps baited with a liquid attractant made from a mixture of wine, vinegar and sugar.

– Monitoring of pre-imaginal stages:

This is done by scraping the bark of approximately ten trees to estimate the number and developmental stage of the pre-imaginal stages (Fig. 7). The presence of traces of sawdust is a cue for monitoring.

Figure 6. Light trap (from Civantos, 1999).

Control methods:

– Cultural measures:

- Plugging of pruning wounds and injuries, which attract females in search of laying sites and are easy for young larvae to penetrate.
- Good tree care (tillage, pruning, irrigation, fertilization, etc.) to avoid debilitation induced by moth attacks.

Larval gallery

Figure 7. Bark scraped to monitor developmental stages.

– Direct control:

This should be targeted at the vulnerable, accessible stages, particularly the adults, the eggs and the young larvae before burrowing into the bark. Close monitoring of adult flights and of the pre-imaginal stages (by scraping the galleries) is required for this purpose.

If necessary (major outbreak sites or infestation of young trees), treatment can be applied to the young larvae and possibly to the adults in the springtime (this period generally coincides with peak flight) by using a mix of organophosphorus products and mineral oil (1.5 L insecticide + 2 L mineral oil in 100 L water) or microbiological product (Spinosad), particularly in the case of organic growing.

Products should be applied to the trunk and branches displaying symptoms of infestation.

If spring treatment does not prove to be sufficient (over 20% of live larvae after the first application) it should be repeated or else resumed for the autumn–winter generation (September-October).

JASMINE MOTH: *MARGARONIA UNIONALIS* HÜBN. *(LEPIDOPTERA, F. PYRALIDAE)*

Synonyms

Glyphodes unionalis HÜBN., *Palpita unionalis* HÜBN.

Common names

Jasmine moth; Pyrale du jasmin (French); Polilla del jazmín (Spanish); Tignola del gelsomino (Italian); Farachat alyassamine (Arabic).

Geographical distribution

This species of Mediterranean origin is widely distributed in the subtropical and tropical regions of all five continents. It is becoming more extensive in nurseries and in intensive orchards, particularly in hot regions (e.g. Egypt).

Figure 1. Jasmine moth adult.

Host plant

It is a polyphagous species, but above all attacks *Oleaceae*, notably olive and jasmine.

Description

– *Adult:* moth with a wingspan of 30 mm, satiny white colour, mainly nocturnal in activity (Fig. 1).

– *Egg:* flat, more or less elliptic in shape, with finely reticulated surface. Whitish in colour and 1 x 0.6 mm in size (Fig. 2).

– *Larva:* six larval stages. When hatched, the young larva is yellowish in colour and measures 1.4 x 0.25 mm. As it develops, it turns a greenish colour (Fig. 3). When fully developed, the larva (18-25 mm long) spins a silk cocoon amongst the leaves where it metamorphoses into a pupa.

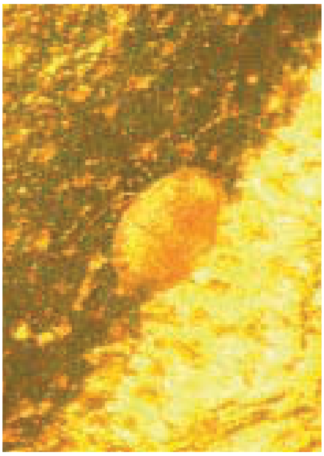

Figure 2. Jasmine moth egg.

Figure 3. Older larva on leaf.

Figure 4. Leaf parenchyma eaten by larva.

Life cycle

– Overwintering as larvae.
– Adult flight: The first adults emerge in March-April and the last ones in October-November. There can be a succession of several, overlapping generations.
– Oviposition and larval development: The eggs are laid singly or in clusters on either side of the young leaves of terminal shoots. The emerging larva first feeds on the leaf parenchyma (Fig. 4), then eating the leaves and young shoots (Fig. 5) and even the olive fruits in cases of heavy attack (Fig. 6).

Figure 5. Damaged leaves and young shoots.

Symptoms and damage

Larvae do not cause major damage to young shoots and leaves in mature orchards. On the other hand, they can have an economic impact on nurseries and young orchards (Fig. 7), especially when they attack the fruit (Fig. 6).

Monitoring

- Control of adult flights with pheromone traps following the development of (E)-11–hexadecenal and (E)-11 hexadecenyl-acetate (Mazomenos *et al.*, 1994): Between two and three Funnel traps are used per hectare. The pheromone capsule is changed monthly and weekly counts are taken of captures (Fig. 8).
- Shoot sampling: Sampling is still the most reliable method for monitoring pre-imaginal stages and for treatment decision-making. Around ten young shoots are collected from 5–10 control trees from early spring until October–November.

Figure 6. Damaged leaves and fruit.

Figure 7. Major damage to young shoots.

Figure 8. Funnel trap.

Management strategy

In general, infestations of jasmine moth do not require treatment except in the case of severe attacks of young plants or fruits in which case the following is recommended:

- Application of a microbiological product (*Bacillus thuringiensis*, *Saccharopolyspora spinosa*) as soon as the first signs of attack appear in the spring.
- Mass release of *Trichogramma* parasites such as *Trichogramma bourarachae* or *Trichogramma cordubensis* (at a rate of 500,000 to 1,000,000 Trichrograms/ha) in several batches.

Order: Homoptera

BLACK SCALE: *SAISSETIA OLEAE* OLIVIER *(HOMOPTERA, F. COCCIDAE)*

Common names

Black scale; Cochenille noire or cochenille tortue (French); Cochinilla negra (Spanish); Cocciniglia mezzo grano di pepe (Italian); Cochonilha negra (Portuguese); Ennemcha Essaouda (Arabic).

Geographical distribution

This species is widespread throughout the Mediterranean region.

Host plant

Black scale is very polyphagous, attacking numerous cultivated and ornamental species, amongst which the oleander (*Nerium oleander*), *Olea europaea* and citrus appear to be its preferred hosts.

Description

– *Adult*: female black scales, 2-5 mm long and 1-4 mm wide. Light brown when young, gradually turning dark brown and almost black as they approach the reproduction stage when they develop a characteristic, H-shaped ridge on the back of the scale covering (Fig. 1).

Although males have been reported, female black scales reproduce without mating, laying between 150 and 2,500 eggs (average = 1,000).

– *Egg*: oval, initially white, then turning orange-tinted pink as they develop (Fig. 2).

Figure 1. Black scale adult.

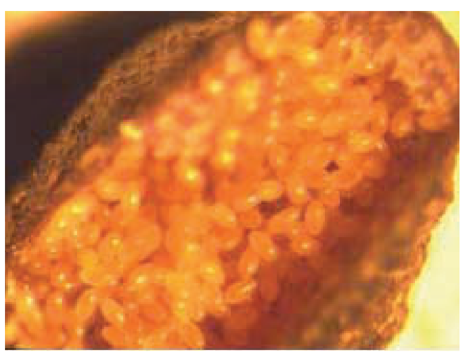

Figure 2. Eggs underneath scale.

– *Larva*: There are three larval instars (Fig. 3):

- First-instar larva (crawler):

After the egg hatches, the light yellow, newly born crawler moves about for some time before settling preferably on the lower surface of leaves (Fig. 3).

Figure 3. Different larval instars on lower surface of leaves.

- Second-instar larva:

Very similar to the L1 crawlers. The back of the scale cover is more convex and an H-shaped ridge develops by the end of this stage.

- Third-instar larva:

Oval, with a more dome-shaped scale cover and more pronounced H ridge.

Life cycle

Generally, there is one generation of black scale a year; however, a second, partial generation can develop if the climatic conditions are favourable (southern Mediterranean area). In such cases, in early summer part of the L1 larvae will develop rapidly into egg-laying females in autumn and winter, while the rest of the population will have to wait until the following spring to complete their development.

The insect overwinters as L2 and L3 larvae, sometimes with a very small proportion of females. In the spring, the larvae move on to the shoots and moult into young females which lay in May-June. The larvae which emerge establish themselves on the lower surface of the leaves.

Figure 4. Sooty mould on shoots heavily infested with black scale.

Symptoms and damage

Damage is of two types:

– Direct damage: The larvae and adults suck the sap, which debilitates the tree when the population density is high.

– Indirect damage: The secretion of honeydew and the development of a black fungal complex on the leaves known as sooty mould hinders photosynthesis and leads to leaf drop (Fig. 4).

Treatment threshold:

Between three and five larvae per leaf; 10 females per linear metre of shoot.

Regulatory factors

Throughout its developmental cycle the black scale is subject to high natural mortality which can reach rates as high as 90% due to the following:

Abiotic factors

High temperatures above 35 °C, coupled with low humidity, have a drastic effect on the young larvae, as do wind and rain during dispersion of the L1 larvae.

In contrast, mild temperatures, high relative humidity (hollows, excessive irrigation, etc.), over-application of chemical fertilizers (especially nitrogen) and lack of tree aeration or high planting densities encourage black scale development.

Other factors of equal importance can be conducive to the species such as abusive treatment with chemicals and industrial pollution.

Biotic factors

The parasitoid and predator complex plays a very important role in keeping black scale populations at tolerable levels.

– Parasitoids:

Several autochthonous or introduced parasitoids are very active against black scale:

Hymenoptera belonging to the genera *Metaphycus: Metaphycus helvolus*, Encyrtidae endoparasitoid of L2 and L3 larvae; *Metaphycus lounsburyi* and *Metaphycus bartletti*, parasitoids of L3 larvae and females; *Diversinervus elegans* which attacks adults; *Coccophagus scutellaris* and *C. lycimnya*, endoparasitoids of L2 and L3 larvae.

– Predators:

- *Scutellista cyanea*, Hymenoptera *Pteromalidae*, egg predator (Fig. 5).
- Coccinellidae, notably *Exochomus quadripustulatus*, black with two irregular spots on the elytra (3–5 mm), and *Chilocorus bipustulatus*, shiny pinkish black with two round spots on the elytra.

Black scale predated by *S. cyanea*

Figure 5. Exit hole of Scutellista cyanea.

Monitoring

– *Sampling:*

- Collection of samples from approximately ten trees (ten shoots/tree) or of approximately 100 leaves per plot (Italy, Spain) to estimate black scale density per leaf or linear metre of shoot and the status of the different stages present.
- Period and frequency:

Every 15 days from May to October and monthly from November to April.

Management strategy

Control should be centred on managing the orchard properly and on limiting insecticide use as much as possible.

– *Cultural measures:*

- Suitable pruning to aerate canopies and to remove heavily infested shoots and small branches.
- Balanced fertilization avoiding excessive application of nitrogen and irrigation.

– *Biological measures:*

- Conservation of natural enemies by avoiding chemical treatments.
- Intensification of the role played by autochthonous fauna by introducing–acclimatizing exotic enemies or by mass releasing parasitoids and/or predators which are easy to rear on their natural hosts bred on oleander or olive, or on substitute hosts such as *Coccus hesperidum* and *Chloropulvinaria urbicola.*

The following parasitoids are recommended:

Metaphycus helvolus (endophagous parasitoid of L_2 and L_3) in October–November, *Metaphycus bartletti*, *Metaphycus lounsbury* and *Diversinervus elegans* against the later instars and adults (late spring, early summer).

Coccinellidae appear to be very effective black scale predators: *Rhizobius forestieri* introduced from Australia (Fig. 6), *Chilocorus bipustulatus* and *Exochomus quadripustulatus* (polyphagous predator).

Figure 6. Rhizobius forestieri *eggs laid under black scale cover.*

– *Chemical control:*

Chemical control is only envisaged in cases of extreme necessity to manage the young stages, preferably after checking the effect of high summer temperatures and the extent of the impact of auxiliary fauna (September-October). Contact products alone or combined with mineral oils are recommended. Care should be taken to wet the tree well.

OLEANDER SCALE: *ASPIDIOTUS NERII* BOUCHÉ (*A. HEDERAE* VALLOT) *(HOMOPTERA, DIASPIDIDAE)*

Common names

Oleander scale; Cochenille du lierre or Cochenille blanche (French); Piojo blanco (Spanish); Cocciniglia bianca degli agrumi (Italian); Escama da oliveira or Cochonilha branca (Portuguese); Ennemcha el baidha (Arabic).

Figure 1. Female oleander scales on leaves.

Geographical distribution

This species is very common throughout the southern Palearctic region. In the Mediterranean region it attacks the olive in coastal and sub-coastal areas of North Africa, mainland Greece and the Greek islands, the Middle East, Spain and Italy.

Host plant

Very polyphagous species which attacks many cultivated and spontaneous plants (over 400 species recorded).

Description

– *Adult*: female scale, circular or subcircular, slightly domed. Pale blackish brown in colour, uniform and matt; subcentre larval exuviae (Fig. 1). Male scale, oval, matt white; offcentre larval exuviae.
– *Egg*: oval, yellowish in colour (Fig. 2).
– *Larva*: three larval instars; the L1 are crawlers (Fig. 2).

Figure 2. Eggs and young larvae under female scale cover.

Life cycle

There are three generations a year:

– The first generation begins in February (southern Mediterranean) or March (colder regions) with the egg-laying females emerging from the overwintering generations.

– The second begins in June and ends in August–September, coinciding with the olive fruits.

– The third generation is observed from September until February of the next year.

The developmental duration of each generation depends on the ambient temperature conditions.

When hatched, the young crawlers move towards shaded parts of the tree to settle on the leaves and fruit.

Regulatory factors

Abiotic factors

- High temperatures combined with a reduction in humidity are not conducive to the survival of the young larvae, particularly in hot regions.
- Leaf drop and collection of infested olives help to reduce the populations.

Biotic factors

In natural conditions, the parasite and predator complex can help to limit the populations to tolerable levels in the absence of chemical treatment.

Parasitoids include *Aphytis chrysomphali* (autochthonous species), *Aphytis chilensis* (ectoparasite of L2 and L3 larvae), *Aphytis melinus* and the endoparasite *Aspidiotiphagus citrinus* (introduced species) and lastly the ladybird *Chilocorus bipustulatus*, which predates on the larvae and females (Fig. 3).

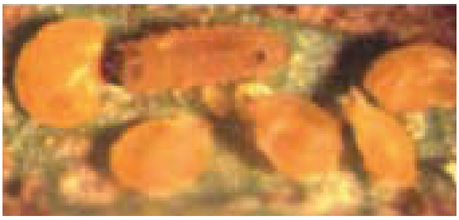

Figure 3. Chilocorus bipustulatus *predator larva eating a female oleander scale.*

Symptoms and damage

As a rule, the presence of the oleander scale on the leaves is tolerable except at very high densities which could debilitate or wither the shoots.

Second-generation attacks of the olive fruits are more serious because they cause fruit deformation, weight loss and a reduction in oil yield as well as deterioration of the quality of the oil (Fig. 4).

The threshold fixed in Greece and Tunisia for oil-varieties is approximately 10 oleander scales per fruit; however, it is much lower for table olives (Fig. 5).

Figure 4. Oil-olive heavily infested with oleander scale (from Arambourg, 1986)

Figure 5. Table olive infested by oleander scale.

Monitoring

Sampling: collection of approximately 10 fruit-bearing shoots per tree from June onwards and oleander scale population counts on the leaves and fruit.

Control methods

– Cultural measures:

Removal and burning of heavily infested shoots.

– Biological control:

- Intensification of the role of auxiliary fauna, avoiding the use of chemical control.
- Rearing of two ectoparasites *Aphytis chilensis* and *Aphytis melinus* on their natural host *A. nerii* bred on potato, and mass release to combat the second and third stages at rates of 10–30 individuals/tree.

– Chemical control:

Chemical control can be envisaged as a last resort to combat the first-instar crawlers by using mineral oils, organophosphorus products or pyrethroids.

OLIVE PSYLLID: *EUPHYLLURA OLIVINA* COSTA (*HOMOPTERA, F. APHALARIDAE*)

Common names

Olive psyllid; Psylle de l'olivier (French); Algodón del olivo (Spanish); Cotonello dell'olivo (Italian); Algodao da oliveira (Portuguese); Psylla azzaitoun (Arabic).

Geographical distribution

This species is present in all the Mediterranean olive-growing areas. It is distinguished from two other similar species of olive pests, *Euphyllura phillyreae* and *Euphyllura straminea,* by the nervature of its fore wings. It is more important in the southern Mediterranean region, notably in North Africa and more particularly in Tunisia.

Host plants

Cultivated olive tree and oleaster.

Description

– *Adult:* chubby, 2.4–2.8 mm long, wings folded roof-like at rest. Pale green when young, later turning darker hazelnut green when older (Fig. 1).

– *Egg:* elliptic, conical and rounded at the anterior end, hemispherical at the posterior end with short peduncle attaching it to the plant tissue.

When freshly laid, the eggs are white, then turning orangey yellow as they develop (Fig. 2).

Figure 1. Olive psyllid adult.

Figure 2. Olive psyllid eggs laid in crack of flower bud corolla.

The eggs are generally laid in tight clusters along the main nervature of the leaflets and young leaves of terminal buds, or in a circle on the inner sides of the calyx or the area between the calyx and the corolla.

– *Larva:* five larval instars, flattened, ochre to pale yellow, distinguishable by their size, the antennae articles and the developmental status of the wing buds and wax-secreting areas (Fig. 3).

During their development, the larvae secrete honeydew, a white wax and a cottony mass which becomes greater as they mature and gives the infested plant a characteristic appearance (Fig. 4).

Figure 3. Colonies of different larval instars of olive psyllid on flower clusters (very heavy infestation).

Figure 4. Characteristic cottony appearance of young flower clusters and shoots infested with olive psyllid.

Life cycle

Psyllid activity is closely linked to plant growth status and climatic conditions (winter and summer temperatures). The number of generations each year therefore tends to vary according to country: 2-6 in Italy, 4 in France, 2-3 in Morocco, 2–5 in Tunisia.

– Overwintering: The insect spends the winter in the form of eggs, larvae and adults, generally on suckers, watersprouts or young shoots, particularly in hot regions with mild winters where it can develop a winter generation (case of Tunisia).

– Spring: This is the main activity season of the psyllid when two generations develop; there may even be a third, partial generation. The first generation begins in late winter/early spring on young shoots, buds and young flower clusters. The second develops mainly on flower clusters (stages D, E) (Fig. 5) where the eggs are laid between the calyx and the corolla (Fig. 6) and to a lesser extent on young shoots. Lastly, a third generation may occur on young set fruitlets if the conditions remain favourable, although it is often halted by the rise in temperatures in late spring–early summer.

