Nutritional recommendations for

OLIVES

Haifa

Pioneering the Future

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Contents:

1. General information

Scientific name: *Olea europaea L.*

Family: *Oleaceae*

Related species: Wild Olive (*Olea africana*), Oleaster (*O. europaea* var. *oleaster*).

Distant affinity: American Olive (*Osmanthus americana*), Fragrant Olive (*O. fragrans*).

Common names: English: Olive. French: Olivier; Spanish: Olivo; Italian: Olivo; German: Olive; Arabic: Zeitoun

1.1 Origin and history

Olive cultivation dates back more than 6,000 years and it is still flourishing today, not only in its countries of origin, but now in most areas of the world.

The olive is native to the Mediterranean region, tropical and central Asia and various parts of Africa. The olive has a history almost as long as that of Western civilization, its development being one of civilized man's first accomplishments. At a site in Spain, carbon-dating has shown olive seed found there to be 8,000 years old. The cultivation of *O. europaea* may have been initiated independently in both Crete and Syria. Archeological evidence suggests that olives were grown in Crete as long ago as 2,500 B.C. From Crete and Syria olives spread to Greece, Italy and other parts of the Mediterranean area.

The leafy branches of the olive tree have been used for thousands of years as a symbol of abundance, glory and peace, such as to crown the victors of friendly games and bloody wars. As emblems of benediction and purification, they were also ritually offered to deities and powerful figures; some were even found in Tutankhamen's tomb.

Over the years, the olive has been the symbol of peace, wisdom, glory, fertility, power and pureness. The olive tree and olives are mentioned over 30 times in both the New and Old Testaments of the Bible. It is one of the first plants mentioned in the Bible, and one of the most significant. For example, it was an olive leaf that the dove brought back to Noah to demonstrate that the flood was over.

An olive tree in Algarve, Portugal, is 2,000 years old, according to radiocarbon dating. The age of an olive tree in Crete, claimed to be over 2,000 years old, has been confirmed on the basis of tree ring analysis. According to a recent scientific survey, there are dozens of ancient olive trees throughout Israel and Biblical Palestine, 1,600-2,000 years old. Ancient trees include two giant olive trees in Arraba and five trees in Deir Hanna (both in the Galilee region), which have been determined to be over 3,000 years old, although the credibility of the study that produced these dates has been questioned. All seven trees still bear olives.

1.2 Nutritional and health values of the olive fruit

The nutritional value of the olive stems from the fact that it has very little carbohydrate and is a great source of monounsaturates. This makes it a good element in a low-carbohydrate diet. There are many different types of olives and the broad categories are the green olives and the ripe black

olives. Olives are a rich source of polyphenols, which are critical as our body's defense against cancer. Polyphenols have many good properties, and these elements, which are the reason for the taste and the smell of the olive, can also help as an anti-inflammatory.

Olive oil

Olive oil, which is extracted by pressing olives, is also a good source of many beneficial nutrients and minerals. The oil is a good source of antioxidants and, as a special bonus, it greatly adds to the flavor of dishes. As it contains monounsaturated fat, it does not elevate the level of cholesterol in the body. It is said that olive oil prevents the adherence of cholesterol to the walls of the artery. Additionally, monounsaturated fats also help in controlling blood sugar. This affects the insulin regulation in the body in a positive way.

In terms of their phytonutrient content, olives are nothing short of astounding. Few high-fat foods offer such a diverse range of antioxidant and anti-inflammatory nutrients, some of which are unique to olives. The following list specifies only the most important phytonutrient categories: Simple Phenols; Terpenes; Flavones; Hydroxycinnamic acids; Anthocyanidins; Flavonols; Hydroxybenzoic acids and Hydroxyphenylacetic acids.

According to the USDA, a single serving of 10 medium-sized green olives contains the following:

Table 1.1: The nutritive value of 10 medium-sized green olives

Energy	49 kcal	Vitamin A	7 mcg
Protein	0.35 g	Vitamin B1	0.007 mg
Fat, total	5.21 g	Vitamin B6	0.01 g
Carbohydrates	1.31 g	Niacin (Vitamin B3)	0.08 mg
Dietary fiber	1.1 g	Vitamin E	1.3 mg
Saturated fatty acids, total	0.69 g	Lutein + zeaxanthin	173 mcg
Monounsaturated fatty acids, total	3.85 g	Choline, total	4.8 mg
Polyunsaturated fatty acids, total	0.44 g	Folate	1 mcg
Calcium	18 mg	Beta-carotene	79 mcg
Magnesium	4 mg	Iron	0.17 mg
Potassium	14 mg	Sodium	529 mg
Phosphorous	1 mg	Zinc	0.01 mg
Copper	0.04 mg	Selenium	0.3 mcg

1.3 Plant description and physiology

The olive tree is an evergreen tree or shrub, short and thick, and rarely exceeds 8 – 15 meters in height. Olives are long-lived with a life expectancy of 500 years. The trees are also persistent, easily sprouting back even when chopped to the ground.

The trunk is typically crooked and twisted. The bark of the tree is pale gray. It has many thin branches with opposite branchlets.

The leaves are opposite each other and are feather-shaped or elliptic, measuring 4 – 10 cm long and 1 – 3 cm wide. They are smooth and pale green on top and silvery on the bottom and their skin is rich in tannin, which gives the mature leaf a grayish-green hue. The leaves are replaced every two to three years, leaf-fall usually occurring at the same time that new growth appears in the spring.

Flowers

Olive trees produce two different types of creamy white flowers, a perfect flower, which contains both male and female parts, and a staminate flower with stamens only. The small white, feathery flowers, with ten-cleft calyx and corolla, two stamens and bifid stigma, are borne generally on the last year's branches, in racemes springing from the leave's axils. The flowers are largely wind pollinated with most olive varieties being self-pollinating, although fruit-set is usually improved by cross pollination with other varieties. There are self-incompatible varieties that do not set fruit without other varieties nearby, and there are varieties that are incompatible with certain others. Incompatibility can also occur for environmental reasons such as high temperatures.

Flower induction and fruit-set

The tree is mature enough to produce flowers and fruits at the age of about four years. Changes affecting fruit-set start in the preceding summer.

- Absence of water stresses during preceding summer assists the change from vegetative buds into flower buds.
- Other stresses, like pests, diseases and nutrient deficiency, can severely affect fruit development and yield.
- Optimal status during July and August is critical for ensuring a tree is in peak condition to produce maximum flowers.
- Dry-land trees can have as many as 52% sterile (staminate) flowers, compared to suitably irrigated trees with only 7% – 8% of sterile flowers.
- Trees must be exposed to winter chill to bear fruit. Average temperature for winter should be 120 Celsius or somewhat less for adequate chilling.
- Hot, dry winds during flowering will tend to increase flower drop and reduce fruit-set.
- Flowering in the northern hemisphere usually occurs in September – October, depending on variety and conditions.

- Olive trees in suitable environments produce abundant pollen.
- Correct irrigation and windbreaks reduce the detrimental effects of heat and wind on fruit-set.

The fruits are a green drupe 1 – 2.5 cm long, becoming generally blackish-purple when fully ripe. A few varieties are green when ripe and some turn a shade of copper brown. The cultivars vary considerably in size, shape, oil-content and flavor. The shapes range from almost round to oval or elongated with pointed ends. Raw olives contain a bitter alkaloid (oleuropein) that makes them bitter and unpleasant, but not harmful to health. This means that the fruit cannot be consumed directly from the tree and has to undergo curing processes. Some olives are, however, an exception to this rule because as they ripen they sweeten right on the tree; in most cases this is due to fermentation. One case in point is the Thrubolea variety in Greece. A few varieties are sweet enough to be eaten after sun drying.

Thinning the crop will give a larger fruit size. Wild varieties are thinner-fleshed and smaller than in orchard cultivars. They can be either almost round or oval, and the fleshy part is filled with oil. It contains a single seed, commonly referred to as a pit or a rock. When fully mature, the fruit becomes very dark purple. Olives are harvested at the green to purple stage. Canned black olives may contain chemicals (usually ferrous sulfate) that turn them black artificially.

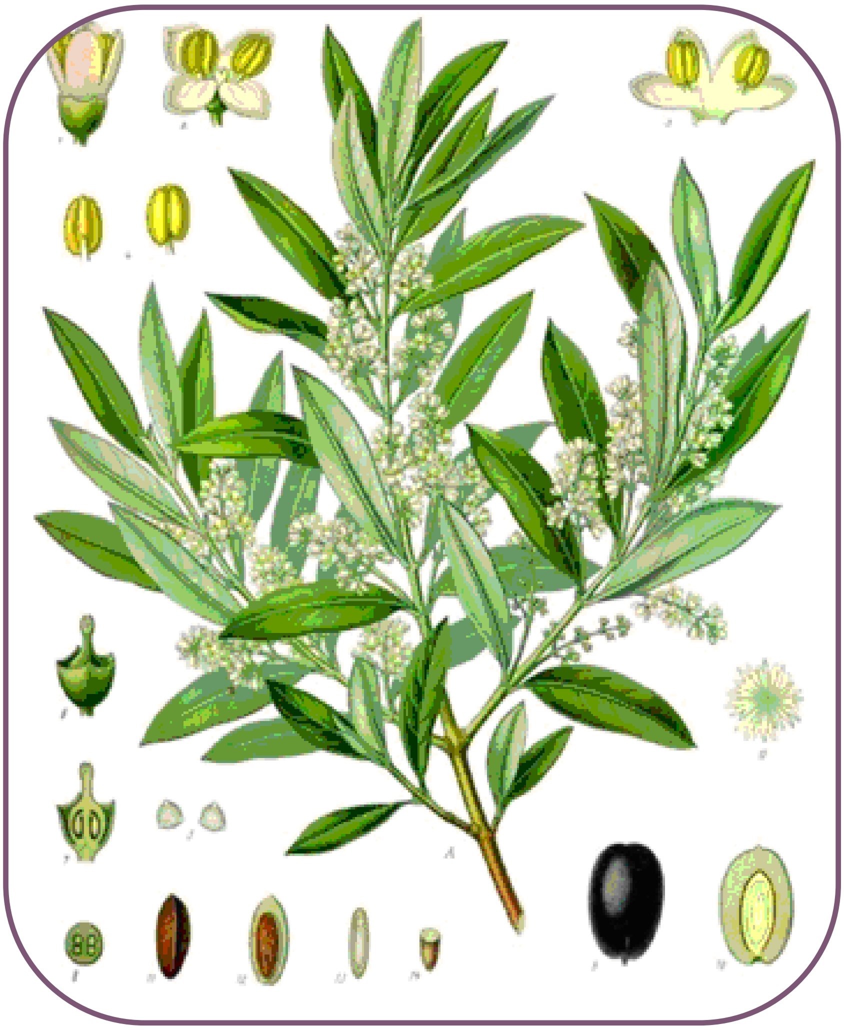


Figure 1.1: A 19th century illustration of the different parts of an olive tree.

1.4 Worldwide cultivation of olives

Spain, Italy, Greece, Turkey, Syria and Morocco are the world's major olive oil producing countries, accounting for some 83% of world olive oil output, and a similar percentage of consumption. A large olive production industry is also found in California, Australia and South Africa.

Table 1.2: Main olive-producing countries in 2009 (Source: FAOSTAT)

	Production (Tons)	Cultivated area (ha)	Yield (Ton/ha)*
World	**18,241,809**	**9,922,836**	**1.83**
Spain	6,204,700	2,500,000	2.48
Italy	3,600,500	1,159,000	3.11
Greece	2,444,230	765,000	3.14
Turkey	1,290,654	727,513	1.77
Syria	885,942	635,691	1.39
Morocco	770,000	550,000	1.4
Tunisia	750,000	2,300,000	0.33
Egypt	500,000	110,000	4.55
Algeria	475,182	288,442	1.65
Portugal	362,600	380,700	0.95
Lebanon	76,200	250,000	0.65
Jordan	189,000	126,000	1.5
Libya	180,000		
Argentina	160,000	52,000	3.08

*All ton terms in this publication are metric, unless otherwise indicated.
(Source: OLIVÆ, Official magazine of the International Olive Council)

1.4.1 Dynamics of production and consumption of table olives

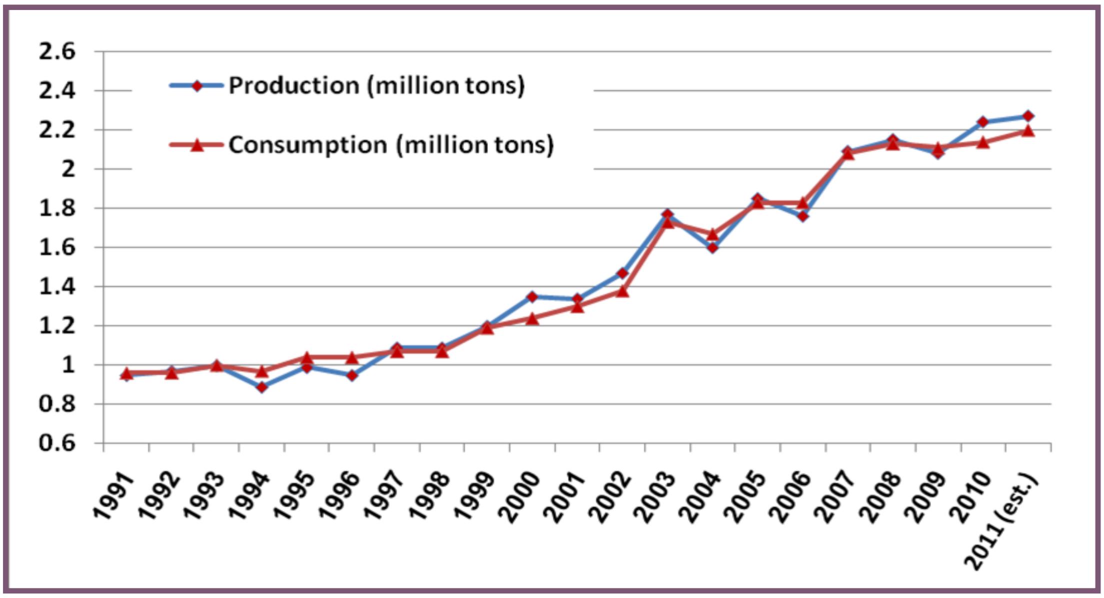


Figure 1.2: World production and consumption of table olives (1990/91–2010/11) **(**Source: OLIVÆ, Official magazine of the International Olive Council)

1.4.2 Olive oil

World olive oil consumption rose by 1 million tons during 1996-2009, while olive oil production for 2009 is estimated at close to 2.9 million tons (Figure 1.3). As the oil production coefficient from the fruit is around 0.153, the said oil production figure represents some 19 million tons of olive fruit that were produced for oil extraction.

The perceived health benefits, a continuing interest in Mediterranean cuisine and promotion by the controlling body of the industry, the International Olive Oil Council, are all stimulating market demand for olive oil, particularly in countries not traditionally associated with olive oil, such as the United States and Japan.

There are a number of classifications of the different grades of olive oil, with the top one being Extra Virgin Olive Oil.

Extra Virgin & Virgin Olive Oil (EVOO & VOO) are the healthiest grades of olive oil; they have the most flavor and aroma. EVOO & VOO are extracted using only mechanical means, without the use of chemicals or excessive heat. EVOO must be free of defects and have an acidity of 0.8% or less; VOO should have an acidity of 2% or less.

Pure Olive Oil is a middle of the line olive oil. It is usually a mixture of refined and virgin olive oil and can be used for cooking or frying, etc.

Extra Light is a lower grade of olive oil and is usually refined olive oil. The term "light" usually refers to it being lighter in color, flavor and aroma. Being refined oil, it has also had some of the health benefits removed from its makeup.