Figure 5. Olive psyllid development on flower clusters.

Figure 6. Olive psyllid eggs laid inside calyx of flower bud.

Figure 7. Olive psyllid development in summer on suckers.

– Summer: The adult psyllids go into summer diapause when temperatures rise; however, a small proportion of the females may continue to lay eggs, doing so on suckers (Fig. 7).

– Autumn: During this season the psyllid generally breeds on suckers and watersprouts and develops between one and two generations. If the conditions are especially favourable (abundant rain in early autumn after drought), the insect may develop on the canopy (Fig. 8).

Figure 8. Olive psyllid development in autumn on tree foliage.

Symptoms and damage

Psyllid development has characteristic, spectacular symptoms (cottony mass, honeydew, wax) (Fig. 9). Two types of damage are caused if the population density is high:

– Direct: Inflorescence abortion or withering and drop, leading to lower fruit set rates (Fig. 9).

– Indirect: Plant debilitation owing to the growth of sooty mould after larval secretion of honeydew.

Economic tolerance threshold

Between 2.5 and 3 larvae per 100 flower clusters, corresponding to an infestation rate of 50-60%.

Figure 9. Heavy drop of cotton and wax underneath canopy with loss of entire crop owing to heavy psyllid attack.

Regulatory factors

– *Climate*

- Indirect effect: Mild temperatures in winter, early spring and autumn, accompanied by abundant rain, particularly in autumn, are conducive to plant growth and hence to insect activity.
- Direct effect: The rise in temperatures in late spring and summer halts psyllid activity and induces female summer diapause. Excessive heat (for instance, the sirocco) has a drastic effect on the eggs and young larvae.

– *Natural enemies*

Although quite varied, the parasite and predator complex identified in Tunisia does not appear to play a significant role in psyllid population regulation.

- Predators: four chrysopids, five species of syrphids, one anthocorid (*Anthocoris nemoralis*), two mites and two coleopterans *Malachis rufus* and *Exochomus quadripustulatus* (Figs. 10 and 11).
- Parasitoids: *Psyllaephagus euphyllurae* and its hyperparasitoid *Alloxysta eleaphila.*

Figure 10. Chrysopid larva eating psyllid adult.

Monitoring

Shoot sampling:

Weekly collection of approximately 10 shoots per tree from 10 control trees during the period of psyllid activity (springtime especially); counting of pre-imaginal stages and estimation of psyllid density per inflorescence and/or per unit of shoot length.

Figure 11. Syrphid eggs on flower cluster.

The inflorescence infestation rate provides information on psyllid density per inflorescence (correlation between colony density and cluster infestation rates).

Control methods

Aside from the rare cases of demographic explosion in certain conducive conditions (case of Tunisia in some years), psyllid population levels are generally tolerable and do not call for treatment in most of the olive-growing countries.

However, when conditions are particularly favourable and the threshold might be reached, certain preventive and remedial measures can be envisaged:

– *Cultural measures:*

- Suitable pruning to let air into the tree, particularly into the flower clusters.
- Removal of suckers and watersprouts in summer and autumn–winter.

– *Chemical control:*

If necessary, chemical control can be envisaged to combat the young larval stages of the first and second spring generations, with the aid of organophosphorus products or deltamethrine. Such treatment generally coincides with treatment for the first generation of the olive moth.

Order: Coleoptera

OLIVE BORER: *HYLESINUS OLEIPERDA* FABR. *(COLEOPTERA, SCOLYTIDAE)*

Common names

Olive borer; Hylésine de l'olivier (French); Barrenillo negro del olivo (Spanish); Punteruolo nero dell'olivo (Italian); Caruncho da oliveira (Portuguese); Hilzinus azzaitoun (Arabic).

Geographical distribution

This species is distributed throughout the Mediterranean region as far as the Near and Middle East, as well as Belgium, the United Kingdom, Denmark, Chile and Argentina.

In the Mediterranean region it is found particularly in North Africa (Tunisia, Morocco and Algeria).

Description

Figure 1. Olive borer adult.

– *Adult:* squat (males 2.5-3 mm long and females 3.5-3.7 mm long), blackish. Easily distinguished from the olive beetle owing to its slightly larger size and clubbed antennae (Fig. 1).
– *Egg:* spheroidal, white, laid in a niche in the mother gallery (Fig. 2).
– *Larva:* five larval instars, arched, apodous and whitish. The larval galleries are perpendicular to the mother gallery, but can criss-cross unlike the galleries of the olive beetle, which remain parallel to each other (Fig. 3).
– *Nymph:* one pro-nymph stage (globulous, light coloured) followed by a more elongated nymphal stage, initially whitish and later light brown.

Life cycle

The number of generations varies from one (Morocco) to two (Tunisia).

– Overwintering as L4 and L5.
– Adult flight:

First generation

This varies according to the region and year from late March–early April until early May. Flight peak: second fortnight of May (Tunisia).

Figure 2. Olive borer egg.

Figure 3. Larval galleries

Second generation (partial)

Eggs laid early by the 1[st] generation develop rapidly. The larvae moult into nymphts, giving adults in September. They are small in number, but mate and give rise to a larval population additional to that of the 1st generation. After overwintering, both larval populations metamorphose into nymphs, giving rise to the first generation adults.

When the cycle is univoltine, it is limited to the spring generation.

– Oviposition and pre-imaginal development:

After emergence, the adults go through a three-week feeding stage. They then start laying eggs by boring a hole in the bark of the trunk or scaffold branches (2–10 cm in diameter) which extends on either side through a mother gallery.

Between five and six eggs are laid in niches in each mother gallery. The larvae which emerge tunnel criss-crossing galleries (unlike the olive beetle which digs parallel tunnels).

The patch of bark above the maternal and larval galleries quickly turns reddish (Fig. 4). Eventually it bursts and cracks after completion of pre-imaginal development and the emergence of the adults (Figs. 5 and 7).

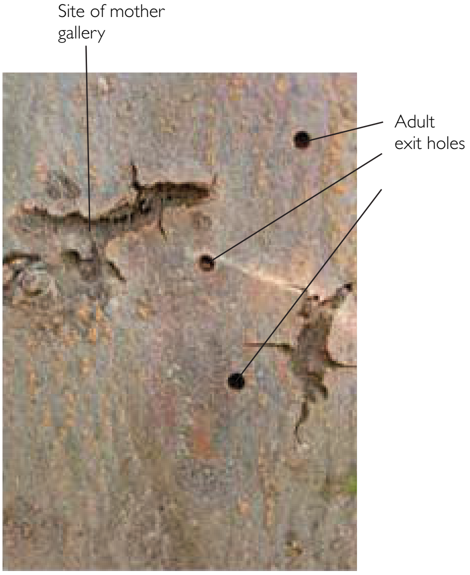

Figure 4. Oviposition and larval development patch with adult exit holes.

Figure 5. Cracked bark after exit of adults.

Symptoms and damage

This primary insect pest attacks young, vigorous trees. When it settles on the trees and digs the mother and larval galleries in the trunk and branches, it hinders sap circulation and debilitates the part located above the patches, which eventually lose their leaves and become withered (Fig. 6).

Economic tolerance threshold

Following research undertaken in Tunisia the tolerance threshold has been fixed at around five patches per tree (approximately 10 years old).

Regulatory factors

– Host plant:

- Olive borer behaviour is influenced by tree age and variety. In young trees (under six years old), the insect is located principally on the trunk. In older trees it tends to spread to the scaffold branches, preferably to branches with a 5–8 cm section (Fig. 7).

Figure 6. Tree heavily attacked by olive borer.

Figure 7. Trunk heavily attacked by olive borer (note cracking).

- Varietal influence: The Tunisian variety 'Chetoui' appears to be the most sensitive to the olive borer, followed by 'Manzanilla', 'Meski' and 'Picholine du Languedoc'. 'Chemlali' seems to be the most resistant.

– Climate and growing conditions:

Very high summer temperatures associated with water stress lead to a natural mortality rate of up to 90%. This percentage is only 50% in irrigated conditions.

– Natural enemies:

The auxiliary fauna is made up of four parasites (*Dendrosoter protuberans*, *Coeloïdes filiformis*, *Eurytoma morio* and *Cheiropachus quadrum*) which play a substantial role in attacking an average 70% of the insects. They affect the first generation more than the second.

Monitoring

Monitoring basically involves checking adult flights of the spring generation from March onwards either by using muslin sleeves (Fig. 8), or by marking the egg-laying patches and counting the adult exit holes (Fig. 9). Scraping the bark can provide information on the developmental stage of the pre-imaginal instars and on the approach of adult flight (Fig. 10).

Figure 8. Muslin sleeves for flight monitoring.

Figure 9. Marking of patches to monitor adult and parasite emergence.

Figure 10. Bark scraped to monitor pre-imaginal stages.

Management methods

– Cultural measures:

- Choice of varieties resistant to the insect.
- Proper orchard care (tillage, pruning) and irrigation (in intensive orchards) to stimulate good plant growth, which limits olive borer development.
- The sedentary behaviour of the insect and the aggregative nature of infestation make it necessary to ensure stringent monitoring from the time the orchard is established and to systematically eradicate outbreak sites, including by mechanical means (scraping the bark).

– Chemical management:

As natural enemies play an important part in management, chemical control is the last resort when the insect is firmly established in the orchard and the threshold is exceeded. In such conditions, one single treatment can be envisaged to control the adults prior to oviposition from two to three weeks before the start of flight, with the aid of deltamethrine or a mixture of deltamethrine and dimethoate. Application should be confined to the infested trunk and branches.

OLIVE BEETLE: *PHLOEOTRIBUS SCARABAEOÏDES* BERN. *(COLEOPTERA, F. SCOLYTIDAE)*

Common names

Olive beetle; Neiroun (French); Barrenillo del olivo (Spanish); Punteruolo dell'olivo (Italian); Arejo da oliveira (Portuguese); Sous hatab azzaitoun (Arabic).

Geographical distribution

Throughout the Mediterranean region and the Middle East, extending as far as Iran.

This species is of major economic importance particularly in the hot southern Mediterranean regions (Tunisia, Morocco in particular).

Figure 1. Olive beetle adult.

Description

– *Adult*: smaller than the olive borer (2-2.4 mm long), rounded and stocky, blackish; antennae with three trident-like lamellae (Fig. 1).

– *Egg:* ovoid, shiny white to yellow when recently laid.

– *Larva:* five larval instars, apodous, arched and whitish (Fig. 2).

– *Nymph*: as in the case of the olive borer, the nymphal stage is preceded by a pre-nymphal stage which is globulous and squat.

Life cycle

Unlike the olive borer, the olive beetle can only develop on cut wood or on debilitated, dying trees. For this reason it is considered a secondary pest.

There can be several generations a year. The exact number varies according to the agri-ecological conditions.

Figure 2. Mature olive beetle instar.

There are three stages in the life cycle of the insect on both cut wood and debilitated trees: overwintering on the trees, breeding on pruned wood or debilitated trees and lastly feeding when the insect leaves the breeding site and moves to neighbouring trees by making feeding bites at the base of the fruit-bearing clusters or at the subterminal part of the shoot (Fig. 3).

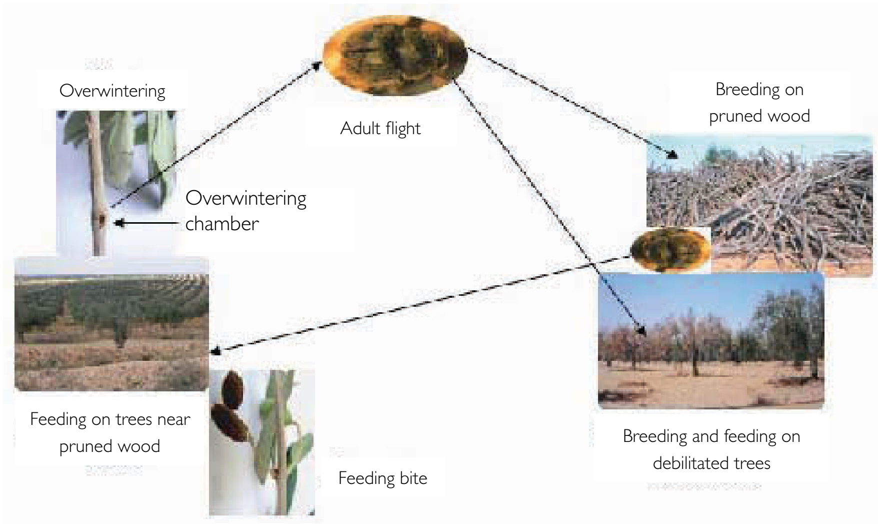

Figure 3. Stages of olive beetle development.

– On pruned wood:

This is the usual way in which the species breeds. After overwintering on trees located close to pruned wood (Fig. 4), the adults move at the end of winter to wood which has just been pruned (Fig. 5) in order to breed (Fig. 6).

Figure 4. Overwintering chamber with sawdust on top.

After mating, the female cuts a mother gallery along which the eggs are deposited in niches.

The larvae which emerge dig tunnels perpendicular to the mother gallery and parallel to each other (Fig. 7).

The wood is attractive to the insect for around four to five weeks, depending on the ambient temperature.

The number of generations likely to develop varies according to the availability of attractive pruning wood (pruning periods) and climatic conditions (2-4 generations).

The duration of the cycle ranges from 45 days at high temperatures of 25 °C (April-May) to several months (winter-early spring).

When they emerge on pruned wood, the adults move to neighbouring trees where they feed by excavating feeding chambers at the base of flower-bearing or fruit-bearing clusters in the axils of leaves or the subterminal part of shoots (Figs. 8 and 10). These chambers make the clusters wither and fall within a relatively short space of time (Fig. 10).

Figure 5. Pruning wood near orchard.

– On debilitated trees:

In conditions of water deficit (marked drought) such as those found in the semi-arid and arid regions of North Africa (Tunisia, Morocco), olive trees suffering from dieback become attractive to the olive beetle and play the part of pruning wood (Fig. 9) while it uses trees that are debilitated or still green for feeding.

In these conditions, this scolytid can be a primary pest because it can kill the trees.

There can be a succession of generations (3-4 in Tunisia) from the start of the year, depending on the progress of debilitation in the olive-growing area concerned.

Figure 6. Adult entry holes in pruning wood (note sawdust)

Figure 7. System of mother and larval galleries.

Symptoms and damage

Figure 8. Feeding chamber covered with sawdust in leaf axil.

Damage can be of two types:

– Olive beetle damage is much more serious on debilitated trees because it can lead to the death of the infested plant after the development of the larval galleries and the emergence of the adults, especially in the case of young trees undergoing the successive development of several generations.

– When pruning wood is stored near the orchards, the adults which emerge from the wood and move to neighbouring trees cause direct damage to flower-bearing and

Figure 9. Tree dieback in pronounced drought.

fruit-bearing clusters during the feeding stage (Fig. 10).

Losses can affect around 10 kg /tree in Tunisia.

Feeding chambers on young shoots are also responsible for causing indirect damage by stopping sap circulation, which makes the shoots wither and drop off at harvesting.

Regulatory factors

– Climate:

Climate is the most important factor in the problems caused by this scolytid, which are aggravated by the storage of wood near olive orchards and poor orchard care.

Figure 10. Damage to fruit-bearing shoots (note wilting).

– Natural mortality:

This is connected with temperature increases and the section of wood where the scolytid nests in that mortality is greater at higher temperatures and smaller wood diameters.

– Natural enemies:

Although wide and abundant in variety, auxiliary fauna plays a relatively limited role in reducing the populations owing to the great breeding capacity of the species.

Monitoring

Normal conditions:

– Estimation of the density of overwintering chambers per linear metre of shoot in winter.
– Installation of pieces of pruning wood to monitor and estimate the extent of adult entry holes.

Conditions of severe drought:

– Monitoring for presence of trees on decline.
– Surveillance of initial appearance of entry holes on dying trees.

Management strategy

Normal conditions:

– Take good care of the orchard (tillage, pruning, fertilization,…) to keep the trees in good vigour.

– Leave bundles of wood under the trees for one month, then remove or burn.

– Keep pruning wood away from the orchards. If this is not possible, treat at the start of adult entry or exit by treating with insecticides (deltamethrine, oleoparathion, …).

Drought conditions:

– Prune withered parts of the tree in winter. Immediately install bundles of wood as bait and burn after one month; repeat this exercise if necessary (Fig. 11).

– In tandem, irrigate debilitated trees; repeat this exercise whenever necessary (Fig. 12).

– As a last resort, apply chemical treatment – decis-dimethoate – preferably upon the appearance of the adult entry holes (presence of sawdust) or upon their emergence.

Figure 11. Installation of bundles of wood as traps.

Figure 12. Irrigation of trees suffering from dieback.

‘A’ WEEVIL: *OTIORRHYNCHUS CRIBRICOLLIS* GYLL. *(COLEOPTERA, CURCULIONIDAE)*

Common names

‘A’ weevil; Otiorrhynche de l’olivier or Charançon (French); Escarabajuelo picudo (Spanish); Oziorrinco dell’olivo (Italian); Gorgulho (Portuguese); Soussat aourak azzaitoun (Arabic).

Geographical distribution

This species is distributed throughout the Mediterranean region and is adventive in California, Australia and New Zealand.

Originally of very secondary importance, it is growing in extent in intensive, irrigated orchards.

Host plant

Besides attacking the olive tree, this polyphagous weevil attacks several other plant species: fruit trees (apple, peach, almond, citrus, ornamentals (jasmine, privet, lilac,…), and several crops (cotton, artichoke, lucerne,etc.).

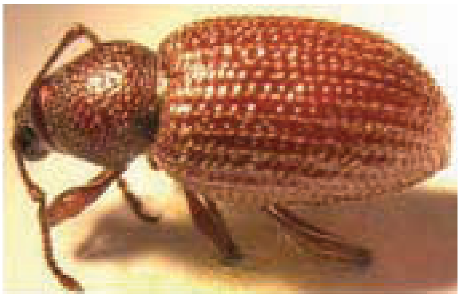

Figure 1. 'A' weevil adult.

Figure 2. 'A' weevil soil larva.

Description

– *Adult:* 6-9 mm long, oblong, shiny dark brown, with short, thickset rostrum. Nocturnal species displaying thelytoky parthenogenesis (Fig. 1).

– *Egg:* oval, smooth chorion, creamy when freshly laid, then turning blackish during incubation.

– *Larva:*

- Young larva: 1.5 mm long, light coloured, curved.
- Mature larva: 8-9 mm long, light yellow, rusty head with reddish brown mandibles, generally curved (Fig. 2).