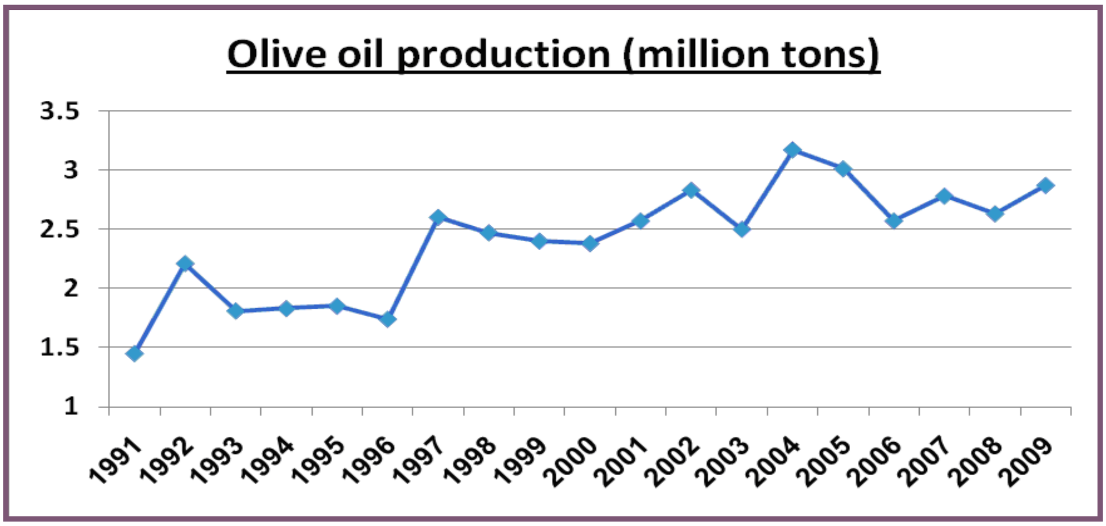


Figure 1.3: World olive oil production, 1990–2009 (million tons)
(Source: OLIVÆ, Official magazine of the International Olive Council)

1.5 Olive cultivars

There are two basic products: olive oil and table olives. Olive oil products dominate the marketplace and 80% to 90% of olives produced are devoted to olive oil production. Most interest is in producing high quality extra virgin (EV) olive oil, for which there is good demand.

Over the centuries mankind has produced and propagated a myriad of olive varieties. Most were selected for one use only, generally oil production. In recent decades, however, some new varieties were bred for a dual purpose, oil production and as table olives. One of these is ***Barnea***, which was developed in Israel and is very popular in new, modern plantations, e.g., Australia. Today several dozen varieties are grown commercially around the world. DNA typing shows that some varieties

with different names are actually the same. All have their own particular characteristics, such as: oil yield, organoleptic (taste and smell) characteristics, resistance to stress, productivity, tree vigor, time of ripening and ease of harvest.

There are many aspects to be considered simultaneously when deciding on the variety mix of an olive grove. Local conditions, productivity and oil or fruit quality are some of the important factors that should be evaluated. Tolerance or sensitivity to different pests, diseases or climatological conditions, together with pollination and ripening periods, are important points to evaluate in the final layout of the grove.

Varieties such as ***Leccino, Picual, Pendolino, Arbequina, Picholine*** or ***Hojiblanca*** have proven in the Mediterranean area to be more tolerant to cold temperatures than other varieties. Varieties such as ***Frantoio, Manzanillo*** or ***Barnea*** are considered to be moderately to highly sensitive to frost damage.

Since many cultivars are self-sterile or nearly so, they are generally planted in pairs with a single primary cultivar, and a secondary cultivar for cross-pollination, to optimize yield. In general, it is best to have at least three to four different varieties to optimize cross-pollination.

In recent times, efforts have been directed at producing hybrid cultivars with qualities such as resistance to disease, quick growth and larger or more consistent crops.

Following is a list of some particularly important olive cultivars arranged in alphabetical order:

- ***Amfissa*** is an excellent quality Greek table olive grown in Amfissa, Central Greece. Amfissa olives enjoy protected designation of origin (PDO) status, and are equally good for olive oil extraction.
- ***Arbequina*** is a small, brown olive grown in Aragon and Catalunia, Spain, good for eating and for oil.
- ***Ascolano***, Very large, ellipsoidal fruit. Skin color very light even when ripe, pit very small. Fruit is tender and must be handled carefully. Contains very little bitterness and requires only moderate lye treatment. Excellent for pickles, but needs proper aeration during pickling to develop "ripe" color. Tree is a heavy bearer, widely adapted.
- ***Barouni***, Large fruit, almost as large as Sevillano. Trees spreading and easy to harvest. Withstands extremely high temperatures. This variety is usually used for making home-cured olives. Originally from Tunisia.
- ***Barnea*** is a modern dual-purpose cultivar bred in Israel to be disease-resistant and to produce a generous crop. The oil has a strong flavor with a hint of green leaf. Barnea is widely grown in Israel and in the southern hemisphere, particularly in Australia and New Zealand.
- ***Bosana*** is the most common olive grown on Sardinia. It is used mostly for oils.
- ***Chemléli Sfax***, a Tunisian vigorous tree, which is productive and resistant to the arid conditions, has fruity oil mainly at the start of the harvest period with pleasant flavors of green almond and high health values due to its high sterol content.
- ***Chetoui***, the second principal variety of olive tree in Tunisia gives a fruity oil with green almond flavors and contains very high (> 300 ppm) phenolic compound which guarantees to this variety a stability against oxidation.
- ***Cornicabra***, originating in Toledo, Spain, comprises about 12% of Spain's production. It is mainly used for oil.
- ***Empeltre***, from Pedrola, Aragon, is a medium-sized black olive grown in Spain. Especially in Aragon and the Balearic Islands, it is dual purpose.
- ***Frantoio and Leccino*** cultivars are the principal raw material for Italian olive oils from Tuscany. Leccino has a mild, sweet flavor, while Frantoio is fruity with a stronger aftertaste. Due to their highly valued flavor, these cultivars are now grown in other countries.

- ***Gemlik*** is a variety from the Gemlik area of northern Turkey. It is a small to medium sized black olive with high oil content. This type of olive is very common in Turkey and is sold as a breakfast olive in cured formats. The sign of a traditionally cured Gemlik olive is that the flesh comes away from the pit easily.
- ***Gordal*** is a medium to large, plump fruit, ripening early. It resembles Sevillano. A popular pickling olive and principal cultivar in Spain.
- ***Hojiblanca*** originated in the province of Córdoba, Spain; its oil is widely appreciated for its slightly bitter flavor.
- ***Kalamata***, a large, black olive with a smooth and meat-like taste, is named after the city of Kalamata, Greece, and is used as a table olive. These olives are usually preserved in wine, vinegar or olive oil. Kalamata olives enjoy PDO status.
- ***Koroneiki*** originated from the southern Peloponese, around Kalamata and Mani in Greece. This small olive, though difficult to cultivate, has a high yield of olive oil of exceptional quality.
- ***Manzanillo*** or ***Manzanilla***, "Manzanillas" means "little apples" in Spanish. A large, rounded-oval fruit, it originated in Dos Hermanas, Seville, in southern Spain. Known for its rich taste and thick pulp, it is a prolific bearer, grown around the world. Its skin is a brilliant purple, changing to deep blue-black when mature. It resists bruising and ripens early, several weeks earlier than Mission. The pulp parts readily with its bitterness and is exceedingly rich when pickled. Excellent for oil and pickles. Tree spreading and vigorous.
- ***Lucques*** is found in the south of France (Aude département). It is a green, large and elongated fruit. The stone has an arcuated (bow) shape. Its flavor is mild and nutty.
- ***Maalot*** (Hebrew for merits) is a disease-resistant, eastern Mediterranean cultivar derived from the North African Chemlali cultivar. The olive is medium sized, round, has a fruity flavor and is used almost exclusively for oil production.
- ***Mission*** originated on the California Missions and is now grown throughout the state. It is more cold resistant than other cultivars. It is a black, medium sized, oval fruit and is generally used for table consumption. Skin deep purple changing to jet-black when ripe. Flesh very bitter but firm, freestone. Ripens rather late. Good for pickling and oil, specially ripe pickles. Most widely used for cold-pressed olive oil in California. Tree vigorous, heavy-bearing.
- ***Nabali***, a Palestinian cultivar, also known locally as Baladi, which, along with Souri and Malissi, is considered to produce among the highest quality olive oil in the world.
- ***Picholine***, is grown in the south of France. It is green, medium sized, and elongated. The flavor is mild and nutty. Small, elongated fruit. Its skin is light green, changing to wine red, then red-black when ripe. The pulp is fleshy and firm-textured. The tree is vigorous and medium-sized and bears heavy crops regularly. Cured olives have a delicate, subtle, lightly salty, nut-like flavor. Usually salt-brine cured. Popular in gourmet and specialty markets.
- ***Picual***, from the province of Jaén, southern Spain, is the most widely cultivated olive in Spain, comprising about 50% of Spain's olive production and around 20% of world olive production. It has a strong but sweet flavor, and is widely used in Spain as a table olive. Moreover, its oil has some of the best chemical properties found in olive oil, being the richest in oleic acid and vitamin E.
- ***Rubra*** is a medium-small, ovate fruit. Its skin is jet-black when ripe. It ripens 3 to 4 weeks earlier than Mission. It is best suited for oil, but is also used for pickling. The tree is large and precocious, often producing fruit the second year. An exceptionally prolific bearer. Very hardy and reliable, even in dry situations. Originated in France.