– *Nymph:* 6-7 mm long, enclosed in an earthen cell.

Figure 3. Characteristic notched bites on leaves attacked by 'A' weevil.

Life cycle

– There is one generation a year.

– The weevils overwinter as larvae in the soil.

– Adult emergence begins in late spring (May) and continues into June. The adults are very active at night when they climb up the tree trunks and feed on the leaves, producing characteristic notched bites (Fig. 3). They then drop to the ground where they spend the daytime hidden in a wide variety of shelters (clods of earth, weeds at the base of the trunk, etc.) at a depth of 20-30 cm.

– Ovipositional activity:

Oviposition begins in September and continues until the approach of winter.

Symptoms and damage

The only damage is caused by the adults to the canopy, particularly to young shoots in young orchards. Damage usually goes unnoticed on mature trees.

Regulatory factors

Climatic conditions (high relative humidity, mild temperatures) combined with lack of cultural care under the trees, particularly in intensive and irrigated orchards, favours weevil breeding (Fig. 4).

Figure 4. Badly looked after intensive orchard (note weeds under canopies).

Figure 5. Strips wrapped around the trunk.

Management strategy

As a rule, no management is envisaged except in the event of heavy attack when the following measures can be recommended:

– Tillage or hoeing at the base of the tree trunks to turn the soil and destroy weeds and part of the larvae and nymphs they house.

– Placement of strips (sticky/non-sticky) around the trunks of the trees to capture the adults and stop them from reaching the foliage (Fig. 5).

Order: Acarina

ERIOPHYID MITES (*ACARINA*, F. *ERIOPHYIDAE*)

Mediterranean olive orchards are home to several species of plant-eating mites belonging to different families. The most important from the economic point of view are the Eriophyidae.

They were long considered secondary pests. However, for twenty years or so, extensive damage in some olive-growing areas has caught the attention of scientists who have been able to list 13 species to which the olive is a host. Of these, nine species to date are known to be eriophyids: *Aceria oleae* (Nalepa, 1900), *Oxycenus maxwelli* (Keifer, 1939), *Aculus olearius* (Castagnoli, 1977), *Aceria olivi* (Zaher and Abou-Awad, 1980), *Aculops Benakii* (Hatzinikolis, 1968), *Tegonotus oleae* (Natcheff, 1966), *Oxycenus niloticus* (Zaher and Abou-Awad, 1980), *Tegolophus Hassani* (Keifer, 1959) and *Ditrymacus athiasellus* (Keifer, 1960).

Geographical distribution of eriophyids

Figure 1. Aceria oleae *on lower surface of leaf* (from Chatti, 2006).

Aceria oleae (Fig. 1):

Species found extensively in the majority of the olive-growing countries: Jordan, Palestine, Israel, Cyprus, Greece, Spain, Italy, North Africa (Tunisia, Libya, etc.), South Africa, etc.

Oxycenus maxwelli (Fig. 2):

Species also found very extensively: North Africa (Algeria, Tunisia, etc.), Egypt, Italy, Greece, Portugal, California.

Oxycenus niloticus and *Aceria olivi:*

These two species have been reported in Egypt only (Fayoum) where they are found together.

Aculus olearius:

This species has only been reported in Tuscany and Apulia (Italy).

Aculops benakii:

Reported in Greece only.

Tegolophus hassani:

Reported in Egypt, Greece, Cyprus, Italy and Portugal

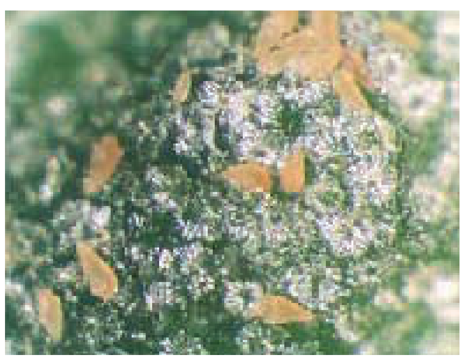

Figure 2. Oxycenus maxwelli *on upper surface of leaf* (from Chatti, 2006).

Dytrymacus athiasellus:

Reported in Italy, Greece, Algeria and Portugal.

Tegonotus oleae:

Species found on leaves in Bulgaria and on inflorescences in Greece.

Morphological and biological characteristics of eriophyids

Microscopic in size (100–350 μ), with sausage-like, elongate, two-part bodies with two pairs of legs.

Fertilization is external: the males deposit spermatophores on the plant which fertilize the females as they walk around. The females lay eggs.

Development from egg to adult goes through two stages (protonymph and deutonymph).

The eriophyids are all high-specificity plant pests and some species can transmit viruses.

Mite biology and damage are only known in the case of some species, in particular *Aceria oleae*, *Oxycenus maxwelli*, *Aculops benakii*, *Aculus olearius*, *Tegolophus hassani* and *Ditrymacus athiasellus*.

As a rule, single species are not found on their own in most countries; instead two or three are found together on the same leaves. As a result, it is hard to estimate the damage attributable to each species.

Nevertheless, three to four species appear to be more widespread: *Aceria oleae*, *Oxycenus maxwelli* and to a lesser extent *Tegolophus hassani* and *Ditrymacus athiasellus.* Roughly speaking, most eriophyids behave similarly in that their development is closely linked to plant phenology as they attack the most tender organs, beginning with the buds and leaves, then the flower clusters and lastly the young fruits.

The majority of the species overwinter as adult females hidden on buds and under the trichomes on the lower surface of the leaves.

At the resumption of vegetative activity in the olive (beginning of spring), which varies depending on the region, eriophyids quickly leave older leaves and invade shoots and young, newly-formed leaflets as springtime progresses.

Upon the start of flowering , they move first to the flower clusters, then to the young set fruitlets without totally abandoning the leaves.

After fruit set, some remain on the fruits while others continue their development on tender organs (young shoots, suckers, watersprouts,…).

Several generations (up to four) can succeed each other between the springtime and the approach of winter.

Symptoms and damage

Eriophyids can cause substantial damage affecting both plant growth and the volume and quality of olives and oil. Damage is worse when they attack young nursery plants because besides jeopardizing plant growth it spreads the eriophyids through new orchards. Damage can take the following forms:

– Tissue malformations and deformations after the mites bite the leaves, buds and shoots. Characteristic symptoms are now described:

- Light or yellowish green hollows on the lower surface of leaves and corresponding bumps on the upper surface in the case of attack by *Aceria oleae* and vice versa in the case of attack by *Oxycenus maxwelli* (Fig. 3).

Figure 3. Leaves infested by Aceria oleae *(note hollows on lower surface and bumps on upper surface).*

Figure 4. Eriophyid damage to buds and young shoots.

- Deformation of the leaf edges which become irregular (Fig. 3).
- Bud abortion and poor growth with weak shoots displaying short internodes (Fig. 4).

– Withering of leaves, buds and shoots in the event of heavy infestation (Fig. 5).

– Darkening and drop of flower clusters.

– Deformation of young set fruits, which may even affect the stone and produce deformed fruits (Fig. 6), which lowers the market value of table olives.

– Depreciation of fruit quality as olives become wrinkled after autumn attacks of the peduncle (Fig. 7).

– Lastly, eriophyid attacks lead to a decrease in oil yields (by up to 46%) and oil quality (lower chlorophyll and polyphenol content, decreased resistance to oxidation and higher acidity).

Figure 5. Shoot dieback on tree heavily infested by Aceria oleae *and* Oxycenus Maxwelli.

Monitoring

- Appearance of first symptoms on leaves visible to the naked eye.
- Sampling of young shoots from the beginning of spring to monitor female ovipositional activity and to estimate eriophyid density per leaf surface unit.

Management strategy

Little attention has been paid to management methods because acarids are considered secondary pests in the biocoenosis of the olive.

However, for some years now there has been an upsurge of eriophyid mites as a result of orchard intensification and insufficient sanitary control of nursery plants.

Control may be necessary when populations are high, given the extent of the damage caused:

- Preventive measures:

Use healthy plants when establishing new orchards.

- Remedial measures:

At present, these are limited to applying chemical treatments in the nursery and field.

Figure 6. Deformed fruits (from Chatti, 2006).

- Timing of treatment: generally the middle of spring.
- Products: various sulphur formulations, notably calcium sulphide (authorized in organic growing), various organic synthesis products (carbofenthion, vamidothion, carbaryl, keltane, dimethoate…), specific, selective acaricides (e.g. acrinathrin, organic sulphate and tin-based compounds, etc.) which have a limited action on auxiliary fauna, and fungicides to control eriophyids (in the case of mixed treatment targeted at olive leaf spot and eriophyids).

Figure 7. Olives wrinkled after eriophyid attack of peduncles (from Chatti, 2006).

In the event of repeated treatments, products should be alternated to prevent the occurrence of resistance phenomena.

7.4.3.2. Diseases

OLIVE LEAF SPOT: *SPILOCAEA OLEAGINA* (= *CYCLOCONIUM OLEAGINUM* CAST.)

Common names

Olive leaf spot, bird's eye spot, peacock spot ; Oeil de paon or Tavelure de l'olivier (French); Repilo (Spanish), Occhio di pavone (Italian), Olho de pavao (Portuguese), Aïn Taous (Arabic).

Pathogen

This disease is caused by the fungus *Spilocaea oleagina* which develops and forms colonies under the upper cuticle of the leaves. The colonies develop parallel to the leaf surface through very fine hyphae from which the conidia (usually two-celled) emerge (Fig. 1).

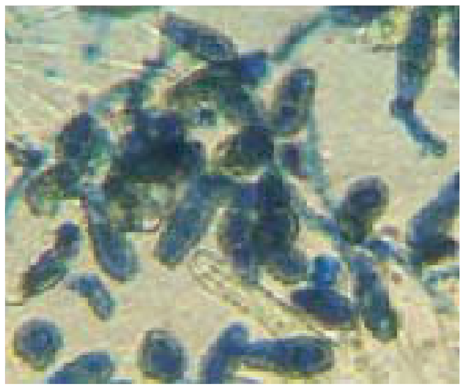

Figure 1. Olive leaf spot conidia.

Symptoms and damage

The symptoms of this disease are generally lesions on the leaf blade, petiole, fruit peduncle and fruit. These occur on the upper surface of the leaves in the form of small round blotches with a grey or muddy spot in the centre 6–10 mm in diameter, reminiscent of a peacock's eye (Fig. 2).

The most characteristic damage is to the leaves and eventually causes almost total defoliation. The shoots become almost bare, which leads to pronounced debilitation of the trees (Fig. 3). In the majority of cases, yields are affected by the small proportion of flower buds.

Figure 2. Typical olive leaf spot blotches on leaves.

Monitoring and risk prevention

Sampling

Weekly leaf samples should be taken throughout the year in areas affected by olive leaf spot. The method is to choose four adjacent trees at random as the primary unit. Five shoots are selected from each tree, from each of which two leaves are then taken. In all, there will be 40 leaves per plot, i.e. 200 leaves for the five plots which make up the observation field.

The Ip index is then calculated as the percentage of leaves displaying the typical blotches of the disease after being soaked for 25-35 min in a sodium hydroxide solution.

- In areas with a high risk of infection:

– If Ip ≥ 5% in summer ⇒ take preventive treatment before the autumn rains and in the following spring.
– If Ip < 5% in summer ⇒ do not apply any treatment until more spots occur.

- In areas with a medium risk of infection:

If Ip ≥ 5% in summer ⇒ apply only one treatment in late summer or early autumn.

- In areas with a low risk of infection:

Figure 3. Heavy defoliation of the Tunisian cv Meski, which is very sensitive to olive leaf spot.

Treatment is necessary if the climatic conditions are optimal for the development of olive leaf spot (saturated humidity and temperature of 18-21 °C).

Control

The management of this fungal disease entails taking cultural measures and chemical control.

Cultural measures

Preventive cultural measures include the following chief recommendations:

- Avoid planting the trees in damp hollows and keep a good distance between them
- Prune the trees properly to let air in
- Take cuttings from healthy trees
- Propagate and place the plants in a healthy, disinfected rooting medium (free from diseased leaves)
- Avoid applying nitrogen fertilizers, which tend to make the plant tissue thinner and less resistant to the disease
- If possible, collect and burn fallen leaves in infested areas
- Strengthen the resistance of the olive trees through balanced fertilization
- Grow varieties which are more resistant to the disease, particularly varieties with thick cuticles
- Prevent potassium deficiencies which are conducive to the development of the disease

Chemical control (authorized for organic production)

- As a preventive measure (in early spring and autumn), apply a copper-based fungicide or Bordeaux mixture (copper sulphate + hydrated lime) to the whole canopy once or twice.

- Repeat the application if there is more than 20-25 mm of rainfall (in one go or cumulative).

VERTICILLIUM WILT: *VERTICILLIUM DAHLIAE* KLEB.

Common names

Verticillium wilt; Verticilliose de l'olivier (French); Verticilosis del olivo (Spanish); Tracheoverticillosi (Italian); Maradth dhouboul Azzaitoun (Arabic).

Pathogen

Verticillium dahliae Kleb. (*V. dahliae*) is a highly polyphagous fungus which survives in the soil for many years (up to 14) as microsclerotia.

When observed under a photon microscope, the thallus has whorled conidiophores with groups of three or four phialides. The phialides have a mucilaginous mass at the end which burst on contact, releasing hyaline, single-celled, ellipsoidal conidia (Fig. 1). The black pigmentation is due to the presence of a large number of typical microsclerotia.

Symptoms and damage

On coming into contact with a root, the fungus sends out a filament which enters the vascular system of the tree. It develops by branching towards the aerial parts where it impedes sap circulation and causes withering of the part infested. Symptoms are sectorial, i.e. they are seen on the branches, on the scaffold branches or merely on a few shoots (Fig. 2). Verticillium wilt causes the unilateral decline of the infested parts, and the symptoms then become general. Young vigorous trees are particularly vulnerable.

The leaves on infested shoots roll inwards and turn light brown. They become brittle and can fall off. The olive fruits are heavily mummified but continue to hang from the diseased shoots (Fig. 3).

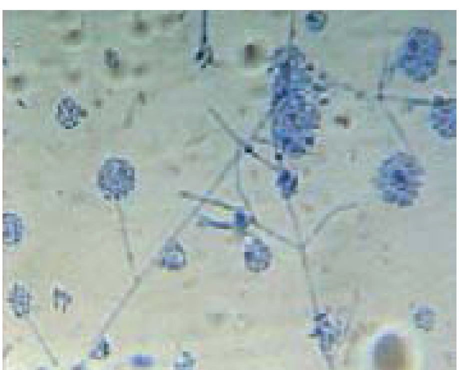

Figure 1. Verticillium wilt phialides and conidia.

Figure 2. Symptoms of verticillium wilt in olive.

The bark of the affected branches is often a violet brown colour, which progresses from the apex towards the base (Fig. 4).

Cutting the diseased tissue crosswise or lengthwise often reveals darkening of the wood (Fig. 5).

Monitoring and risk prevention

Sampling of olive trees showing symptoms of decline

- Take samples of wood from diseased trees from the living part below the necrotic area in order to isolate any pathogens.
- Take a root sample if necessary.

Disinfection and carefull isolation of the pathogen from the diseased organs in the laboratory.

Figure 3. Leaf rolling on infested shoots.

Control

Cultural measures

- Avoid intercropping market garden crops sensitive to verticillium wilt (*Solanaceae*, *Cucurbitaceae*, etc.).
- Avoid growing olives in soils in which crops conducive to the disease have been cultivated.
- Reduce tillage, keeping it superficial to avoid injury to roots.
- Apply balanced fertilization and irrigation.

Figure 4. Violet brown bark of infested branch.

Figure 5. Darkened internal wood.

– Remove and burn all withered shoots and branches during winter pruning and protect pruning wounds with a systemic fungicide.
– Carefully disinfect pruning implements after pruning each tree.
– Solarize the infested plots during the hottest part of summer to reduce the extent of the verticillium wilt inoculum in the soil.

Direct management (remedial)

Trunk injections of carbendazime (fungicide) appear to stop attacks for five months.

CERCOSPORA CLADOSPORIOIDES SACC.

Common names

Cercosporiose (French); emplomado (Spanish), Piombatura (Italian).

Pathogen

This disease is caused by the fungus *Cercospora cladosporioides* Sacc. The conidia are narrow and elongated and have a variable number of septa (Fig. 1).

Figure 1. Cercospora cladosporiodes *conidia.*

Figure 2. Typical blotches on leaves caused by Cercospora cladosporoides.

Symptoms and damage

Characteristic damage is observed primarily in the leaves in the form of a brownish colouring on the upper surface (Fig. 2) and lead-grey, irregularly shaped spots on the under surface (Fig. 3). The infested leaves eventually drop off.

Prematurely fallen leaves turn brown on the upper surface and grey on the under surface with darker patches where the fungal fruiting is located. This disease has also been observed in olive fruits, although less frequently, where the symptoms are round, reddish brown blotches between 3 and 15 mm in size.

The main damage is abundant leaf drop, which causes pronounced debilitation of the tree. The aerial part of the tree can be seriously injured, leading to decreased crop production.

Monitoring and risk forecasting

Attacks by this fungus are normally associated with attacks of olive leaf spot. The same preventive and remedial measures can therefore be recommended.

Figure 3. Irregularly shaped lead grey blotches on under surface of leaves.

Control

Chemical control

This disease has been controlled by spraying infested plots with Bordeaux mixture (2%) in early spring and late summer.

OLIVE ANTHRACNOSE: *GLOEOSPORIUM OLIVARUM* ALM ; *COLLETOTRICHUM GLOESPORIOÏDES*, (TELEMORPHIC FORM: GLOMERELLA CINGULATA (STONEMAN) SPAULDING & SCHRENK)

Common names

Olive anthracnose; Anthracnose des olives (French); Aceituna jabonosa (Spanish); Lebbra dell´olivo (Italian); Gaffa (Portuguese).

Pathogen

Gloesporium olivarum ALM. is a mitospore fungus belonging to the Coelomycetes group. It forms acervuli and unicellular, hyaline, elliptic, slightly curved conidia measuring 15-24 x 4-6 µm. The conidia remain viable for one year inside the mummified fruits at low temperature and probably act as the primary inoculum source. It is spread by rain which facilitates separation of the conidia from the fruiting body and their dispersion in the raindrops. The conidia always need free water to germinate. Fruit penetration takes place through the intact epidermis although infection is facilitated by the presence of lesions. In natural conditions, infection takes place at between 15 and 25 °C, although the optimum appears to be 23 °C at which the typical symptoms of the disease and the acervuli appear at 2-3 days and 5-6 days of inoculation, respectively.