- ***Sevillano*** is a very large fruit, bluish-black when ripe. The stone is large and clinging. The fruit ripens early and has a low oil content; it is only useful for pickling. It is used for making Sicilian style salt brine cured olives and is also the leading canning cultivar. The tree is a strong grower and a regular bearer. It requires a deep, rich, well-drained soil and will not stand much cold.
- ***Souri***, grown in Lebanon near the town of Sur (Tyre) and widespread in the Levant, has a high oil yield and exceptionally aromatic flavor.

Some other varieties are very important in their original countries, as follows:

GREECE:

- ***Gaidoroelia***, which means donkey-olive, owes its name to its large size. Usage: Table olive. Characteristics: Large. Found mainly in northern Greece, especially in Chalkidiki.
- ***Conservolea***. Usage: Table olive. Characteristics: 80% of Greek table olives belong to this variety and carry several local names. It is oval or round, 5-8 grams and it is served with salty food.
- ***Koroneiki***. The name derives from the Greek word "korona" which means crown. Usage: Mainly for oil production. Characteristics: The produced oil has a very light and harmonious aroma, often with a light lemon fragrance.
- ***Kothreiki***. Usage: Table olive and oil production. Characteristics: Similar to Conservolea in size and color.
- ***Megara***. Usage: Table olive and oil production. Characteristics: Small, green in tin and black in salty curing.
- ***Stafidoelia***, which means raisin olive. Usage: Table olive. Characteristics: It doesn't need to be processed. It gets black on the tree from maturity until it shrinks. Can be placed in a tin with some salt or oil.
- ***Throuba***. Usage: Table olive. Characteristics: Small to medium fruit. It loses its acidity by maturing on the tree. Its bitter ingredients are lost due to a microorganism.

ITALY: **Cipresino; Coratina; Grappoio; Intrana; Moraiolo; Pendolino; Santa Caterina; Taggiasca**.

1.6 Yields

Traditional, extensive, rain-fed olive plantations yield ranges between 7 and 14 ton / ha, which transforms to 1,700 – 2,400 liters of oil, according to a coefficient of ~170 liters of oil per ton of fruit.

Intensively cultivated, super-high density olive plantations, 5 years old or more, yield an average of 24 ton / ha, which transforms to 4,560 liters of oil, according to a coefficient of ~190 liters of oil per ton of fruit.

Expected yield of table olives range: 14 – 32 tons/ha and the harvest removal rate range is 60% – 80%.

The following figures can be used as a guide to expected yields for a mature, fully irrigated olive grove (Table 1.3). The expected yield for non-irrigated crops is substantially lower.

Table 1.3: Expected yield of mature and fully irrigated olive trees

Annual yield of fresh olives per tree	50 kg
% oil in oil varieties	20%
Mass of olive oil per tree	10 kg
Specific mass of olive oil	0.9 kg/liter
Oil production per tree	11.1 liters
Tree planting spacing	8m x 5m
Tree density	250 per hectare
Yield of fresh olives per hectare	12.5 ton
Liters of olive oil per hectare	2,778 liters

2. Growing olives

2.1 Climate

Olives can be and are grown in a wide range of climates in many different countries. The crop is mainly distributed between 25° – 40° North and South latitudes. The crop requires:

- Mild to cool winters with a chilling period of about two months, with average temperatures varying between 1.5°C to 10°C for flower bud differentiation.
- No late spring frosts that may kill the blossoms.
- Long, hot and dry summers to properly ripen the fruit.

It is, therefore, best suited to a Mediterranean-type climate.

Some olive varieties, such as those grown in Egypt, Tunisia or Israel, bloom and fruit with very little winter chilling, whilst other varieties require more chilling for a normal flower differentiation.

Areas receiving a mean annual rainfall of 400 to 700 mm are most suitable for olive growing. Supplemental irrigation during summer increases fruit yields by 30% – 50%. A long, sunny, warm summer results in a fruit with high oil content. Olives perform well, with humidity varying between 40%–65 %. High humidity, above 80%, at flowering causes flower drop and infestation by sooty-mold producing insects. The olive is a long-day plant and benefits from prolonged sunlight (2,400 – 2,700 sunshine hours annually) and a warm environment.

Being an evergreen tree, the olive is sensitive to hard freezing temperatures. Buds and fruiting shoots are usually damaged by temperatures below -5ºC. Large branches and whole trees can be killed if temperatures fall below -10ºC.

Main source: Netafim.

2.2 Soil type

Olives grow well on almost any well-drained and aerated soil with pH values of 6.5 – 8.5. Therefore, sites where water stands during rainy periods or where ground water is shallower than 1.2 meters deep should be avoided. Olive trees are tolerant to mild saline conditions, but extremely salty or sodic soils should be avoided. Olives have a relatively shallow root system (Figure 2.1) and consequently they only require a 1.0 – 1.5 meter deep soil profile without any serious physical limitations. Olives prefer moderately fine textured soils ranging from sandy to silty clay, loamy soils.

Figure 2.1: Olives do well on shallow soils with good drainage.
(Source: Connell, UC Davis)

Sodic (Alkali) Soils

Soils that contain excessive amounts of exchangeable sodium in proportion to calcium and magnesium are termed sodic or alkali soils. They are characterized by a dispersion of soil particles that reduces the soil permeability to water and air. By definition, a sodic soil has an exchangeable sodium percentage (ESP) of greater than 15. This means that 15% of the soil exchange capacity is associated with sodium, and the rest with calcium, magnesium and other cations. Olive trees are affected when ESP levels reach 20 – 40.

Source: http://www.oliveoilsource.com/page/fertilizers-and-amendments

2.3 Propagation

None of the cultivated varieties can be propagated by seeds. Seed-propagated trees revert to the original small-fruited, wild variety. The seedlings can, however, be grafted or chip-budded with material from desired cultivars. The variety of an olive tree can also be changed by bark grafting or top working. Another method of propagation is transplanting suckers that grow at the base of mature trees. However, these would have to be grafted if the suckers grew from the seedling rootstock. A commonly practiced method is propagation from cuttings. Twelve- to fourteen-inch long, one-inch thick cuttings from the two-year-old wood of a mature tree are treated with a rooting hormone, planted in a light rooting medium and kept moist. Trees grown from such cuttings can be further grafted with stems from another cultivar. Cutting-grown trees bear fruit in about four years.

2.4 Tree spacing

Before analyzing the concept of tree spacing, it is important to introduce the concept of optimal volume of canopy. Many scientific works have proven that there is a single optimal volume of canopy per hectare that depends exclusively on environmental conditions and is independent of the chosen spacing within certain limits.

The optimal volume will be determined by a combination of climate, soil, irrigation and other management practices, and with this volume the grove will produce consistently high yields of high quality fruit.

It is possible to achieve the same optimal volume of canopy per hectare, and consequently yields, with various spacing variations. The main advantage of higher densities (Figure 2.2) is the possibility of achieving the optimal volume in a shorter period of time.

In practice, olives are cultivated in three main production systems according to tree density (see Table 2.1).