Symptoms and damage

This disease generally affects the olive fruits, causing 40-50% weight loss, premature fruit drop and acidification of the resultant oil.

When ripe, the olive fruits have brown, roundish or irregularly shaped spots, which grow larger and may even join up. Attacks frequently start at the apex of the fruit which is where raindrops and dew accumulate. The progress of necrosis causes complete or partial rotting of the infected fruit, which dries up, shrivels and becomes mummified. The mesocarp becomes hard and leathery and does not take long to fall off.

The fungus can pass through the fruit peduncle to cause necrosis of young shoots (2–3 years old) and the ensuing development of cankers where the fungus forms its conservation structures.

At high ambient humidity, numerous acervuli develop on the infected parts of the fruit with the accompanying formation of a pink mucilaginous substance containing numerous conidia. The olive fruit looks soapy, which gives it its name in other languages (soapy olive).

Figure 1. Symptoms on olive fruits.

Monitoring and risk prevention

- Sampling of olive fruits displaying necrotic spots.
- Collection of samples of olives displaying lesions.
- Disinfection and laboratory isolation of infected part.

Control

- Collect and burn fallen leaves and fruits.
- Prune infested branches before the first rains.
- In endemic areas, apply preventive copper-based fungicides at the end of the summer or mixtures of copper oxychloride, Zineb (0.4%) and Bordeaux mixture (2%).
- Control *Bactrocera oleae* to reduce the development of the disease to the maximum.

SPHAEROPSIS DALMATICA (THÜM., BERL. MORETTINI) = *MACROPHOMA DALMATICA* (THÜM.) BERL. & VOGL.

Common names

Lèpre de l'olive (French); Escudete (Spanish and Portuguese); Marciume delle drupe (Italian).

Pathogen

Sphaeropsis dalmatica THÜM. is a mitospore fungus belonging to the Coelomycetes group. The chestnut brown mycelium forms black, ostiolate, unicellular pycnidia, which are globose or slightly piriform and measure 125-270 µm in diameter, inside which develop unicellular, ellipsoidal conidia 5-7 x 16-27 μm. These are hyaline at first and dark brown later. In conditions of high humidity, the pycnidia ripen and then the cirri emerge. The conidia are spread to the fruit by rain, wind and insects.

Figure 1. Olives on shoots showing characteristic symptoms of the disease.

Symptoms and damage

This disease solely affects the olive fruits when they are still green (Fig. 1). Roundish, ochre coloured lesions develop on the fruits, 3–6 mm in diameter; the centre looks dented and the edges clearly stick above the epidermis of the fruit (Fig. 2A). Pycnidia develop on the necrosed tissue. The disease sometimes spreads over the fruit, which becomes mummified (Fig. 2B) and is reminiscent of the symptoms of *Gloesporium olivarum* Alm.

The development of this disease is closely correlated with attacks of olive fruit fly and *Prolasioptera berlesiana* in that the conidia released by the pycnidia penetrate primarily through the entry and exit holes of these insects.

This disease is of little importance but can affect the quality of olive oil and table olives.

Monitoring and risk prevention

- Sampling of olives displaying necrotic blotches.
- Sampling of olives displaying lesions.
- Disinfection and careful laboratory isolation of infected parts.

Figure 2. Symptoms on the olive: (A) lesion on the fruit; (B) mummified fruit.

Control

- Because this disease is of little importance, plant pathologists have paid little attention to searching for means of control.
- Copper-based treatments for olive leaf spot are not effective against *Sphaeropsis dalmatica* THÜM. Hence, to avoid attacks from this fungus, steps should be taken to control olive fruit fly and *Prolasioptera berlesiana* because their entry and exit holes have an incidence on the development of this disease.
- To decrease the primary inoculum rate, growers are strongly recommended to collect and burn the olives that drop to the ground.

ROOT ROT FUNGI: *ARMILLARIA MELLEA*; *MACROPHOMINA PHASEOLI* (= *RHIZOCTONIA BATATICOLA*); *FUSARIUM OXYSPORUM*; *FUSARIUM SOLANI*; *PHYTOPHTORA* SP. *SCLEROTIUM ROLFSII*; *CORTICIUM SOLANI*; *ROSELLINEA NECATRIX*

Common names

Root rot; Pourriture des racines (French); Decaimiento del olivo or Podredumbre de las raíces (Spanish); Putrefazione delle radici or Deperimento dell'olivo (Italian).

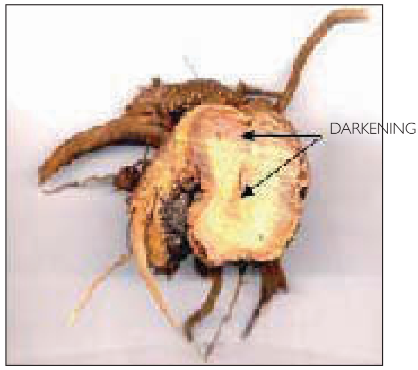

Figure 1. Internal tissue of the root of a young olive plant darkened by a combined attack of Rhizoctonia bataticola *and* Fusarium solani.

Pathogen

Several soil-borne fungi are the cause of root rot. These fungi remain in the soil in various forms (chlamydospores, oospores, sclerotia, etc.) for several years.

Symptoms and damage

The fungi infect the roots of the olive after penetration of the mycelium either directly or through injuries. From the root, the mycelium reaches and obstructs the xylem vessels. Transversal cuts show darkening of the sap conducting vessels often caused by *Rhizoctonia bataticola* and *Fusarium solani* (Figs. 1 and 2). This attack causes either general tree decline or solely withering of shoots. Young trees are generally vulnerable.

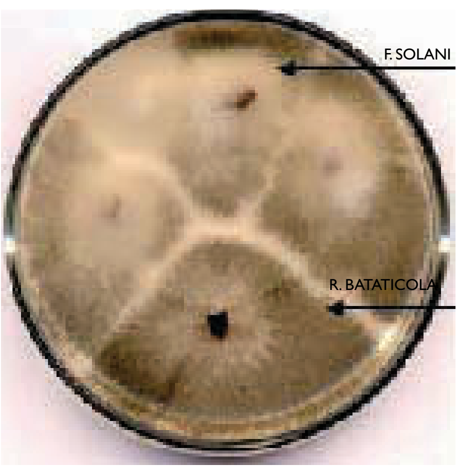

Figure 2. Mixed isolation of Rhizoctonia bataticola *and* Fusarium solani *from a rotted root.*

Figure 3. Withered new shoot on a young olive tree caused by Fusarium oxysporum.

Certain fungi such as *Fusarium oxysporum* and *Rhizoctonia bataticola* cause withering of new shoots on young nursery plants (Fig. 3). The infected plants exhibit rot and necrosis at the base of the trunk and in the bark of secondary roots (Fig. 4).

Figure 4. Root rot caused by Fusarium oxysporum *and/or* Rhizoctonia bataticola.

Monitoring and risk forecasting

Sampling of olive trees exhibiting signs of decline

- Sampling of roots to isolate any pathogens.
- Sampling of living wood above the necrosed area of shoots on diseased olive wood.

Disinfection and careful laboratory isolation from diseased organs

Management

Cultural measures

- Avoid intercropping market garden crops sensitive to soil-borne fungi (*Solanaceae, Cucurbitaceae,* etc.).
- Avoid growing olives in soils in which crops conducive to attacks by soil-borne fungi have been cultivated.
- Reduce tillage, keeping it superficial to avoid injury to roots.
- Apply balanced fertilization and irrigation.
- Use double basins to avoid water stagnation around the tree trunk (furrow irrigation).
- During winter pruning, remove and burn all withered shoots and branches.
- Protect pruning wounds with a systemic fungicide.
- Carefully disinfect pruning implements after pruning each tree.

Direct management (remedial)

- Pull out and burn plants that are totally debilitated.
- Renew the soil in the planting holes before replanting.
- At the beginning of infection (start of yellowing), treat trees by applying a systemic fungicide (active matter: benomyl, metalaxyl, thiophanate-methyl, etc.) in the irrigation water.

OLIVE KNOT: *PSEUDOMONAS SAVASTANOI PV. SAVASTANOI* (SMITH) (= *P. SYRINGAE PV. SAVASTANOI*)

Common names

Olive knot; Tuberculose de l'olivier (French); Tuberculosis (Spanish); Rogna dell'olivo (Italian); Tuberculose da oliveira (Portuguese); Maradh essoul (Arabic).

P. syringae pv. savastanoï was renamed *P. savastanoi pv. savastanoï* by Garden *et al*. (1992). This new nomenclature has recently been validated by Braun-Kiewnick and Sands (2001).

Description of bacterium

This motile, gram-negative bacillus (0.4-0.8 x 1.2-2.3 µm) has between one and four polar flagella. One of its characteristic features is that it produces fluorescent pigments in an iron-deficient medium such as King's B medium (Fig. 1). The bacterium produces an auxin (indol-3-acetic acid: IAA) encoded by a gene which may be carried by a plasmid in certain strains or by the chromosome in others.

Figure 1. Aspect of olive knot colonies.

Geographical distribution

Olive knot occurs in all the olive-growing countries and attacks other plants as well such as oleander (*Nerium oleander*), ash (*Fraxinus excelsior*), privet (*Ligustrum japonicum thunbi*), jasmine (*Jasminum spp*.), forsythia (*Forsythia intermedia zab*) and *Phyllera* sp. (Bradburry, 1986). Regions exposed to hail and frost are particularly prone to the proliferation of this bacterium.

Symptoms

Olive knot appears as rough galls or swellings (the "knots"). At first, they are soft, green and smooth. As the disease progresses they grow larger, becoming darker and ligneous. The galls usually develop on twigs, branches and scaffold branches (Fig. 2). They can also be found on the trunks of young trees (Fig. 3).

The severity of damage is closely linked to the number of galls on each tree. When infection is heavy, the infected shoots may lose their leaves and wither.

Epidemiology

The bacteria survive in the galls, which are an important reservoir for their conservation and dissemination. When it rains, they are extruded to the surface where they are washed out. Tissue is

Figure 2. Symptoms on a bearing olive tree A: scaffold branches; B: fruit-bearing shoot.

infected through wounds and scars caused by hail, pruning and defoliation. Inside the host tissue, the bacteria synthesize IAA which is responsible for cell proliferation and gall formation.

Control

The most effective means of control is to select varieties that are resistant to or tolerant of the disease.

However, prophylactic measures from tree planting to pruning are effective in helping to control this disease by affecting the initial bacterial inoculum. Hence, it is essential to:

- Choose pathogen-free plant stock.
- Avoid transporting plants and cuttings from diseased orchards.

Figure 3. Symptoms on young olive plants (A & B).

- Avoid harvesting and pruning in damp conditions (rain, dew).
- Harvest healthy trees first, avoiding injuries as much as possible. Pole harvesting causes wounds and is conducive to the installation of the bacteria and the dissemination of the disease.
- Prune healthy trees first, and then sick trees to avoid spreading the disease. Pruned wood from sick trees must be burned on the spot.
- Remove as many galls as possible.
- Apply copper-based products to pruning wounds and leaf scars, which will reduce the bacterial population considerably.

CROWN GALL: *AGROBACTERIUM TUMEFACIENS* (SMITH & TOWNSEND)

Common names

Crown gall; Tumeur du collet (French); Agalla del cuello (Spanish); Galla del colletto (Italian).

Description of bacterium

A. tumefaciens is a gram-negative, rod-shaped bacterium with rounded ends measuring 0.6-1 × 1.5-3 µm. It is non-sporing and motile thanks to six peritrichous flagella (Jordan, 1984). It produces large amounts of polysaccharides on sugar-containing media (Moore *et al*., 2001). The colonies are whitish, circular, convex and translucent (Fig. 1).

Figure 1. Aspect of crown gall colonies.

Geographical distribution

Crown gall basically attacks fruit trees. It has only recently been reported in olive in Jordan and Australia in galls formed on roots and the crown of young olive plants (Barbara, 2001, Khlaif, 2001). In Tunisia, the disease has been reported for the first time in the roots of cv 'Chemlali' in the region of Kairouan.

Symptoms

Symptoms take the form of spherical, whitish galls which are spongy to firm, with an irregular surface reminiscent of the inflorescence of cauliflower. As they develop, the galls rapidly grow larger, the surface becomes nippled and hardens and becomes cracked along the edges, and they turn darker (Fig. 2).

Epidemiology

The bacterium can stay in the soil for years. When the host plants are cultivated in infected soils, the bacterium penetrates the roots and/or base of the stem (or trunk) through wound sites caused by cultural practices or insects. Once inside the tissue, it develops intercellularly, then inducing the forma-

Figure 2. Galls on olive roots.

tion of the galls through its plasmid tumour-inducing (Ti) intermediary. Later, when the peripheral cell layers of the galls die and decompose, the infected debris containing the bacteria is washed away by rain and may infect new healthy host plants.

Cultural and biological management

All controls should be preventive in the nursery, because by the time the disease reaches the orchard it is too late. Nurseries should be established on soils that are not infected by the bacteria, and in the event of attack all the infected plants should be removed and burned. At the time of planting in the orchard, it is advisable to soak the roots of the plant in a suspension of the bacterial strain K1026 of *Agrobacterium radiobacter* which is antagonistic to phytopathogenic strains.

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Olive fruit fly *Bactrocera oleae*	**1. Trapping:** - McPhail trap baited with 3% diammonium phosphate (DAP). - Pheromone trap. - Yellow sticky trap. - Density 2-3 traps/ha (50-70 metres between traps). **2. Dissection of females (fertility):** 50 females/week. **3. Fruit sampling:** 10 fruits/tree from a minimum of 20 trees. **4. Climatic data monitoring** (maximum temperatures).	**Oil-olives:** 1st application: Captures: 5 adults/trap/day (for guidance, may vary according to region). Presence of fertile females (% varies according to region). Maximum favourable temperature (< or close to 30 °C). Following applications - Captures: 1 adult/trap/day (for guidance,may vary according to region). - Fertile females > 60 % (for guidance). - Fruit infestation > 5 %. **Olives for table production:** - Presence of fertile females. - 1st puncture mark on fruit.	- Installation of varieties sensitive to fruit fly as trap trees - Soil tillage to a depth of 15-20 cm under the canopy in autumn-winter to bury the pupae. - Earlier harvesting in event of autumn infestation.	- Mass trapping of adults at the start of the season (1st summer generation): 1 trap/tree or every 2 trees. - Release of *Opius concolor* at the start of the season: 500-1,000 parasites/tree (in event of small-medium population.	- Preventive treatment for adults: localised treatment with insecticide (decis) + food attractant, pheromone treatment, or treatment with products authorized in organic production (Spinosad, Kaolin, Bordeaux mixture, etc.). - Remedial treatment for larvae and adults (dimethoate). - Treatment of trap trees. - Autumn treatment deadline: late September-early October (one month at least before harvest).

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (contd)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Olive moth *Prays oleae*	**1. Pheromone trap:** 2-3 traps/ha (50-70 metres between traps). Installation: 1st generation: hot regions (late February); cold regions (late March). 2nd generation: late April (hot regions) to late May (cold regions). 3rd generation: early September. Change pheromone capsule for each generation. **2. Sampling:** - Flower clusters: 50-100/tree from 10-20 trees. - Fruits: 10-30/tree from 10 trees.	**Economic threshold:** <u>1st generation</u>: 4-5 % infested flower clusters. 2nd generation: 20-30% infested fruit (small oil-olives). Lower threshold for table olives. **Captures:** > 100/trap/week. Total capture/trap > 300 (varies according to region). **Egg hatching rates:** > 50% **Treatment timing:** 1st generation: first open flowers (start of treatment).	- Prune in December-January to reduce larval leaf-eating populations. - Till soil to a depth of 15-20 cm under the canopy in autumn to reduce the emergence of 2nd generation adults.	- Apply *Bacillus thuringiensis* or *Saccharopolyspora spinosa* (Spinosad-Tracer) for ground management of 1st generation (drench well) as soon as first flowers open. Apply exceptionally to combat the 3rd generation (L4) in the event of heavy infestation.	<u>Treatment of 1st generation</u> in the event of very heavy infestation: deltamethrin - dimethoate, trichlorfon… <u>Treatment of 2nd generation</u>: systemic product (dimethoate).

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (contd)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Leopard moth *Zeuzera pyrina*	**Trapping:** **Light trap:** 2- 3 traps/ha (150- 200 W) for flight monitoring of adults. **Pheromone trap** **Sampling:** - Late summer/early autumn: collection of young infested shoots from approximately 20 trees. - Late winter-early spring: survey of traces of mature larvae on trunk and scaffold branches.	Economic threshold: 5 larvae/8-year-old tree; 5-15 larvae on 20-year-old trees; 20-30 larvae on trees over 20 years old.	- Mechanically destruct the caterpillars in their galleries using iron wire (March-April). - Plug the gallery holes with modelling clay (late August -September). - Cut and burn infested shoots. - Remove heavily infested branches. - Retain sprouts from September to late December, then cut and burn them.	- Apply *Bacillus thuringiensis* or Spinosad to combat young larvae at start of penetration or inject into the galleries after the last migration to the branches and trunk. Mass trapping of adults: 10-20 light or pheromone traps/ha.	Treatment of young larvae in autumn: deltamethrin + dimethoate if necessary.
Jasmine moth *Margaronia unionalis*	**Pheromone trap** (being tested). **- Sampling:** % shoots attacked; density of eggs and larvae/ml of shoots.	Young trees: 5-10 % shoots attacked. Adult trees: start of attacks to fruits.	Remove sprouts from adult trees.	- Apply *Bacillus thuringiensis* or Spinosad as of the first infestations.	Deltamethrin as of the first infestations if necessary.

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (contd)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Pyralid moth *Euzophera pinguis*	- Flight monitoring by light, pheromone or food trapping. - Monitoring of pre-imaginal stages by scraping the bark.	- Extent of adult flight. - Density of larval galleries/ tree.	- Plug pruning wounds. - Look after trees properly.	- Apply microbiological products (Spinosad, *Bacillus*) to combat young larvae before they penetrate the bark.	Apply localised treatment to trunk and branches targeted at adults and young larvae before they penetrate the bark. Use a mix of organophosphorous products-mineral oil or decis-dimethoate for this purpose.
Black scale *Saissetia oleae*	**Sampling:** Ten shoots/tree from approximately 10 trees: => density of larvae and females/ml of shoot or leaf => pre-imaginal stages of the insect => frequency: every 15 days from May to October; every month from November to April.	**Threshold:** - 3-5 larvae per leaf. - 10 females/ml of shoot. Young larval stages	- Prune properly to let air into the tree, remove small branches and shoots which are heavily infested - Apply balanced fertilization avoiding excessive nitrogen	- Intensify the action of entomophagous fauna and avoid chemical treatments - Release entomophagous fauna: **Parasitoids:** *Metaphycus helvolus* *Metaphycus bartletti* *Metaphycus lounsbury* *Diversinervus elegans* **Coccinellidae:** *Exochomus quadripustulatus* *Rhizobius forestieri*	Treat with mineral oils, deltamethrin, methidathion (ultracide) if necessary.