Table 2.1: Main tree densities of olive orchards

Production system	Spacing	Tree density (trees/ha)
Traditional	7 – 20 m	30 – 200
Intensive	intra-row: 3 – 4 m	250 – 600
	inter-row: 6 – 8 m	
Super-intensive	intra-row: 0.9 – 1.5 m	1,655 – 2,990
	inter-row: 3 – 4 m	

The main problems associated with high densities are an elevated incidence of pests and diseases like scales and peacock spot, light limitations and difficulty in keeping optimal volumes of canopy per hectare without excessive pruning that would affect the yields.

Figure 2.2: Super high density olive oil orchard, with spacing of 1.5-1.8 m x 5.5m = 2,300-2,680 trees per hectare

Another important element to consider is the minimal distance between the rows where the machinery will need to operate. In the particular case of harvesting by shakers, a minimum distance of 6 – 8 meters between rows is required.

Planting time: Year round, except July – August and November – January.

2.5 Planting design for cross pollination

Pollination and ovule fertilization are essential steps to guarantee a normal fruit-set and crop. Successful pollination requires the pollen grain to germinate and its pollen tube to grow fast enough to reach a still viable embryo sac to fertilize the ovule.

Olive flowers are largely wind pollinated with most olive varieties being self-pollinating, although fruit-set is usually improved by cross pollination with other varieties. When environmental or management conditions are not optimal, the presence of pollen from another variety will normally guarantee a better fertilization and fruit-set. Since many cultivars are self-sterile, or nearly so, they are generally planted with a single primary cultivar and 1 – 3 additional cultivars for cross-pollination to optimize yield.

2.6 Pruning

The most important fact to bear in mind when pruning, is that the olive tree usually bears fruit on the previous year's new growth, and never bears in the same place twice.

Proper pruning is important for the olive tree. Pruning both regulates production and shapes the tree for easier harvest. The trees can withstand radical pruning, so it is relatively easy to keep them at a desired height. The problem of alternate bearing can also be partially amended with careful annual pruning. For a single trunk, prune suckers and any branches growing below the point where branching is desired. Prune flowering branches in early summer to prevent olives from forming. Olive trees can also be pruned to espaliers.

Pruning between mid-February and the ripening of fruit in the fall, except for the lightest tipping of new shoots, can result in a reduced crop.

Pruning is necessary to adjust the trees to the climatic conditions of the area and increase the productivity of a plantation. The aims of pruning are: (1) to balance vegetation with fruit yield, (2) to minimize the non-productive period, (3) to prolong the productivity of the trees, (4) to delay senescence, and (5) to save soil water, a critical factor in non-irrigated orchards.

There are three main types of pruning:

- Regulated pruning. It aims to develop the tree’s frame and is of great importance in the first years of the tree’s life.
- Pruning for fruiting. The aim of this pruning is to induce productive branches to form fruits, leaving the structural branches unaffected. Additionally, it maintains uniform production in terms of yield and quality, a feature that is particularly important in table olive varieties.
- Renovating pruning. This aims to stimulate sprouting in order to rejuvenate senescent trees.

For intensive cultivation where trees are densely planted, short pruning shapes are desired, namely the "short cup" and the "bush". In the former shape, branching takes place very close to the ground, at a height of 30 – 40 cm, while in the latter no pruning is done in the first 5 – 6 years. Afterwards, only weak shoots and top branches exceeding 3 m are removed. The bush shape has certain advantages for intensive cultivation systems, such as:

- Earlier fruiting period
- Higher yields per hectare compared with other pruning shapes
- Lower labor costs, due to the possibility of harvesting from the ground without using ladders.

However, both shapes present a major disadvantage because they obstruct mechanical cultivation of the soil. In addition, harvest is difficult particularly for fruits that have fallen on the ground. An improved short shape without the latter disadvantages is shaping the tree with one central trunk into a Christmas-tree type shape.

The main pruning shapes applied in the wider Mediterranean area are the following:

1. The two-branches shape, which is common to Andalusia, Spain, for table-olive varieties.
2. The candlestick shape in Tunisia.
3. The double- or triple-trunk shape in Seville.
4. The multi-conical shape, in which every branch has the shape of a cone, found in some regions in Italy.
5. The spherical cup shape in France, Italy and Greece.
6. The spherical shape, which is not so common because it does not provide ample light to the whole tree.
7. The short cylindrical shape
8. The non-trunk shape in Tunisia.
9. The free palmate. This shape presents some difficulties and it is not widely used.

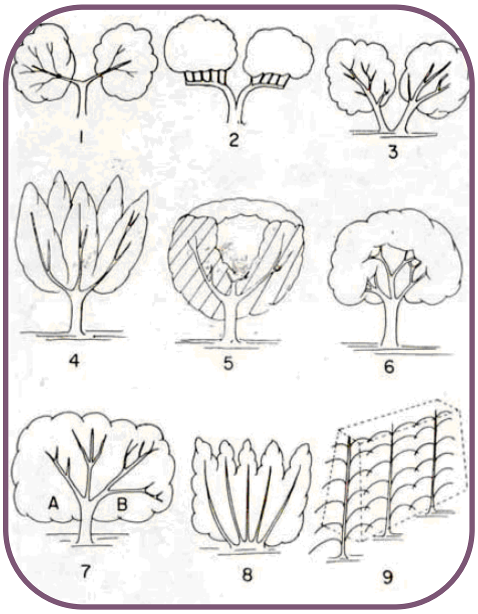


Figure 2.3: Different pruning systems, as explained above
(Main source: http://oliveoilsindia.com/Olive-Tree-Cultivation.htm)

2.7 Alternate bearing and means to reduce its impact

The olive tree is, genetically, highly alternating in fruit production. In non-irrigated olive groves, the yield may vary between 7 – 8 tons / ha and a few hundred kg. The occurrence and development of alternate bearing is also potent in intensive orchards with controlled irrigation, nutrition and training techniques, although the level of fruit production is higher and better controlled. Without specific intervention, the gap between 'off' and 'on' years may vary between 5 and 30 tons / ha. Therefore, alternate bearing is of high economical severity.

- The degree of alternate bearing is highly dependent on environmental conditions. The environmental conditions affect both the flowers and the endogenous metabolic processes of the tree by inducing specific gene activation or repression.
- Growth regulators, particularly gibberellins were shown to reduce flower bud induction in the olive, as well as in many other fruit species when applied during the major growth season in the summer or in fall.
- Specific changes in the mineral content of leaves between 'on' and 'off' years were found and related to the activity of internal growth regulators. A considerable depletion process of the N and K contents in the leaves took place during the 'on' year, while these values increased during the 'off' year as shown in Figure 2.4 Other elements, like P, Ca, Mg, Fe, Mn and B showed rather minute changes.

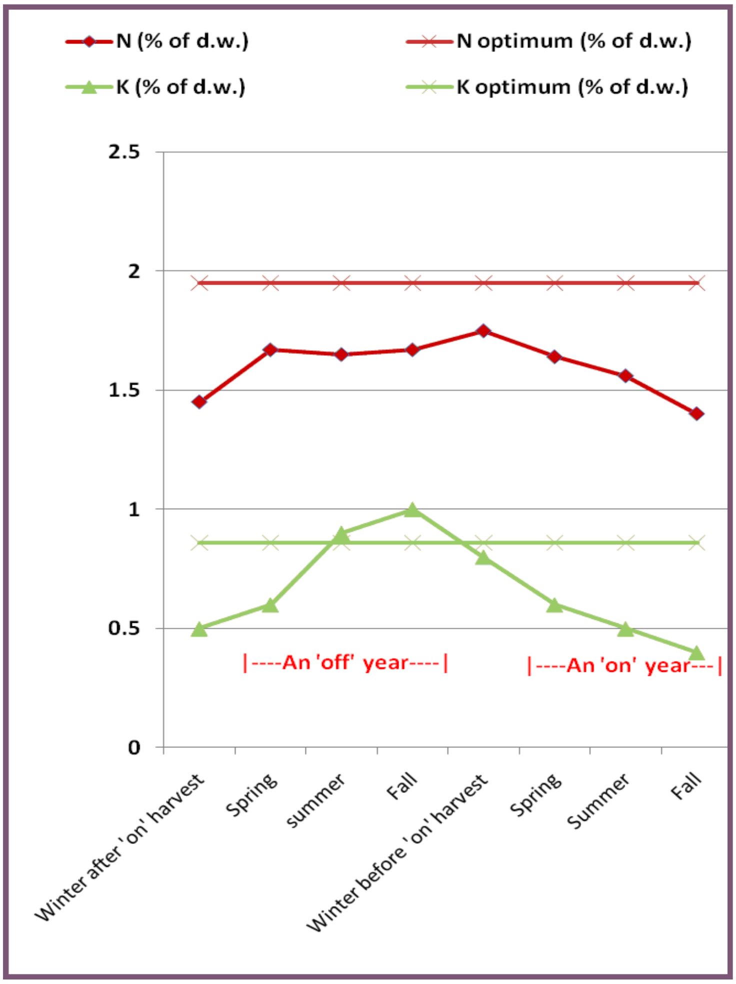


Figure 2.4: Leaf nitrogen and potassium contents in different phases of the production cycle

The possible involvement of nutrition, irrigation and fertigation in controlling alternate bearing was checked in numerous studies. Under normal, balanced growing conditions all aspects of intensification have little influence on alternate bearing. Intensive olive cultivation increases production but does not significantly affect the alternate fruiting habit of the tree. Nutritional deficiencies and / or water stress might enhance alternate bearing. In such cases nutritional or irrigation intervention would affect the level of biannual bearing as well. Spot-wise use of nutritional and water application are useful to avoid or correct alternative bearing, when induced by an acute nutritional deficiency or water stress, particularly during the early induction period.

However, alternate bearing can be balanced by supplying the trees with more water, nitrogen and potassium fertilizers during the "on" years so that they can produce ample shoot growth despite the heavy crop; and reduce the inputs during an "off" year so that they don't over-grow in the absence of fruit.

Horticultural intervention via pruning, thinning, girdling, etc. can reduce and even eliminate alternate bearing in regions with favorable and stable climatic conditions. Under more marginal and unstable environmental conditions, alternate bearing is most difficult to control and even drastic horticultural means have to be reinitiated anew after each of the various climatic events.

Sources: Lavee, 2007, and Vossen & Devarenne, 2007.

2.8 Fruit thinning

Wherever table olives enjoy special premium for greater fruit sizes, it is advisable to thin the fruits, when bloom is plentiful only.

Spray the foliage 10 days after full bloom with an NAA (Naphthalene-acetic-acid) product at a concentration of 100 ppm, and spray volume of ~2,000 L / ha. If spraying is carried out at a later time, the concentration should be increased by 10 ppm for every day of delay. A surfactant such as Triton X-100 should be added to the final spraying solution at 0.025%.

Spraying must not be done if the following days are expected to be very hot and dry.

2.9 Irrigation

Because of its small leaves with their protective cuticle and hairy underside that slow transpiration, the olive tree survives even extended dry periods. However, this defense system is at the expense of growth and productivity of the tree. Once established, olive trees are among the most drought-resistant trees in the world. But the olive tree is not a desert plant. It needs regular watering to thrive. Insufficient water will cause the plantation to suffer and even die if left too dry for too long. Thus, olive yield is greatly increased by applying small amounts of water. Moreover, if commercial yields are desired greater amounts of water will be needed, provided that soil humidity does not become excessive.

There are 2 – 3 extremely critical periods, during which soil moisture must be kept optimal, for maximum bearing, as follows:

For <u>oil production</u>, the most critical periods to avoid water stress are <u>fruit-set</u> and <u>oil accumulation</u>.

For fresh fruit production, fruit-set and fruit growth, stages # 1 & 3 are the most critical.

Table 2.2: The major growth stages of the olive tree and the impact of water stress on tree growth and fruit development

Growth stage	Impact of water stress
Shoot growth	Reduced shoot growth
Flower bud development	Reduced number of flowers
Bloom	Incomplete flowering
Fruit-set	Poor fruit-set and increased alternate bearing
Fruit growth stage 1 - cell divisions	Reduced fruit size
Fruit growth stage 2 - pit hardening	Minimal impact on fruit size
Fruit growth stage 3 - cell enlargement	Reduced fruit size
Oil accumulation	Reduced oil content

Table 2.3: Options for irrigation and their implications

Irrigation method	Implications	Water availability
Furrow / flood irrigation	Uneven water application, often wasteful.	Less than 50%, depending on soil and slope
Overhead sprinkler	High set-up costs, good filtration needed, encourages wider root formation, higher evaporation losses than drip irrigation.	65% – 75%
Drip irrigation	High set-up costs, good filtration needed, reduced evaporation losses, can restrict root development; can be buried, easiest to manage for saline water.	75% – 85%
Micro-sprinkler	High set-up costs, good filtration needed, encourages wider root formation, higher evaporation losses than drip irrigation	Greater than 85%

Olive trees are very sensitive to over irrigation and will not perform well in waterlogged soils. Waterlogged soil, often a result of poor drainage, causes poor soil aeration and root deterioration and can lead to the death of the trees. Trees cultivated in saturated soils are more susceptible to varying weather conditions and soil borne pathogens such as phytophthora and verticillium.

Drip irrigation in many diverse agro-ecological conditions brought about considerably higher olive oil yield (30% – 50%), water savings (30% – 45%), and improvement in oil qualitative characteristics, in comparison to rain-fed and surface flood irrigation methods. Subsurface drip irrigation (SDI) proved even better than on-surface drip irrigation, as shown in Table 2.3.

Figure 2.5: The olive tree has a shallow, spreading root system, especially when irrigated by a dripping system

Table 2.4: The effect of subsurface drip irrigation in comparison to rain fed olive orchard (Source: Netafim)

	Rain-fed orchard	Subsurface drip	Increase by
Fruit yield (tons/ha)	4.6	12.6	174%
Olive oil yield (tons/ha)	1.1	2.4	118%

Following are some examples for successful irrigation scheduling:

Plantations in a Mediterranean climate

As no rain is expected in the summer, the first irrigation should be done 3 weeks after the last effective rain. It should be at a rate of at least 100 m3 / ha to saturate the entire root zone. As mentioned above, water stress during bloom and fruit-set is specifically harmful; effective irrigation should therefore take place during that period. Water consumption increases during flower-bud development and the daily evapo-transpiration (the loss of water to the atmosphere by the combined processes of evaporation from soil and transpiration from plant tissues). It is therefore advisable to adopt the following regime during the spring, summer and fall seasons.

A. Young orchards

Table 2.5: Irrigation schedule and water amounts for young olive trees in a Mediterranean climate

Age (years)	Irrigation interval (days)	Season							
		Early spring	Spring	Late spring	Early summer	Summer	Late summer	Early fall	Fall
		Daily rate (liters/tree)							
1	3-7	5	6	8	10	10	9	8	7
2	3-7	7	10	15	20	20	18	15	15
3	3-7	15	25	35	40	40	35	30	30
4	3-7	30	40	50	60	60	60	50	30

B. Mature orchards

The irrigation rate of mature olive orchards should be calculated based on the Class 'A' Pan evaporation data, multiplied by the season-specific crop coefficient (CC) (see Table 2.6).

Seasonal crop water requirement: Intensive 600 – 800 mm / ha / year; traditional 350 – 600 mm / ha / year, under drip irrigation for range of environments.