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (*contd*)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Oleander scale *Aspidiotus nerii*	**Sampling:** 10 shoots/tree from approximately 10 trees => density of scales/ fruit.	**Threshold:** 10 scales/fruit. Stages: young larvae.	Remove heavily infested twigs.	- Intensify the role of entomophagous fauna and avoid chemical control. - Release entomophagous fauna: *Aphytis chilensis, A. melinus,* Coccinellidae.	Treat with mineral oils, Deltamethrin if necessary.
Olive scale *Parlatoria oleae*	**Sampling:** 10 shoots/tree from approximately 10 trees. - Visual inspection of scales on fruits.	**Table olives:** appearance of first scales on fruits.			Treat with mineral oils, deltamethrin
Olive psyllid *Euphyllura olivina*	**Sampling:** 10 shoots/tree from approximately 10 trees: => flower cluster infestation rate, => density of pre-imaginal stages/ flower cluster.	**Threshold:** 50-60% infested flower clusters or 2-3 larvae/flower cluster. - Appearance of first symptoms of cottony mass.	- Prune properly to let air into the tree. - Remove sprouts and suckers in summer and autumn-winter.		Treat young stages in spring (1st or 2nd generation): dimethoate, deltamethrin.

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (contd)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Olive borer *Hylesinus oleiperda*	- Adult flight: • Use muslin sleeves • Mark ovipositional patches - Scrape bark: insect stages	**Economic tolerance threshold:** - 5 egg-laying patches/ 10-year-old tree. - Appearance of 1st egg-laying patches on young trees. - Period: 15-20 days after the start of adult flight in the spring.	- Choose varieties resistant to the olive borer (new orchards). - Take good care of the orchard. - Prune properly. - Mechanically eradicate first outbreak sites.	- Intensify role of auxiliary fauna and avoid chemical control.	Treat adults in spring (15-20 days after the start of flight). Product: decis, decis-dimethoate.
Olive beetle *Phloeotribus scarabaeoides*	- Position pieces of pruned wood in the orchard (wood traps). - Sampling: density of overwintering cells/ml of shoot. - First olive borer attacks on debilitated trees. - Climatic data if possible (southern areas).	- Adult entry holes in the pruned wood or wood traps. - First olive beetle entry holes in debilitated trees.	- Place wood traps during pruning time for one month. - Collect and remove pruned wood and wood traps. - Prune properly (sickly trees). - Emergency irrigation of trees in the event of pronounced water deficit.		Treat piles of pruned wood or debilitated trees from the start of adult entry or exit. Product: methidathion (ultracide), decis, decis-dimethoate.

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (contd)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Otiorrhynchus cribricollis	Observation of first symptoms of attacks on leaves.	Observation of first symptoms on leaves.	- Till and hoe soil at the base of the tree trunk. - Place sticky/non-sticky strips around the trunk.		- Treat the soil at the base of the trunk. - Treat the trees late in the day. Product: deltamethrin (decis) if necessary.
Eriophyid mites	- Visual inspection of first symptoms on leaves and young shoots. - Laboratory sampling and observations.	Estimate of eriophyid density per unit of leaf surface.	Use healthy plants when establishing new orchards.		Treat with acaricides (sulphur, Acrinathrin…), alternating the products if necessary.
Olive leaf spot: *Spilocaea oleagina*	- **Leaf sampling:** 10 leaves/tree from approximately 20 trees (5 plots). - Early laboratory diagnosis by soaking in a soda solution.	5% infested leaves.	- Choose resistant varieties. - Prune properly to let air into the tree. - Avoid overhigh density of trees/ha. - Avoid excessive RH (hollows…). - Decrease nitrogen fertilization and avoid potassium deficiencies.		- Treat in spring before the first rains. - Treat in autumn before the first rains. Apply copper-based products/Bordeaux mixture.

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (contd)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods		
			Cultural	Biotechnical and biological	Chemical
Olive knot: *Pseudomonas savastanoi*	- Occurrence of hail. - Appearance of first symptoms.	Observations of first symptoms.	- Avoid making wounds (pruning, harvesting) in damp weather (rain, dew, …). - Cut the infected shoots and burn them. - Disinfect pruning implements. - Use resistant varieties.		Treat with copper-based products; Bordeaux mixture.
Verticillium wilt: *Verticillium dahliae*	- Visual inspection. - Laboratory examination of samples of sick wood and roots (if necessary).	Upon appearance of first symptoms decline in trees.	- Plant in disease-free soil. - Use disease-resistant varieties. - Avoid planting in soils previously planted to verticillium-sensitive crops (cotton, sunflower, tomato, potato,…). - Avoid intercropping market garden crops. - Avoid excessive fertilization (particularly nitrogen). - Grub and burn infected trees. - Decrease irrigation and tillage if the disease appears.	Solarize trees infested during the hot season.	- Inject carbendazime into the trunk (tested with success in Syria).

7.4.3.3. Summary of good practices in the management of the main noxious olive pests and diseases (contd)

Pest/ disease	Monitoring and forecasting methods	Treatment criteria	Recommended management methods: Cultural	Recommended management methods: Biotechnical and biological	Recommended management methods: Chemical
Cercospora cladosporoïdes	Appearance of symptoms of the disease.	Symptoms on leaves.	- Look after the trees properly and let air into the canopy. - Avoid excessive irrigation.		Apply 2% Bordeaux mixture in early spring and late summer.
Gloeosporium olivarum	- Collect samples of olives with necrotic patches. - Disinfect and isolate the pathogen in the laboratory.	Appearance of first symptoms.	- Collect and burn fallen leaves and fruit. - Prune affected branches before first rain.		- Preventive treatment with cooper-based fungicides in endemic areas: mixture of copper oxychloride (37.5%), Zineb at 0.4% (15%) or Bordeaux mixture at 2%.
Sphaeropsis dalmatica	- Collect samples of olives with lesions. - Disinfect and isolate the pathogen in the laboratory.	Appearance of first symptoms.	- Collect and burn fallen fruit.		- Control of *Bactrocera oleae* and *Prolasioptera berlesiana* helps to limit the disease.
Root rot	- Appearance of first symptoms of wilt. - Examine root samples.	Upon appearance of first signs of wilt.	- Grub and burn sickly trees. - Renew the soil in the planting holes before replacing grubbed trees.		At the start of attack treat the tree base with a systemic fungicide.
Sooty mould	- Check for presence of sap-sucking insects (scales, psyllid moth). - Visual inspections.	Appearance of symptoms on leaves.	- Let air into the tree. - Avoid planting in execessively damp hollows. - Avoid high densities/ha.	-	- Remove honeydew-secreting insects . - Treat with copper-based products in spring and/or autumn.

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8

Olive harvesting and mechanization

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8. Olive harvesting and mechanization

8.1. INTRODUCTION

Olive oil production increased sharply in the latter decades of the twentieth century and has continued to do so in the early years of this decade (Table 1). Higher production has been accompanied by higher consumption in all the countries. The roots of this increased usage of olive oil can be traced to the consolidation of traditional consumption in the producing countries and to the significant expansion of consumption in countries where production is small or non-existent owing to the agricultural system or climatic factors (Table 2).

Scientific recognition of its health-promoting properties, coupled with its taste attributes, has generated the widespread dissemination of olive oil, which is in growing demand worldwide. Nevertheless, the fundamental merits of olive oil are closely linked to its grade – extra virgin olive oils are the top quality – as well as to its antioxidant content and organoleptic properties.

The production of quality oil should therefore be a clear goal of every cultural practice in olive growing.

Higher levels of production and consumption have generated more international trading in olive oil. In this context, the amount and quality of oil available, production costs and wholesale and retail prices are decisive factors which, taken together, contribute towards the competitiveness of olive growing in each country. Clearly, olive growing will develop and progress in those countries where it earns the biggest profits in absolute terms or in relation to potential alternative crops in each region.

Periods of stagnation occur in olive farming when high production costs and low market prices translate into lost earnings for growers. In a marketplace characterized by the increasing removal of transnational barriers the emphasis will be on competitive prices. Globalization will tend to heighten competition, with the ensuing market impact of low production-cost oils provided that production and consumption are balanced. However, quality also affects the price of olive oil, and oils displaying specific properties will be able to command a price differential depending on their characteristics and popularity as well as on consumer earning power.

Olive growing can be expected to undergo further development in the near future aimed at producing more and better quality olive oil while paring costs. Globalization of the olive oil

TABLE 1
Recent olive oil production and consumption in traditional countries (thousand tonnes)

	Production			Consumption		
Country	Avge 1997-2000	Avge 2003-2006	Annual increase% 97-06	Avge 1997-2000	Avge 2003-2006	Avge annual increase %97-06
Algeria	38	41	1.3	41	40	-0.2
Argentina	9	14	5.3	7	5	-4.5
France	3	5	4.9	73	96	2
Greece	414	395	-1.4	255	269	0.5
Italy	532	699	2.9	698	807	1.2
Libya	5	9	6.6	8	10	2.8
Morocco	71	67	2.5	53	60	1.7
Portugal	43	34	-0.9	66	66	0
Syria	97	137	2.9	89	127	3.4
Spain	871	1033	3.6	512	591	1.5
Tunisia	197	170	-2.8	57	44	-4.2
Turkey	120	119	-0.7	76	51	-4.4
World	2,459	2,813	2	2,369	2,803	1.5

TABLE 2
Recent olive oil consumption in new consumer countries (thousand tonnes)

Country	Avge consumption 1997-2000	Avge consumption 2003-2006	Avge annual increase %97-06
France	73	96	2
United Kingdom	30	65	6,6
Germany	25	40	3,4
USA	148	209	2,6
Canada	19	25	2,6
Australia	21	32	3,1
Japan	28	31	0,6
Brazil	25	24	-1,4
World	2369	2803	1,5

market and competition will lead to the success and expansion of the businesses that are best organized and which have managed to interpret and cope with a changing sector.

8.2. MECHANIZATION IN THE DEVELOPMENT OF OLIVE GROWING

Mechanization has a strategic role to play in this international economic context of olive development, particularly because it lowers production costs and provides answers to major social and labour problems by overcoming the worker shortage and making cultural practices less tiring.

Labour is becoming in shorter supply everywhere and looks poised to continue to do so. This means there will be fewer and fewer people employed in olive cultivation. Another important aspect of mechanization is that it reduces the time and effort spent on cultural practices, so enhancing working capacity and occupational safety. Mechanization should be envisaged for all cultural practices in general, but particularly for those which have the greatest impact on production costs and which require the largest amount of labour.

When traditional methods are employed, harvesting accounts for between 50 and 80% of the costs of production of olive growing. It is also the cultural practice which comes up against the most problems in finding workers because a large number is needed in a short period of time. Owing to the seasonal nature of harvesting, fewer casual labourers are available and it is becoming more and more frequent for orchards to be left unharvested when they give low yields or when land or tree characteristics make harvesting difficult. It is necessary, therefore, to identify the opportunities offered by harvest mechanization and to determine the conditions in which machinery performance achieves product quality and job safety while cutting labour requirements and harvest costs.

8.3. OPTIMAL HARVEST TIME

Olive fruits should be harvested when the quantity and quality of oil are at their highest and machinery performance is most efficient. This is where the changes in the parameters of fruit ripening come into play. Through their stems, the fruits are supplied with the nutrients elaborated by the leaves, which they use for growth and for the synthesis of the oil and of the substances that enhance its quality. This process is active as long as the olives draw available nutrients from the tree.

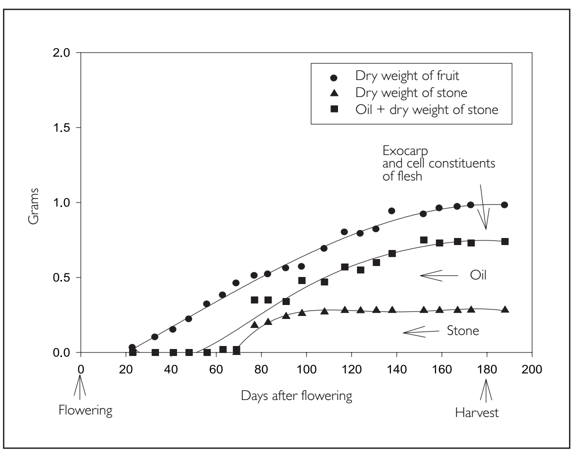

Figure 1. Changes in main constituents of the olive fruits.

The olive fruits grow sharply in the first 45-50 days after fruit set; growth then continues to be constant, but more moderate, until 130–140 days after fruit set. Dry weight, on the other hand, increases at a constant rate up to 140 days and then slows down significantly

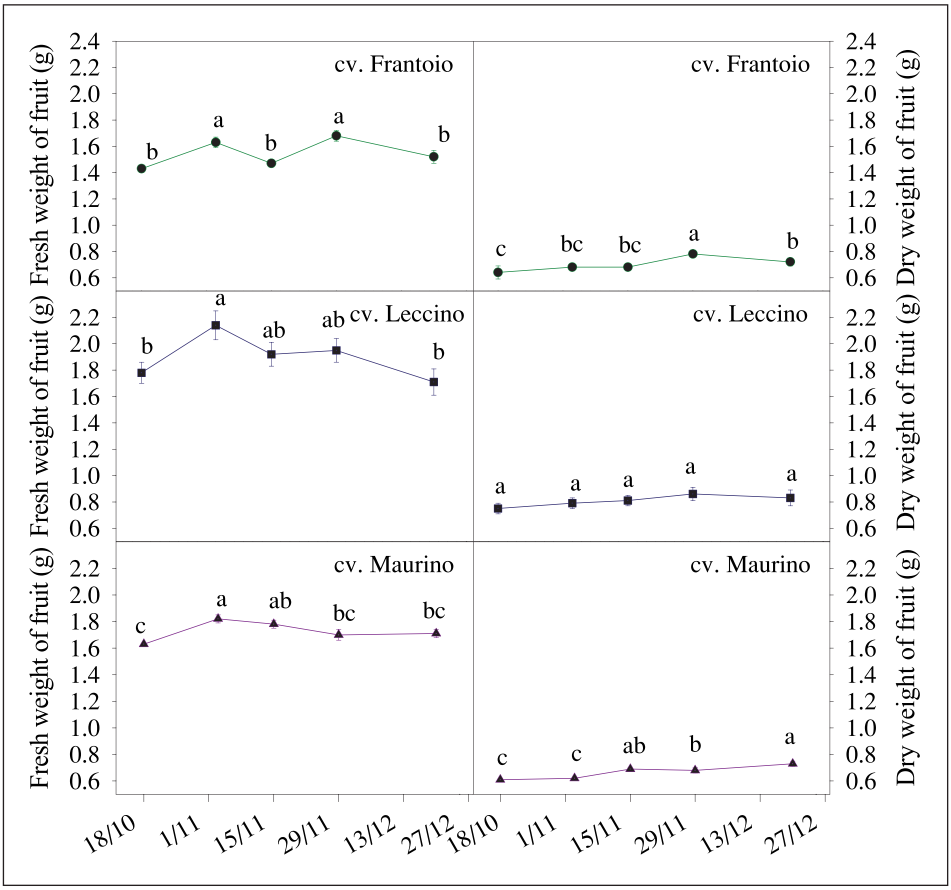

Figure 2. Changes in dry and fresh weight of olives in the final stage of ripening.

(Fig. 1). Oil formation begins 40 days after fruit set. Initially, oil accumulation is slow, but then becomes intense between 60 and 120 days of fruit set, only to slow down again. Over 120 days after full bloom olive fruit metabolism slows down and the processes of senescence begin, depending on the variety. Auxins decrease during this period and abscisic acid and ethylene appear. The binding layers of the middle lamella are weakened in some parts of the stem and cell wall disintegration occurs. This creates a separation layer which expands until eventually it causes the fruits to fall.

During the final stage of fruit ripening, major changes take place in the parameters which affect the quantity and quality of oil. These should be carefully monitored because they help to determine the optimal time to harvest.

The following factors should be taken into account to determine the quantity of oil:

1. Increase in fruit weight
2. Changes in oil content
3. Number of olive fruits on the tree and natural fruit drop

When determining quality, besides taking into account the main parameters envisaged for extra virgin olive oils (fatty acid composition, free fatty acids and peroxide value) it is important to bear in mind the polyphenol content, oxidative stability, colour and organoleptic attributes. These factors can be analyzed directly or by calculating maturity indexes, which provide a quick, simple indication of the stage of fruit ripening and are helpful for determining the optimal harvest time. Attention should concentrate on the final stages of fruit ripening, which lasts approximately two months and is when the olives can be harvested. During this period, the fresh and dry weight of the olive fruits are two parameters which affect the quantity of oil. They do not change significantly although a slight increase is recorded in dry weight (Fig. 2). What does increase considerably is the oil content because this period still coincides with intense oil formation, which later becomes less pronounced (Fig. 3).