Table 2.6: Crop coefficients for evaporation rates (mm / day) for olive orchards yielding over 10 tons / hectare

	Early spring	Spring	Late spring	Early summer	Summer	Late summer	Early fall	Fall
Table olives	0.3	0.35	0.3	0.25	0.25	0.25	0.2	0.15
Oil olives	0.4	0.4	0.5	0.5	0.55	0.55	0.55	0.4
Oil olives under drought	0.18	0.27	0.08	0.1	0.2	0.2	0.15	0.15

Table 2.7: Irrigation schedule for mature table- and oil-olive plantations in a Mediterranean climate

	Early spring	Spring	Late spring	Early summer	Summer	Late summer	Early fall	Fall
Phenological stage	Flower bud development - bloom	Fruit-set	Cell division - pit hardening		Cell enlargement - oil accumulation			Harvest and fall growth
Evaporation (mm/day)	5.6	7.3	8.7	8.7	8.0	6.9	5.4	3.5
No. of days/ stage	15	31	30	31	30	31	30	31
Table olives								
Crop coefficient	0.30	0.35	0.30	0.25	0.25	0.25	0.20	0.15
m^3/ha*	252	792	783	674	600	535	324	163
m^3/ha/day	17	26	26	22	20	17	11	5
***Table - Olives - annual irrigation rate: 4,123 m^3 / ha**								
Oil olives								
Crop coefficient	0.40	0.40	0.50	0.50	0.55	0.55	0.55	0.4
m^3/ha*	336	905	1,305	1,349	1,320	1,177	891	434
m^3/ha/day	19.8	25.6	43.5	43.5	44	38	29.7	14
***Oil - Olives - annual irrigation rate: 7,717 m^3 / ha**								

Water utilization efficiency varies between 0.15 to 0.5 kg of oil per m3 of water.

The recommended irrigation system by dripping is surface drippers during the first two years, followed by subsurface drip irrigation for the rest of life span of the entire plantation, combined with Nutrigation. Nutrigation (= fertigation) is the application of plant nutrients through an irrigation system.

Specifications of the recommended system:

Two laterals per row in traditional and intensively- cultivated plantations, and one lateral per row in super-intensive orchards.

Effective dripline spacing: Traditional (5 -10 m), Intensive (3 -4 m) and Super-intensive (3 - 4 m).

Emitter spacing: 0.50m- 0.75m, depending on soil texture.

Emitter flow rate: 1.0 to 1.6 Liter / h, depending on soil texture.

Dripline installation depth in SDI: 0.3 m.

Source: Netafim.

Specific limits of irrigation water

Recent studies suggest that olives can be irrigated with water containing up to 3,200 mg / l of salt (ECw of 5 dS/m) with an SAR value of 18, producing new growth at leaf Na levels of 0.4 – 0.5% d.w.

Table 2.8: Irrigation water quality guidelines for olives

Water characteristics	Problem scale		
	None	Increasing	Severe
EC (dS/m)	< 2.5	3 - 5	> 5.5
Sodium (g/L)	0.25	0.3 - 1.0	> 1.2
Chloride (g/L)	0.35	0.4 - 1.5	> 1.8
Boron (ppm)	1 - 2		

Source: Chartzoulakis, 2005

2.10 Fertilization

Intensively grown olive trees will greatly benefit from a good nutrition regime. During the first years of the plantation a premium slow-release fertilizer, such as Multicote-Agri 17-9-16+2MgO augmented with trace elements, is recommended.

Alternatively, soluble fertilizers may be used with high efficiency, especially by Nutrigation. If the fertilizers are broadcasted separately, be sure to water very well after application.

Many growers in Mediterranean countries apply organic fertilizers every other year. Organically derived fertilizers are available, but they are often markedly more expensive per nutritive element unit. Top dressing with organic material such as composted manure or kitchen compost can be done, but the grower should consult carefully before using it because it is difficult to achieve a good balance of nutritional elements by this method. It is environmentally responsible but requires more study and understanding by the grower. Always avoid placing compost or any fertilizer next to the trunk of the tree.

Whatever type of fertilizer is used, it is best to feed lightly and often during the growing season. Avoid heavy applications of soluble fertilizers that could damage plants and leach or run-off into groundwater.

Application rate of mineral fertilizers should be based on the target yield, nutrient uptake, soil nutrient analysis, leaf nutrient analysis, leaf deficiency symptoms, results of fertilizer experiment, and nutrient recycling.

Mineral nutrition of olive plantations is presented in the next chapters of this brochure in greater depth.

2.11 Harvesting and curing

Table olives

Fruits that are to be processed as green olives are picked while they are still green but have reached full size. They can also be picked for processing at any later stage, through full ripeness. Ripe olives bruise easily and should be handled with care. Mold is also a problem for the fruit between picking and curing. There are several classical ways of curing olives. A common method is the lye-cure process in which green or near-ripe olives are soaked in a series of lye solutions for a period of time to remove the bitter ingredients, then transferred to water and finally to a mild saline solution. Other processing methods include water curing, salt curing and Greek-style curing. Both green-cured and ripe-cured olives are popular as a relish or snack. The black color of black olives is obtained by exposure to air after lye extraction and has nothing to do with ripeness.

Oil olives

For olive oil production, irrigation should be stopped for the weeks leading up to harvest to avoid accumulation of high moisture content in the fruit and difficulties during oil extraction. Optimum moisture content is 50%. Use freshly picked olives (no longer than 24 – 48 hours from picking to processor) for producing extra virgin olive oil. Harvest olive fruits at the correct time. Immature fruit will give less oil. Use the IOOC olive maturation index guide to ascertain the stages of olive ripening. A maturity index enables growers to evaluate varieties in order to specify the oil quality the producer wants to obtain and repeat in successive years. Methods of harvesting include manual, such as small hand rakes, picking bags with harness, pneumatic olive harvesters and limb shakers. Additional methods include mechanical harvesting such as trunk shakers, limb shakers, straddle harvesters and oscillating combs (singular or dual models).

The traditional method of beating olives off the tree is not recommended.

Figure 2.6: Mechanical olive harvesting in Israel

Mechanical harvest

High costs and low labor availability at olive harvest time are the main economic constraints in oil and table olive production, reaching 40% – 60% of the total income. This subject is the main reason for the adoption of mechanical harvesting solutions, using various types of tree shakers / vibrators.

Mechanical harvest has proven particularly difficult because (1) fruit require considerable force to be removed from the tree. (2) Trunks of olive trees become stout, fluted and knobby with age, which complicates the use of mechanical shakers that attach to the trunk, often resulting in tree trunk damage, bruised fruit, and poor removal efficiency. Hence there is limited acceptance of mechanical harvesters. Mechanical harvest equipment is not efficient enough and at optimal conditions (variety, tree shape, temperature, ripening, etc.) produces up to 85% fruit release, resulting in the necessity to follow up with manual picking.

The ratio between fruit mass and pedicel strength is relatively small as compared with other fruits. As a result, a huge amount of force is required to shake off the fruit from olive trees. Fruit damage is an industry concern because bruising may compromise the quality of the final product. Chemicals of various kinds were tested to promote pedicel loosening. Chemical harvest aids, such as pre-harvest treatment, facilitates fruit removal by lowering the mechanical force required to harvest the fruit, thus minimizing fruit damage. Fruit-specific abscission agents for loosening fruits are used in order to improve mechanical harvesting efficiency.

Numerous chemical products have been developed in order to ease the abscission of the fruits from the tree, thereby increasing the picking efficiency of hand-held, as well as mechanical devices. Most of these products are based on Ethrel® (2-Chloroethylphosphonic acid), which is converted in the leaves into the natural plant growth substance ethylene, which promotes natural fruit abscission in olives. Other compounds have been developed that are not based on interference with the hormonal balance of the plant, but have a specific and different mode of action. An outstanding example of this kind of product is Haifa Chemicals' product OliveDrop™, which not only acts as an abscission agent, but also supplies plant nutrients. OliveDrop™ also has practically no adverse defoliation effect, unlike other abscission agents. For more details, including test results, please refer to Chapter 5, paragraph 5.9.

3. The mineral nutrition of olive trees

Although the olive tree has relatively modest mineral nutrition requirements, it will respond to fertilizers with healthy vegetative growth and bountiful yield. It is important therefore to keep close, continuous track of the mineral condition of the tree to avoid periods of under-nutrition, which would jeopardize the entire year-long efforts. Moreover, as mentioned earlier, it is important to maintain a balanced mineral nutrition regime, with special focus on the correct amounts of nitrogen and potassium, in order to reduce the amplitude of alternate bearing.