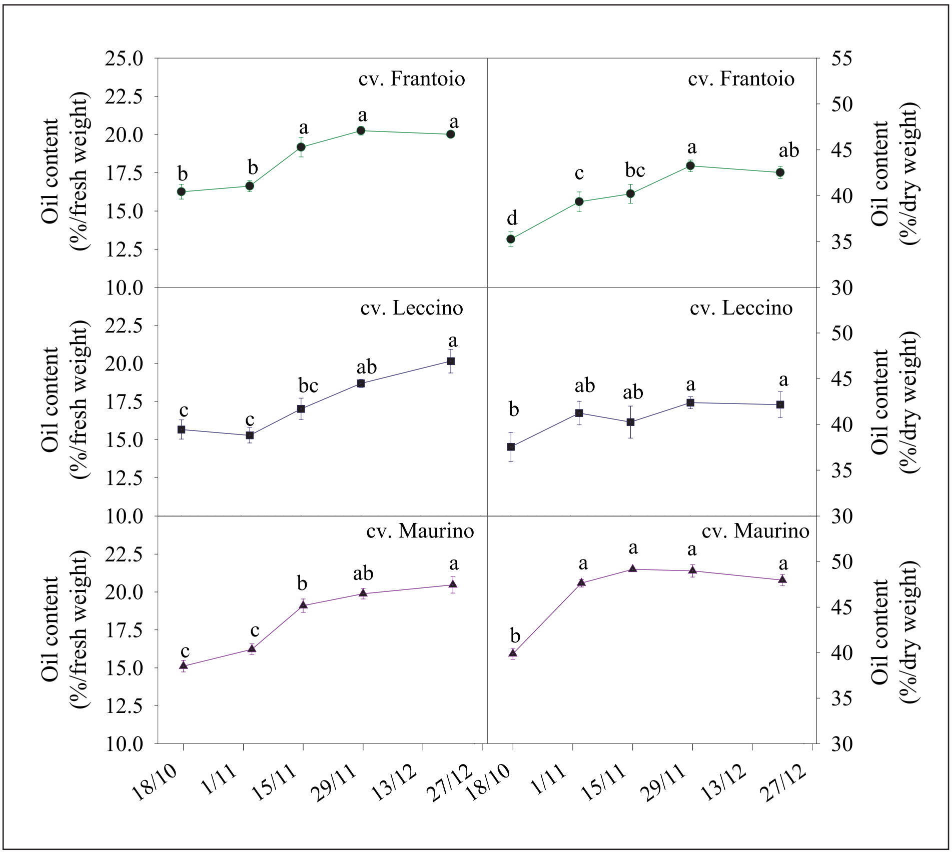

Figure 3. Changes in oil content in relation to fresh and dry weight in the final stage of ripening.

The point at which this switch from intense to limited oil formation occurs is a characteristic peculiar to each variety. For instance, it is early in cv. 'Maurino' (beginning of November) and intermediate in 'Frantoio' and 'Leccino' (end of November).

Where fruit efficiency is concerned, i.e. fruit attachment capacity to the tree shoots, fruit removal force (FRF) has to be evaluated. This is measured using a simple dynamometer and indicates cell at-

Figure 4. Wide-meshed bag for determining natural olive drop.

tachment force and cellular changes. When the fruits approach senescence, the FRF decreases so much that it only takes a light wind to knock the olives off the tree. Hence, natural fruit drop or abscission and FRF are two important indicators for defining the optimal harvest period. The experimental methods employed to determine natural fruit drop entail covering small fruiting branches with wide-meshed bags and regularly counting the number of olives which drop off the branches and fall to the bottom of the bags (Fig. 4). FRF is usually measured in sample trees every 10–15 days by using a dynamometer with a spiked sensor which is applied to the stem/fruit attachment point (Fig. 5).

FRF differs according to variety. It is approximately 6 N before the start of the processes leading to the formation of the fruit separation layer. During an intermediate stage it is around 4–4.5 N and then it drops below 3 N at the advanced stage of ripening. Natural fruit drop begins when FRF values are medium or low; it occurs when abscission of olives with a limited FRF is encouraged by strong winds or gales (Fig. 6). FRF values below 3 N are usually a sign of imminent fruit drop. When more than 5–10% of the olives has dropped off the tree, it has a significant impact on the quantity of oil obtainable. If the olive fruits are healthy, the level of free acidity and the peroxide value of the oil do not change during ripening. In contrast, the polyphenol content, organoleptic characteristics and colour can vary.

Polyphenol content is cultivar-characteristic. Changes in content tend to be bell-shaped, rising in the initial stage of maturation and later declining (Fig. 7). Polyphenol content is generally at its highest when the FRF starts to decrease. Optimal values should be above 100 ppm expressed as gallic acid.

Oil characteristics are basically defined by the sensations of fruitiness, bitterness and pungency or pepperiness (Fig. 8).

Fruitiness is more pronounced during the period of intense oil accumulation and starts to lessen when FRF tends towards intermediate values. Bitterness and pungency are characteristics of oils obtained from early-harvested olives. As a rule, balanced, prime quality oils are

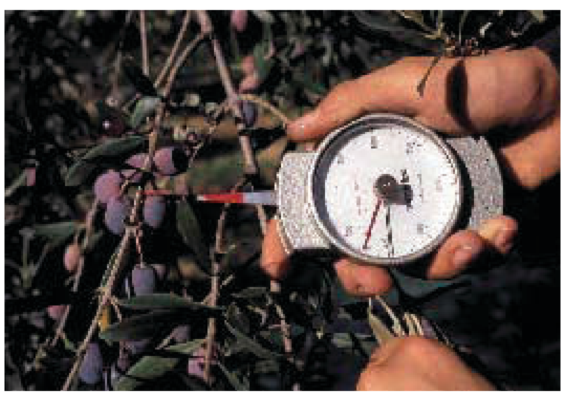

Figure 5. Dynamometer with spiked sensor for determining fruit removal force.

very fruity and display a balance between the bitter and pungent attributes which are noted at medium intensity. Tocopherols and sterols tend to decrease during the advanced stages of ripening. Palmitic acid decreases as ripening proceeds whereas linoleic acid increases and oleic acid rises or remains steady; as a result, there is a decrease in the ratio of monounsaturated to polyunsaturated fatty acids. Oil resistance to oxidation basically depends on the polyphenols present and varies according to their content.

The optimal time to harvest each variety (Fig. 9) can be determined by combining the parameters relating to the quantity and quality of oil obtainable. This period should span at least 10–15 days to allow harvest operations to be arranged. Measuring FRF helps to identify the optimal period in time. When 10-20% of the olive fruits has a FRF of less than 3–3.5 N, the separation process is at an advanced stage and the fruits can be expected to start falling off the tree between 10 and 15 days later.

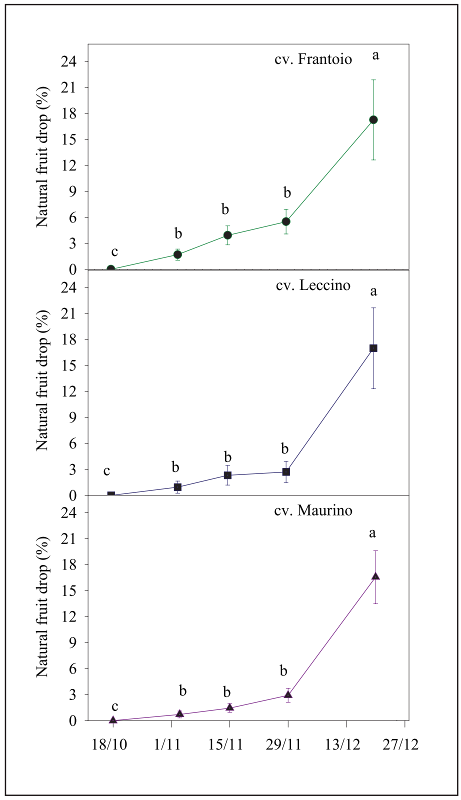

Figure 6. Changes in natural fruit drop.

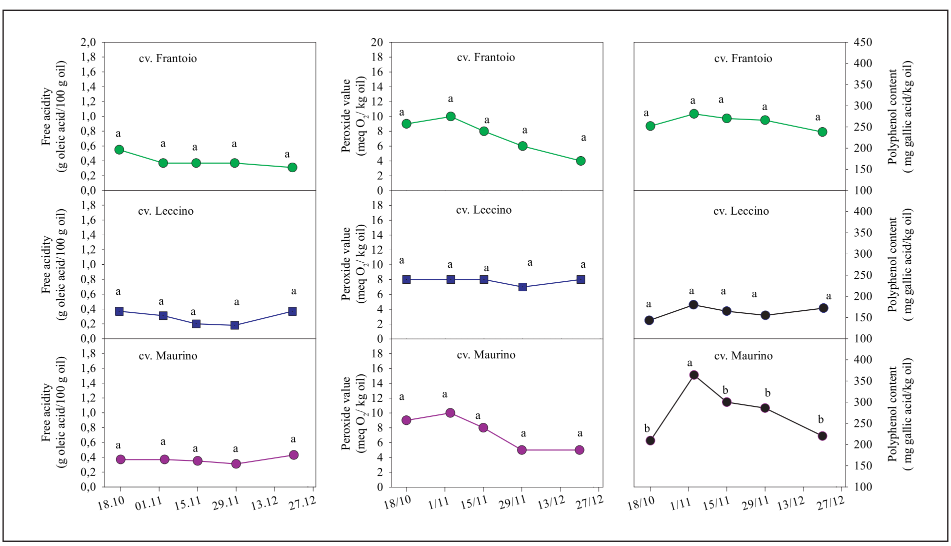

Figure 7. Changes in free acidity, peroxide value and polyphenol content of the oil during ripening.

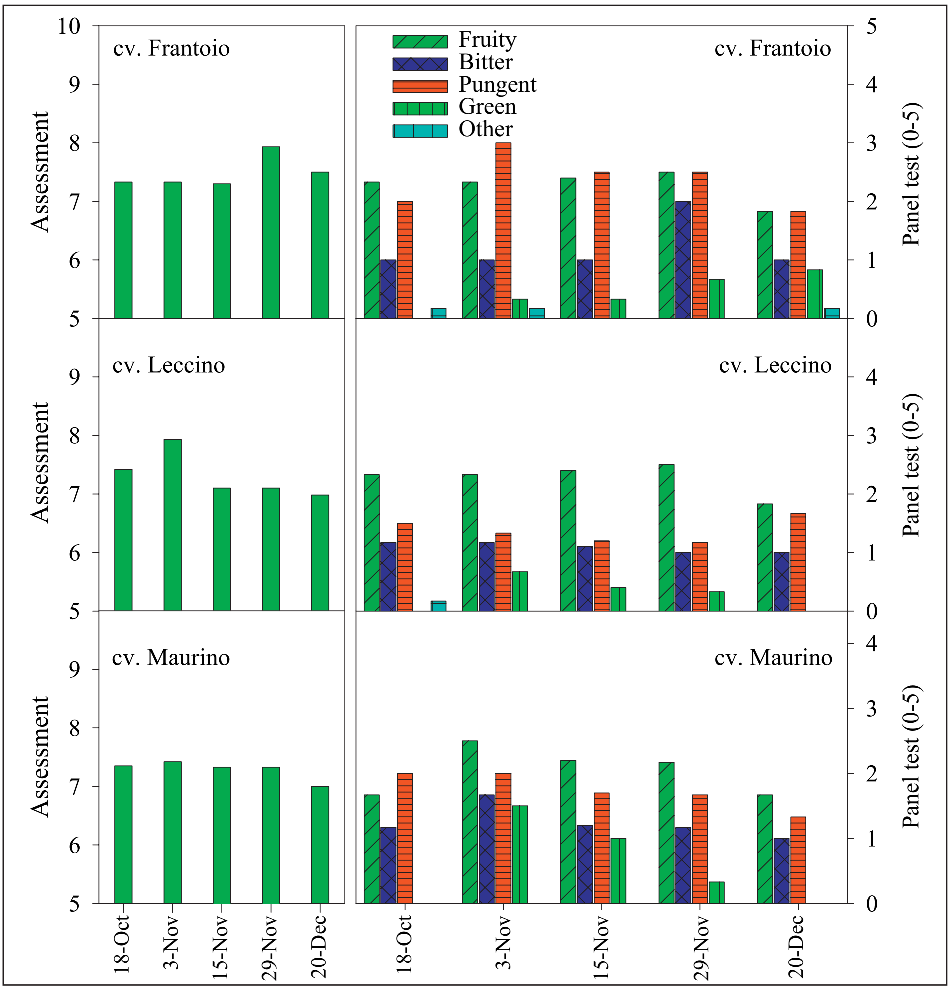

Figure 8.Changes in the organoleptic assessment of certain oil attributes during olive ripening.

It is advisable to begin harvesting when these conditions occur so that it is finished before 5–10% of the olives fall off the tree and there is not a significant reduction in the amount of oil obtainable. Organoleptic characteristics are also optimal in these conditions and likewise help to define the most suitable time to harvest.

The ratio between FRF and fruit weight is an important parameter which determines the percentage of olives which can be dislodged from the trees by almost all harvest machinery. Hence, the optimal harvest time can be defined as the period when a large number of olives on the tree have a high content of top quality oil and can be machine harvested.

Other fruit characteristics subject to variation are colour change (also known as veraison), fruit firmness and moisture content. Colour change differs in each variety. Some varieties may turn from green to violet early in the season while others remain predominantly green even up to advanced maturity. Colour change is affected by crop load and irrigation (Fig. 10). Fruit colour affects oil colour because part of the chlorophyll remains in the oil; conversely, yellow and orangey pigments predominate in oils obtained from olives which have changed colour.

Fruit colour is used to determine the maturity index, which expresses the average colouring of a sample of fruits. The Jaén index is the most widely used (Ferreira, 1979). It is calculated by collecting approximately 1 kg of olives at shoulder height from around the tree. A sample of 100 olives is then selected and the fruits are sorted into the following categories:

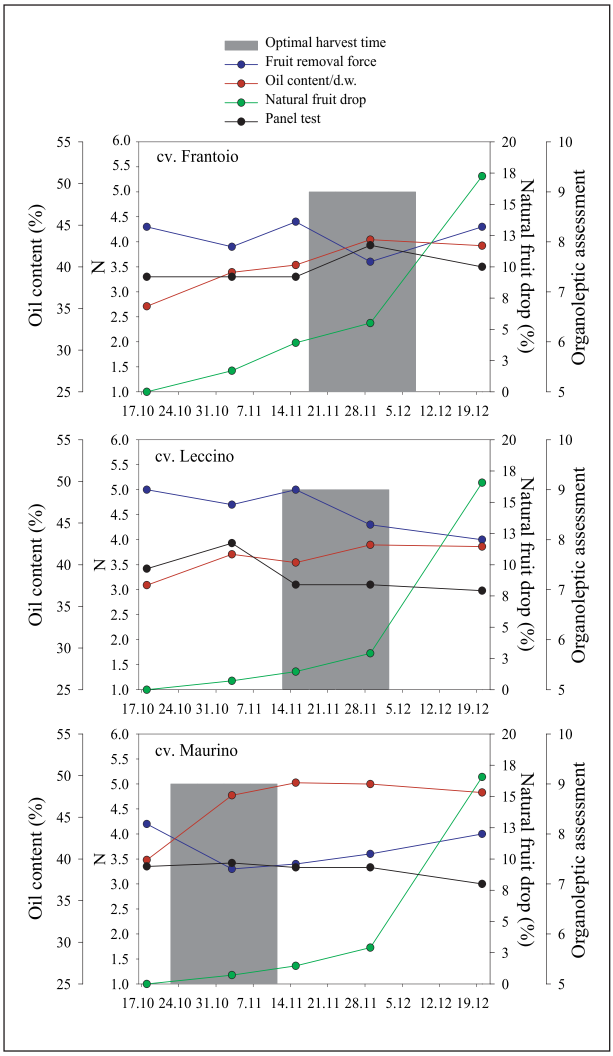

Figure 9. Optimal harvest time according to the most important maturation indicators.

0 = skin colour deep green
1 = skin colour yellow-green
2 = skin colour green with reddish spots on < half of fruit surface; start of colour change
3 = skin colour reddish or light violet on > half of fruit surface; end of colour change
4 = skin colour black with white flesh
5 = skin colour black with < half of flesh turning purple
6 = skin colour black with flesh turning purple almost through to the stone
7 = skin colour black with all the flesh purple to the stone

The number of olives A, B, C, D, E, F, G and H in each category 0, 1, 2, 3, 4, 5, 6 and 7 are counted and the maturity index is calculated as the weighted average of the values obtained:

Maturity index = (Ax0+ Bx1+ Cx2 + Dx3 +Ex4 + Fx5 + Gx6 + Hx7)/100

Fruit firmness depends on the stage of pectin polymerization. In this process the pectins turn from complex to simple and the flesh becomes softer as ripening advances (Fig. 10).

In these conditions the olive fruits are more sensitive to damage from product handling during and after harvest. Every effort should therefore be made to avoid bruising softly fleshed varieties, which should be crushed straight away for oil extraction to avoid product deterioration. A high content of moisture in the fruit makes the flesh less resistant and can affect oil extraction processes. Moisture content depends on variety, climatic conditions and cultural techniques. High moisture availability tends to delay fruit ripening.

Consequently, olives intended for oil production should be harvested at the optimal time when they are still hanging on the tree and they have a high content of good quality oil.

When the olives are intended for table olive production, the most important maturation indicators are the sugar content, pectin substances, fruit removal force, colour and the ease with which the flesh comes away from the stone.

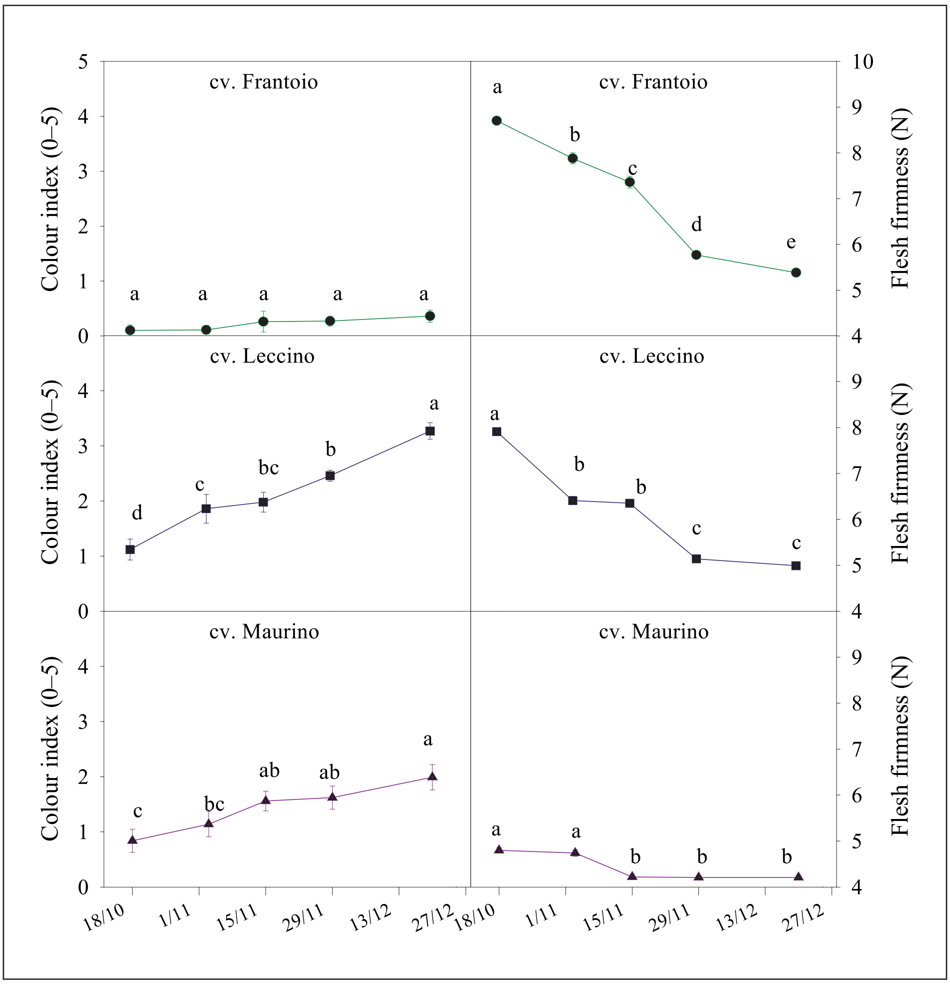

Figure 10. Changes in colour index and flesh firmness during olive ripening.

When the fruit is for processing as green olives, it should be from green to yellowish in colour (categories 0–1), none should have started colour change and the stone should come away easily from the fruit. If it is intended for processing as black olives, it should be a purple colour up to 2 mm from the stone, which equates with category 5 or 6.

8.3.1. Real-time determination of start of harvest

Monitoring the changes in the maturity indicators will help to pinpoint the exact time for harvest to start, or a few days in advance to allow the farm to get ready to begin at the right time. Monitoring includes checking the FRF and the changes in natural fruit drop. These two parameters are easy to determine and can predict when to begin harvesting and how long it will last before natural fruit drop or fruit quality leads to deterioration of the end product.

The harvest period depends on the working capacity of the harvest setup or of the farm. Mechanization speeds up harvest operations, helping to concentrate them in the best period. It has to be remembered that adverse climatic conditions can hinder harvesting and that low temperatures can damage the fruit and affect the quality of the oil. When harvesting is expected to be spread over time, it is preferable to bring it forward to make sure that the product harvested is good quality.

8.4. HARVEST MECHANIZATION

Harvest mechanization has proved to be the sole way of lowering production costs, making up for the shortage of labour and attenuating the problems caused by adverse weather conditions. However, to make harvesting more efficient, it is necessary to examine the scientific advances applied to machinery mechanisms and olive response and to take into account the agronomic aspects of the crop in order to make the cropping model chosen as functional and productive as possible.

8.4.1. Fruit detachment

Olive fruits are dislodged by forces of traction, flexion and torsion acting on the fruit–stem–shoot system.

In traditional hand harvest the olives are detached mainly by traction. When harvested by beating, forces of traction and flexion are transmitted; the same is the case when streams of air are applied.

Machinery which produces vibrations causes torsion in addition to traction and flexion. Of the many attempts made in recent decades, the vibratory method has been the most effective in dislodging fruit. Initially, the vibrations were produced by cable or mallet shakers or knockers; inertia shakers later made their appearance and are used extensively nowadays. By rotating eccentric weights this last type of shaker generates vibrations with a frequency of up to 30–40 Hz and an amplitude or stroke of a few millimetres (Fig. 11). The stroke depends on the mass and weight of the eccentric masses as well as of the mass of the shaker and of the limb being shaken. Experimental trials have demonstrated that $S = 2mr/(M_{shaker} + M_{limb})$ where S = peak-to-peak stroke in m, m = eccentric mass of shaker in kg, r = eccentricity of shaker in m, M_{shaker} = total mass of shaker and M_{limb} = effective mass of limb in kg. The fruit is dislodged when effective combinations of frequency and stroke generate sufficient acceleration to detach the olives, which is achieved more easily with resonance frequencies of the system or multiples of them. The components of the forces which generate torsion dislodge the fruit more easily than those which produce solely traction or flexion. Consequently, the vibrations delivered at the shaker attachment point should be transmitted through the fruiting area so as to widen the stroke and cause forces in horizontal and vertical directions.

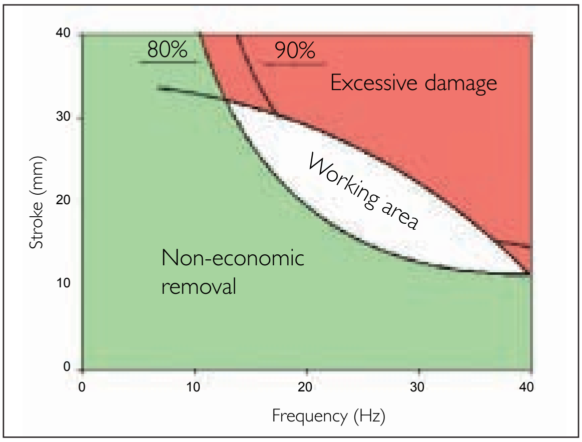

Figure 11. The working area of inertia shakers corresponds to effective combinations of frequency and stroke to achieve satisfactory fruit dislodgement while avoiding tree damage.

The most widespread shakers found nowadays are basically made up of two eccentric masses rotating in opposite directions or one single eccentric mass rotating around an axis. Both options make for effective combinations based on a wide stroke amplitude in the one case and a high frequency in the other. The second type of shaker is easier to construct and requires lighter supporting structures.

8.4.2. Types of machinery

8.4.2.1. Mechanical harvest aids

These small machines are carried by the operator and applied directly to the canopy. They are mounted on long handles up to 2–3 m in length and driven by 12–24 V electric engines, compressed air or small endothermic engines. They can be divided into the following categories:

1. Battery-operated aids:

(a) Rod harvesters with 4–6 straight or curved oscillating rods mounted on a head and subjected to reciprocating motion or made to rotate around their own axis. They weigh just over 2 kg (Figs. 12 and 13).

(b) Rake harvesters with 10–12 undulating tines, 17–30 cm in length, which turn simultaneously as they move up and down the canopy, dislodging the olive fruits in the process. They weigh between 1.2 and 2 kg (Fig. 14).

(c) Rake harvesters with eight metal reciprocating tines and mounted on extensions (Fig. 15).

Figure 12. Straight-rod harvester.

Figure 13. Curved-rod harvester.

2. Pneumatic aids:

These are vibrating combs made up of two sets of 3–6 plastic teeth which are oscillated at a medium frequency by means of cylinders of compressed air (Fig. 16).They directly comb the olive fruits or fruit-bearing shoots.

They are equipped with extension handles to allow access to high parts of the canopy.They are connected to air compressors and can also be operated by battery or autonomous engine.

3. Small shakers:

These have an oscillating rod which is clamped onto small branches (Fig.17).The vibration is produced by a crank connected to an endothermic engine. Stroke amplitude is around 50 mm and the strokes are produced at a frequency of 1,000–1,500 per minute.

Figure 14. Rake harvester.

8.4.2.2. Mechanical beaters

(a) Beater with flexible teeth between 1 and 1.5 m in length, fitted onto an oscillating plate (Fig. 18).

It moves inside the canopy to explore the fruit-bearing areas and dislodge the fruit onto nets spread on the ground.

Figure 15. Metal tine rake harvester.

Figure 16. Pneumatic comb.

(b) Beater with an oscillating reel-type head fitted with semi-rigid teeth which turn at a specific angle at a frequency of approximately 700 oscillations per minute. They can reach a height of 8–9 m and rotate 360° (Fig.19).

(c) Vibrating shaker with a shaft fitted with stiff radial rods (Fig. 20) and rotating eccentric masses which generate high-frequency vibrations. It is run over the canopy where it shakes the fruit-bearing shoots.

8.4.2.3. Inertia trunk shakers

These are divided into:

(a) Shakers with two vibrating masses which turn in opposite directions and which are driven by two independent hydraulic engines arranged in line or on the top and bottom of the supporting structure (Fig. 21). They create multi-directional vibrations and use powers of 30–50 kW; the vibrations have a frequency of 15–30 Hz and an amplitude of 20–30 mm. The shaker head weighs a total of 400–600 kg.

Figure 17. Mechanical hand-carried shaker.

Figure 18. Oscillating rod beater.

Figure 19. Reel-type beater with radial rods.

Figure 20. Vibrating reel.

Figure 21. Shaker with two vibrating masses and two engines.

(b) Shakers with two vibrating masses driven by a single hydraulic engine (Fig. 22) by means of a drawback pulley. The two masses can differ in weight and turn at different speeds. The working features are similar to those described in (a).

(c) Shaker with one vibrating mass driven by a hydraulic engine. They work at high frequencies over 20 Hz and generate orbital movements. They weigh between 100 and 300 kg, require 30–50 kW of power and are easy to manoeuvre. (Fig. 23).

8.4.2.4. Over-the-row or straddle harvesters

(a) Modified grape harvesters

The side-shaking harvesters found extensively in grapevine growing have been adapted for olive harvesting by increasing the number of shaker bars from 4 to 10–12 (Fig. 24). The size of the shaker cage, which normally measures 0.8 m wide and 2.00–2.5 m high, has also been adapted. In some models, the height has been increased to a maximum of 3.5 m (Fig. 25). In others the shaking system, which operates at a frequency of 400–500 cycles per minute, has been improved by varying the curvature of the beater rods. The fruit

Figure 22. Shaker with two eccentric masses and one hydraulic engine.

Figure 23. Shaker with a single eccentric mass.

catching device has also been rationalized by using differently shaped bucket chains and bins to reduce product losses.

The machines are equipped with auto-levelling, anti-skid systems to guarantee stability even on sloping land. Fruit can be harvested above 15 cm from the ground. It is cleaned by two fans and run into two containers with a capacity of 1600 litres each.

(b) Modified coffee harvesters. This type of machine has two upright shafts fitted with plastic radial rods which move over the canopy (Fig. 26). The shafts are subjected to vibration, which is transmitted to the fruit-bearing shoots and causes the detachment of the olives.

(c) Giant over-the-row harvesters

The height and width of machinery has been increased to overcome the difficulties encountered when olive canopies are larger than what grape harvesters can cope with. A first prototype was brought out in Italy in the 1990s but did not take off because of the difficulties in moving it from one olive orchard to another and because of problems of fruit catchment and machinery reliability. One machine of this kind is the Colossus harvester found in Australia and Argentina (Fig. 27). It has a 4 x 4 m frame with side vibrating rods which slap the tree canopy.

8.5. FRUIT CATCHMENT AND HARVEST EFFICIENCY

When the fruit has been detached it has to be collected and sent to the storage or processing facilities. The dislodged olives are caught on plastic nets of differing mesh size and thickness, which are moved by hand or by semi or fully mechanized means.

Figure 24. Modified grape harvester.

Figure 25. Shaker featuring larger shaker cage.

Figure 26. Modified coffee harvester.

Figure 27. Giant over-the-row harvester.

8.5.1. Mechanical aids and nets

When mechanical aids are going to be used, nets are usually spread underneath the trees by hand over a larger area than the tree to catch any fruit that drops outside the canopy projection area (Fig. 28), and they are later moved by hand. Work productivity is approximately 100 kg of olives per hour and operator.

Mechanical aids facilitate harvest by carrying out specific operations such as fruit detachment, using sources of energy external to the operator. They are a first step towards mechanization and achieve removal rates of 80–95% depending on when they are used and the FRF. They work well in areas of the canopy close to the operator; however, when extensions are used to reach high sections of the canopy they are overtiring for the operator and rates decrease. Generally, mechanical aids double harvest efficiency with respect to hand picking with plastic rakes, raising it from 10–15 kg/hour/worker to 20/30 kg/hour/worker. Hence, they help to reduce labour use in part, but owing to worker fatigue they can only be used on small areas and not continuously.

Figure 28. Harvesting with mechanical aids and nets.

8.5.2. Mechanical beaters and nets

Mechanical beaters can be used on different types of limbs (Fig. 29). They are operated by a single worker and all the movements are performed mechanically. Nets need to be used to catch and hold the fruit. The beaters harvest the canopy in portions, which means they have to be moved to explore the entire fruit-bearing shell. Consequently, beating is quite a lengthy process on each tree. Fruit removal is medium-to-high and depends on the harvest period, fruit size and FRF.

Figure 29. Mechanized beater with nets.

Work productivity is around 40–50 kg/hour/worker. These aids are used extensively in areas where there is a predominance of olive trees not suited to other kinds of mechanization. Nets are used to catch and hold the olive fruits. As positioning and moving the nets is basically a manual operation, limited mechanization is required.

8.5.3. Trunk shakers and fruit catchment

(a) Trunk shakers and nets

Two nets measuring approximately 10 m x 6 m are placed on either side of the tree. This operation is carried out by 4 +4 operators who move the nets from tree to tree (Fig. 30) and load the fruit directly into trailers or bins. Drawbacks are that it is hard to synchronize shaking and net positioning; also, moving the nets is tiring when working on sloping land or wet ground. Work productivity is approximately 60–80 kg of olives/hour and worker.

Figure 30. Trunk shaker with nets.

(b) Trunk shakers with semi-mechanized catching frames

A catching frame consisting of a trailer with two side rollers for rolling in and out the plastic nets has been developed to cut the labour required for net handling (Fig. 31).

Figure 31. Trunk shaker with semi-mechanized catching frame.

The nets are pulled out manually and positioned under the tree canopy, which is near the trailer. When the shaker has dislodged the fruit, two operators lift up the nets by the edges and unload them into crates in the trailer (Figs. 32 and 33). Work productivity is higher with this method, lying at around 100–120 kg of olives per hour and operator.

(c) Trunk shakers and wrap-around catching frames

The frame, which is rather like an upside-down umbrella, is attached to a bin which is placed underneath the shaker almost at ground level. As the shaker removes the fruit it runs into the bin, which has a capacity of 150–200 kg. When the bin is full, the olives are unloaded into a larger bin or trailer (Fig. 34). This method effectively combines shaking and catching and achieves rates of 200–400 kg per hour and operator; however, the orchard layout has to be suited to this method and the canopy of the trees must not be too large.

Figure 32. Manual lifting of the sides of the catching frame.

(d) Parallel, along-the-row trunk shakers and catching frames

This system entails two vehicles which move along the row parallel to each other; one carries the trunk shaker and the other the catching frame (Fig. 35). These machines adapt to different sizes of trees, reach a good working speed and are easy to transport.

Figure 33. Semi-mechanized fruit catching and storage of the olives in crates.

Trunk shakers are important in mechanical harvesting because they dislodge a large percentage of fruit, taking a few seconds to do so per tree. Much effort has focused on upgrading them to make them more efficient and reliable and easier to maneouvre and to adapt them to different kinds of olive orchards.

Shaker efficiency has been improved by employing optimal stroke/frequency combinations, by using high powers (50–80 kW) and by reducing the shaker head mass. Reliability has been improved by simplifying their constructional characteristics and by using more resistant materials. Shaker head

Figure 34. Shaker with wrap-around catching frame.

Figure 35. Shaker and catching frame working in parallel along the row.

attachment has been improved by using wrap-around clamps and bark damage has been reduced by employing softer, larger pads.

Shaker manoeuvrability has been significantly improved by using lighter shaker heads. As a result, they can be mounted on medium-sized tractors, which broadens the scope for their use. The advent of light shaker heads has led to diversification of trunk and scaffold branch attachment, so facilitating their use on large or irregularly shaped trees. Harvest rates vary from 70 to 95%, depending above all on agronomic aspects of the trees and harvest.

The success of trunk shakers has been further consolidated by the developments in fruit catching frames. With work rates of around 80–100 kg/hour/operator, net positioning slows down harvesting, besides being tiring and requiring a large number of workers. One first improvement was therefore to introduce semi-mechanized catching frames, which cut labour requirements by half and made the job less tiring. As a result, rates increased to 150–180 kg/hour/operator. But the most important step forward was when wrap-around catching frames came into use, fully mechanizing harvest operations. Minimum labour is needed (two per operation), harvesting is much less tiring and work productivity rates of around 200–400 kg per hour and operator are achieved depending on orchard crop production. However, such results can only be obtained if the orchards are suited to this kind of mechanization, which is therefore an important point of reference in olive harvesting.

8.5.4. Over-the-row harvesters

The great advantage of over-the-row harvesters, which are modified versions of grapevine harvesters, is that they operate continuously at a speed of 0.3–1 km/hr. They have a high vibratory efficiency when used on trees of limited canopy size, removing 90–95% of the fruit even when the varieties are small and FRF is high. Tree size is a big problem in this kind of harvest system because grape harvesters can handle trees with a maximum height of 2.00–3.50 m and a width of 0.80–1.20 m. It is difficult to keep many of the varieties cultivated to this size over a length of time. To date, good results have been obtained for the 'Arbequina', 'Arbosana' and 'Koreneiki' varieties which have below-average vigour and a high fruiting capacity. Besides vigour control, this system also still comes up against problems of damage, pest and disease control, the need for constant crop production and orchard lifetime. Extensive experimentation is required into all these conditions. Work productivity is closely linked to crop volume as harvest operating time works out at around 3 hours per hectare.

Giant over-the-row harvesters have not taken off in Europe; however, they are more widespread in Argentina and Australia and can harvest larger trees than the standard size of harvesters. The results are promising but, owing to their size and cost, these kinds of machines can only be employed on large estates. Other prototypes adapted to large trees are still being streamlined to achieve acceptable fruit removal rates and times.

8.6. AGRONOMIC FACTORS

Orchard characteristics are the factor which has the greatest impact on the spread of mechanization. Two types of machinery have proved to be highly efficient for mechanization purposes: shakers and over-the-row harvesters.

Specific requirements have to be met to use trunk shakers. These are now listed:

8.6.1. Orchard productivity

This is a fundamental factor because machinery performance is related to the number of trees or crop area. The higher the level of crop production, the higher the harvest rate of the machinery. Hence, in a mechanized olive orchard, productive efficiency is essential to achieve satisfactory machinery performance and good economic results. This makes it necessary to apply all the options and techniques which encourage better crop production. Olive orchard productivity has a direct impact in lowering production costs. According to the conditions existing in each area, minimum levels of 45 kg of olive have been determined for Spain (Herruzo Sotomayor, 1986), 30 kg for mainland Italy (Paschino *et al.,* 1976) and 15 kg for Central Italy, below which mechanical harvesting is not advisable.

Crop genetic factors and soil and climatic conditions have a bearing on orchard productivity. One of the top requisites for obtaining bigger crops is to grow the best varieties in areas suited to olive growing.

Cultural practices should allow the genetic and environmental characteristics to express their full potential.

8.6.2. Shaker attachment point

Shakers can be attached to the trunk or limbs of the tree (Fig. 36). Larger shakers are employed for trunk shaking, which they accomplish in a short time; however, when shakers are attached to the scaffold branches, they take longer and fruit catching mechanization is more complicated.

In short, the limbs of large trees can be shaken, but the costs involved are higher than when the shaker is clamped to the trunk.

Figure 36. Application of light shaker head to limbs.

8.6.3. Canopy volume

Trunk shakers perform well on canopy volumes of up to 40–50 m^3; at higher volumes performance decreases. Such volumes can easily be obtained in all varieties. This is therefore a feasible requirement, which is fulfilled when tree conditions are balanced. It does not place limitations on irrigation and fertilization and it makes for a long-lasting orchard.

8.6.4. Planting spacing

A 6 m x 6 m orchard layout is a good basis for ensuring shaker efficiency. Machinery is manoeuvred more easily at wider spacings, but shaker action has to be reconciled with canopy volume and crop potential.

8.6.5. Training shapes

Olive trees intended for shaker harvesting must have a single trunk, 1–1.2 m high, especially when the use of fruit catching frames is envisaged. The canopies should be open to allow light exposure, with 3–4 oblique branches and stiff secondary and tertiary branches with abundant fruit-bearing shoots. The fruit should be located in the middle–upper zone of the canopy, which should not have pendulous limbs. Olive trees intended for harvesting with the aid of mechanical beaters do not need to meet any specific requirements, although it is preferable for the fruit-bearing areas to be regular and upright or at a slight angle. The requirements for modified grape harvesters are continuous hedgerows of a predetermined canopy width and height. The fruiting area should be at least 50 cm above ground level to facilitate fruit catching, and there should be no stiff lateral branches.

8.6.6. Fruit size

Trunk shaker performance is better when the olive fruits are large. Harvest rates decrease considerably when the olives are under 1–1.5 g. Generally, good results are achieved for olives weighing 2–4 g. Modified grape harvesters also give good results, including in the case of small-fruit varieties such as 'Arbequina' and 'Koroneiki'.

8.6.7. Fruit removal force

This is an important factor which depends on cultivar and harvest timing. It is considered high when above values of 6 N, and suitable for obtaining good harvest rates at a value of around 4 N. However, the ratio between the FRF and fruit weight (N/g) is also important. At a value of 2, machinery performance is good, but difficulties arise when the value is above 3. It is advisable, therefore, to refer to the optimal harvest time (see section 3).

8.6.8. Cultivar

Cultivar affects mechanical shaker harvesting rates not only through fruit weight and FRF, but also through stem length and whether the fruits are positioned singly or in clusters on the inflorescences. Other cultivar-related factors are the configuration and elasticity of the branches, growth habit (upright or drooping) and ripening pattern (simultaneous or phased). Generally, 'Leccino', 'Frantoio', 'Carolea', 'Coratina' and 'Picual' are varieties which respond well to shakers.

8.6.9. Tree age

Trunk shakers can be applied to trees from the early age of 6–8 years old, when the trunk has a diameter of 8–10 cm, until they are 60–70 years old provided the trunks are healthy and regularly shaped because decayed wood damps vibration transmission and does not guarantee sufficient mechanical resistance at the shaker attachment point.

8.6.10. Terrain

Performance is best on flat terrain although mechanization is feasible on land with a gradient of 25–30% using caterpillar tractors and light shaker heads.

8.7. MACHINERY DAMAGE

The fruits are detached from the fruit-bearing shoots through an effective stroke/frequency combination. The limit to the series of stroke/frequency combinations that can be used is set by the potential damage they cause (Fig. 11). The bark is the tree organ that is damaged most frequently. It has a resistance of 34–41 kg cm^{-2} to radial stress and a resistance of 10–11 kg cm^{-2} to tangential stress (Adrian *et al.,* 1964). Clearly, the state of the tree is a decisive factor in that it is more sensitive when its metabolism is active. Tearing of the bark or separation at the cambium leads to the onset of olive knot (*Bacterium Savastanoi*) besides hindering the transport of elaborated substances.

The application of wide strokes at any frequency can be conducive to limb breakage. As a result, lengthy vibrating can damage the limbs. The most vulnerable areas are the grafting point in mature trees and the insertion point of suckers at the base of rejuvenated trees. Weak, partially devitalized branches are also sensitive.

Leaf drop is caused by high-frequency vibrations, especially above 40 Hz, and vibrations of extended duration; it occurs more often when the branch tips are bare.

Roots do not appear to suffer any particular damage. In some cases, small ones located nearest the trunk are pulled out.

Heavy machinery can cause soil compacting on wet ground. The extent of fruit damage depends on variety, intended product use and harvest timing. Consequently, when using trunk shakers the aim is to work with suitable stroke/frequency combinations which allow satisfactory fruit detachment without injuring the tree; the tips of the branches should also have sufficient foliage.

Harvesting methods based on beating can cause bruising of the olive fruits and abrasion of the fruiting limbs. If damage is limited to 3–5%, it will not cause problems; however, in very wet conditions, it can contribute to the development of olive knot in sensitive varieties. Over-the-row harvesters can cause limb breakage when the trees are larger than the shaker cage. If not extensive, this can be easily remedied by pruning.

If harvesting operations cause extensive abrasion to the tree, it is a good idea to apply copper-based products to avoid the onset of pests and diseases.

8.8. VIBRATION TRANSMISSION THROUGH THE TREE

Vibration transmission can vary within broad limits. Vibrations are transmitted efficiently from the trunk to the branches, but damping occurs in the tertiary shoots and leaves. This introduces a very variable, inconstant factor which depends on the suppleness or stiffness of the stem and the length, suppleness and direction of the fruit-bearing shoots. The natural oscillation frequency of the trunk on its own is 26 cycles per second on average; that of the trunk–scaffold branch system is 16 cycles per second, and notable damping occurs in the branches and leaves. Hence, the existence of critical resonance frequencies is unlikely in the whole tree. This may occur in single portions of the canopy, depending on the type of pruning practised. It is more marked the greater the distance from the central axis and when the branches are twisted and the fruit-bearing shoots are long and drooping.

Higher branch distances from ground level have a positive effect on response to vibration and this effect is greater in trees with little ramification whose branches are not excessively long and which have a predominance of upright over drooping shoots and an inverted cone-shaped canopy. Good canopy configuration can overcome a high FRF/fruit weight ratio. Negative factors include excessive canopy density, lack of pruning, or the application of thinning only. Removal of drooping limbs and pruning to stiffen limbs generally enhance harvest performance.

Multi-trunk trees hinder shaker clamp attachment, lengthen harvesting operations and lower harvest rates. Aged trees do not respond uniformly to vibrating and as a result overall harvest rates are quite low.

8.9. SYSTEMS USED BY GROWERS

The combination of hand harvest and nets is the method in widest use. Attempts to mechanize olive harvesting have taken different approaches. In areas where olive oil fetches a high price, the tendency is for the product left on the tree after shaking to be gleaned afterwards by hand. In this case, work rates are doubled and labour requirements are reduced, so amortizing machinery costs. In areas where olive oil fetches a low price, only the fruit dislodged by the shakers is collected.

In a month, a trunk shaker can harvest 20–25 ha, but it is also suitable for use on 10–15 ha farms.

The use of mechanical aids such as pneumatic rakes depends on the tree type and variety. They can be used on low-canopy trees growing suitable varieties on small holdings 2–3 ha in size (Table 3). Even so, the operation is tiring.

Beaters are used on trees and cultivars not suited to other systems. They have a low working capacity, which means they can be used for olive orchards of not more than 6–7 ha. The last option is

TABLE 3
Working capacity of harvesting systems with mechanical aids

Type of machinery	% fruit harvested	Labour producitivity kg/worker/hour	Operator fatigue	Leaf loss %
Hand harvest + plastic combs	96	14	*	7.7
Pneumatic rakes	93	26	***	5
Electric beaters	92	28	**	6
Knapsack beaters	65	16	****	0.2
Mechanized beaters	90	40	*	4

* Low ** Average *** High *** Very high ****

integral mechanization, which is very efficient and suitable for orchards of the following characteristics: between 6–8 and 60 years old; planted at average densities (300 trees/ha); growing suitable varieties of large-sized fruit; with trunks at least 120 cm in height; trained to open, vase-type shapes and pruned for the use of shakers and catching frames (Table 4).

Harvest rates of 80–90% are achieved with this last system which saves considerably on labour (Fig. 37). Farm size is not a constraint because contractors are keen to include mechanized harvesting amongst their services as they consider it to be a strategic service which will help them attract more business.

Olive growers are also very interested in mechanizing olive harvesting. Before taking any final decisions, though, they have to assess the efficiency and lifetime of the machinery and the cost of us-

TABLE 4
Working capacity of trunk shakers when harvesting 'Frantoio' and 'Leccino' varieties

Type of machinery	Tractor power kW	No. workers	% fruit removal	Trees/hr	Labour productivity kg/worker/hour
Trailed trunk shaker + nets	60	5	90	31	81
Mounted trunk shaker + nets	60	5	88	45	100
Self-propelled trunk shaker + nets	77	5	89	55	172
Mounted trunk wrap-around shaker + catching frame	60	2	92	50	266

ing it, as well as the suitability of their orchards, in order to determine the potential advantages of modernizing their harvesting methods. Harvest machinery has been streamlined in recent years; machines have become simpler in construction and their reliability and efficiency have improved.

Figure 37. Self-propelled vehicle with wrap-around frame.

Quite precise indicators are available for judging orchard suitability for mechanization such as tree size, training shape, cultivar, harvest time, fruit size and tree age. In particular, it is important to design orchards where the canopy volume of the trees is adapted to the volume which the most powerful shakers can cope with; other options are to prune the canopy severely or to attach the shakers to the scaffold branches instead of to the trunk. This possibility should be envisaged when deciding the training shape and in subsequent pruning.

In the agricultural sector, attention is focused on varieties giving medium or large-sized fruits and trees of medium vigour. In the case of small-sized varieties of interest because of the quality of their oil or because of their environmental adaptability, machinery should be used when the FRF is as low as possible. Vase training shapes are best suited to the use of machinery; besides allowing good harvest rates they are easy to maintain. Productivity has to be maintained through regular pruning, fertilization, soil management and pest and disease control. Nevertheless, efficient mechanization calls for continuous fine-tuning of machinery and trees to create synergies permitting further advances.

Another developmental possibility is to improve shaker efficiency by maintaining their power but making lighter heads and fully mechanizing fruit catchment.

Modified grape harvesters give excellent results when employed to harvest trees no more than 3 m in height and 1.0–1.5 in width, which fit into the vibratory cage without suffering significant damage. They are suitable, therefore, for superintensive orchards growing 1,000–2,000 trees/ha which quickly form a hedgerow. Harvesting is continuous and requires only two operators and the working capacity is 3 hr/ha. Some agronomic aspects have not yet been fully resolved for this type of mechanization, for instance how to keep the trees to the right size, how to stop certain parts from losing their flexibility or how to obtain large, constant crops. It is also necessary to know the lifetime of the orchard, and the extent to which pest and disease control can be achieved without applying massive doses of pesticides. In this respect, some of the data available on the 'Arbequina' and 'Arbosana' varieties are promising.

8.10. FRUIT HARVESTING FROM THE GROUND

This is done in orchards characterized by large trees and phased fruit ripening. The first step is careful preparation of the ground under the tree canopy where the fruits drop naturally or after being detached by powerful shakers; then they are piled up close to the trunk by concentric-moving mechanical sweepers or windrowers (Fig. 38). Next, the olives are sucked up by sorting machines or transported by hand or machine in bins to on-farm cleaners (Fig. 39).

Figure 38. Windrower for olives harvested from the ground.

Mechanization affords many advantages, achieving rates of up to 100 kg per hour and worker. An alternative is to position nets under the tree canopies from the start of natural fruit drop.

Figure 39. Sorting machine for olives harvested from the ground.

One drawback is that overripe olives are collected; others are the cost of the nets and the labour needed. Although still widespread, this system should be replaced by taking long-term measures to modify plant structure and size so that the fruit can be harvested economically on the tree.

8.11. USE OF LOOSENING AGENTS

Loosening agents are designed to speed up fruit ripening processes, lower FRF and facilitate harvesting. It has emerged that, when applied, they do not affect all the fruits uniformly, exerting a greater effect on the olives in which the process of senescence has begun. Consequently, besides an overall decrease in FRF, they cause greater natural fruit drop, leading to a 15–20% increase in the efficiency of hand or shaker harvest. Drawbacks are related to the increase in natural fruit drop, product ineffectiveness at low temperatures, phylloptosis and the cost of the agents, which can be attenuated in part by using CGA 15281 for a quicker effect. Loosening agents can be useful when the fruit is collected from the ground because they shorten the harvest period, especially in southern regions where temperatures are optimal, including during fruit maturation.

8.12. TABLE OLIVE HARVESTING

Table olives are harvested when they turn from green to light green or at full ripeness. Generally, they are heavy in weight. Hence, good results are achieved at full maturity and any damage to the fruit flesh is easily surmounted by processing.

Olives harvested when green pose more problems because they have a high FRF and the fruit flesh is sensitive to damage caused by the olives knocking against the structural organs of the tree or parts of the catching frame or against the ground when nets are used.

When 'Manzanilla' olives were harvested under optimized trunk shaker conditions, harvest rates of 35–74% were achieved and fruit damage rates of 58% compared with 6% in hand picking, although the difference in damaged product fell to less than 5% after fermentation. However, it was essential to process the fruit no more than a few hours after harvesting (Humanes *et al.,* 1984). Harvest yields were poor, which made it necessary to use loosening agents which caused additional problems and limited the use of mechanized harvesting.

Harvest rates of 80% have been achieved in Italy, with fruit damage rates of between 3 and 60%, compared with 9–25% damage in hand picking (Lombardo, 1978). The most sensitive olives, in descending order, were 'Nocellara Messinese', 'Nocellara Etnea' and 'Sant'Agostino'. Performance was improved by using catching frames equipped with decelerating bands. In the case of the 'Ascolana' variety, with a flesh firmness of 214 g/cm^2 , some 15% of the fruit was undamaged, compared with 30% in hand picking. In the case of 'S.Caterina' and 'Itrana', with respective flesh firmness values of 340 and 372 g/cm^2, the percentage was 75% compared with 85% in hand picking. Light fruit damage was remedied during processing. Consequently, mechanized harvesting is practicable for 'S.Caterina' and 'Itrana' when the edges of the nets are lifted by hand as harvest rates of 90% are obtained without worrisome damage to the fruit (Antognozzi *et al.,* 1984) (Fig.16).

8.13. CONCLUSIONS

In all the countries where olives are grown for oil or table olive production the reduction of harvest costs is considered of fundamental importance for overcoming economic difficulties and placing olive cultivation in a position where it is competitive and able to satisfy future demand.

The move towards a high degree of crop mechanization not only entails using the right machinery. It also means reviewing crop approaches, adapting the trees to machinery use and optimizing harvesting equipment.

In this context, study of maturation processes has defined the optimal harvest time as the period coinciding with maximum fruit oil content, no natural fruit drop, lower FRF and top oil quality.

Vibration is the most effective means of detaching fruit. The right stroke/frequency combination has to be applied to avoid damage to branches and leaves, and to a lesser extent to roots.

Multidirectional vibrations enhance transmission efficiency, and the use of a succession of different vibration patterns is even more efficient. Significant improvements have been made to shakers to make them lighter, which means they require less power to be equally efficient.

After fruit detachment is resolved, fruit catching is the next important question and should be mechanized in order to lower costs and significantly reduce labour (Fig. 40).

Figure 40. Trunk shaker and wrap-around catching frame make a very efficient combination.

To make mechanical harvesting practicable, attention has to focus on agronomic factors by boosting productivity, disseminating varieties suited to machine harvest and employing training shapes responsive to vibration transmission and machinery requirements.

Harvesting from the ground can also be efficiently mechanized. However, it is tending to be replaced by harvesting from the tree, although this calls for extensive restructuring of the olive orchards in the medium and long term.

Loosening agents pose problems because their effect varies according to climatic factors and they are not always of clear use.

If the right varieties are chosen and sufficient precautions are taken during harvesting and processing, table olives can be machine harvested.

The development of harvest mechanization depends on the most efficient mechanical solutions. At present, these are trunk shakers with wrap-around catching frames and modified grape harvesters.

Olive orchards need to be adapted to the use of such machinery, which makes it necessary to implement a long-term programme to establish new orchards. These can be run along intensive lines where the trees are planted at densities of 250–300 trees/ha and trained to tried-and-tested shapes which can be adapted to almost all varieties and to many olive-growing areas.

Another option is to establish new superintensive orchards after solution of the problems of tree size control and agronomic management.

8.14. FUNDAMENTAL POINTS IN MECHANIZING OLIVE HARVESTING

- Mechanization has a strategic part to play in the development of olive growing because it lowers production costs, limits labour use and makes work less tiring.
- There is an optimal harvest time for each variety when the maximum amount of top quality oil is obtained and machinery efficiency is high.
- The most effective parameters for determining the optimal harvest time are the fruit removal force, natural fruit drop and organoleptic assessment of the oil.

- Harvesting is the cultural practice in greatest need of mechanization because, when done traditionally, it accounts for 50–80% of production costs.
- Fruit detachment is caused by the combined forces of traction, flexion and torsion.
- Vibrating is effective for dislodging fruit when the right stroke/frequency combination is employed and sufficient acceleration is achieved.
- The types of machinery available are mechanical aids, mechanical beaters, trunk shakers, over-the-row harvesters, machinery for harvesting from the ground.
- Mechanical aids and nets double work productivity compared with hand picking but harvesting is still tiring. They are used for small areas and canopies at a short distance from the ground.
- Mechanical beaters perform well but harvesting is slow. They are used on trees not suited to other systems of mechanization.
- Trunk shakers are efficient and perform well when combined with nets. However, they are most efficient when used with wrap-around catching frames.
- Orchards have to be adapted to this kind of mechanization. Trees should have a trunk of at least 1.00-1.20 in height and a mean canopy volume of 30–50 m^3. Varieties of medium to large-sized fruit should be grown on layouts of at least 6 m x 6 m.
- Modified grape harvesters do an excellent job of harvesting small trees (2-3 m in height and 0.8–1.2 m in width). The use and spread of this type of machinery depends on the possibility of maintaining tree size and suppleness, guaranteeing high crop production, effectively controlling pests and diseases and ensuring the orchard has an economic working life.

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