3.1 Summary of main plant nutrient functions

Nutrient	Functions
Nitrogen (N)	Synthesis of proteins (growth and yield).
Phosphorus (P)	Cellular division and formation of energetic structures.
Potassium (K)	Transport of sugars, stomata control, cofactor of many enzymes, reduces susceptibility to plant diseases.
Calcium (Ca)	A major building block in cell wall and reduces susceptibility to diseases.
Sulfur (S)	Synthesis of essential amino acids cystin and methionine.
Magnesium (Mg)	Central part of chlorophyll molecule.
Iron (Fe)	Chlorophyll synthesis.
Manganese (Mn)	Necessary in the photosynthesis process.
Boron (B)	Formation of cell wall. Germination and elongation of pollen tube. Participates in the metabolism and transport of sugars.
Zinc (Zn)	Auxins synthesis; enzymes activation.
Copper (Cu)	Influences the metabolism of nitrogen and carbohydrates.
Molybdenum (Mo)	Component of nitrate-reductase and nitrogenase enzymes.

3.2 The three tools for optimal nutrient management

The three tools for optimal nutrient management are:

1. Observation of trees and environmental conditions.
2. Soil and water analysis.
3. Leaf analysis.

1. Observation

Visual symptoms should be used as an aid to interpreting soil and leaf analyses:

- Look for abnormal symptoms in foliage or growth.
- Look for significant variations in yield.
- Observation can suggest deficiencies of nitrogen, potassium and boron.

2. Soil analysis

Soil analysis is not accurate enough to be used to diagnose fertility needs in olives, but it is useful for determining pH and to diagnose salt problems (excesses or imbalances).

In spite of many discrepancies between soil tests and mineral leaf contents, some empirical relationships were found:

- A minimum P leaves content of 0.058 % corresponds to a soil-available phosphorus value of 4.35 ppm.
- P leaf content of 0.07 % (in dry matter) is suitable for rain-fed olive orchards, whereby exchangeable P in soil is ~8 ppm.
- When a leaf potassium content value of 0.43% is found (quite low!), it may correspond to soil-K availability of 80 ppm, where soil clay is less than 15%, but for clayey soils (> 15% clay), the minimal value of available potassium should be 110 ppm.

Soil analysis is performed to assess the need for soil amendment applications, e.g., lime application to adjust low soil pH, and gypsum application to adjust Ca:Mg ratio or to reclaim alkali soil. Ideally,
3 – 10 spots in a site should be sampled. Because soils differ in composition at different depths, the top 15 – 30 cm (6 – 12") should be a separate sample, as well as each subsequent 30 cm downward. Samples taken at different distances from the trunk may be combined, but different soil depths should be separate. Samples should represent the effective rooting zone. A soil auger may be used to obtain samples. Generally, about 1 liter (1 quart) of soil per sample is adequate. The testing lab will often provide an interpretation of the results, as well as suggestions for corrective action.

3. Leaf analysis

Initial leaf analysis should be undertaken when trees are two years old, and then on a regular 1 – 2 year basis. Ideally, a sample should be taken from similar trees. Different varieties or parts of the orchard with different soils, microclimates, or irrigation systems should be sampled separately. Samples should consist of a few leaves of as many similar trees as possible, selected at random throughout the orchard. Avoid sampling leaves from abnormal trees, unless this is the specific problem to be solved. In this case, the abnormal leaves or trees should become a separate sample.

Summer, and mainly July (Northern hemisphere) or at least 5 – 8 weeks after full bloom, is the best time to perform leaf analysis because the levels of most nutrients stabilize in the olive leaf during that time.

Leaf collection

- Remove 4 mature and healthy-looking leaves per tree from the middle of current season, non-fruit-bearing shoots.
- Pick these leaves from about 20 – 25 trees representing a homogenous plot of up to 10 ha.
- Wrap the leaves in paper bags or newspaper, but NOT in plastic, glass or other material which will cause humidity build-up.
- If testing for boron, mature fruit samples may be more reliable than leaf samples.

Interpretation of leaf analysis results is based on the relationship between leaf nutrient concentration and growth or yield. Comparing actual leaf nutrient concentration to reference values allows the diagnosis of nutrient deficiency, sufficiency or excess. Optimum tree nutrition could be achieved by combining this information with soil and environmental factors that affect tree growth, and symptoms of nutrient deficiency or excess.

Leaf analysis standards

Leaf analysis interpreted as indicated in Mediterranean countries (Table 3.1) is a useful guide for fertilizer management of olive plantations, and may promote more environmentally responsible use of fertilizers in olive orchards.

Table 3.1: Important nutrient level ranges in olive leaves from tissue analysis (dry weight basis)

Nutrient	Deficient	Optimum	Toxic
Nitrogen	< 1.4%	1.5 – 2.0%	> 2.55%
Phosphorus	< 0.05%	0.1 – 0.3%	> 0.34%
Potassium	< 0.4%	0.8 – 1.0%	> 1.65%
Calcium	< 0.6%	1.0 – 1.43%	> 3.15%
Magnesium	< 0.08%	0.1 – 0.16%	> 0.69%
Sulfur	< 0.02%	0.08 – 0.16%	> 0.32%
Iron	< 40 ppm	90 – 124 ppm	> 460 ppm
Zinc	< 8 ppm	10 - 24 ppm	> 84 ppm
Boron	< 14 ppm	19 – 150 ppm	>185 ppm
Manganese	< 5 ppm	20 – 36 ppm	> 164 ppm
Copper	< 1.5 ppm	4 - 9 ppm	> 78 ppm
Sodium			> 0.20%
Chloride		100 ppm	> 0.50%

Sources: Connell & Vossen, 2007; Producing Table Olives, by Stan Kailis, David Harris, 2007

3.3 Seasonal nutrient requirements of olive trees

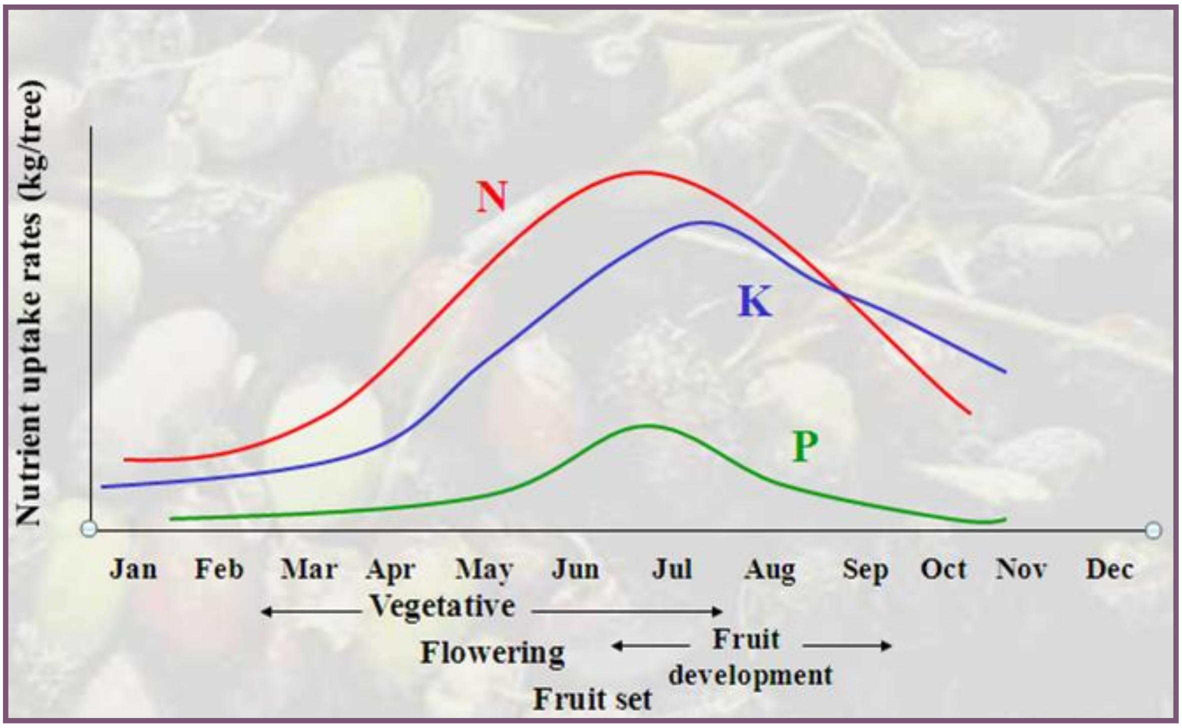


Figure 3.1: Seasonal nutrient requirements of olive trees

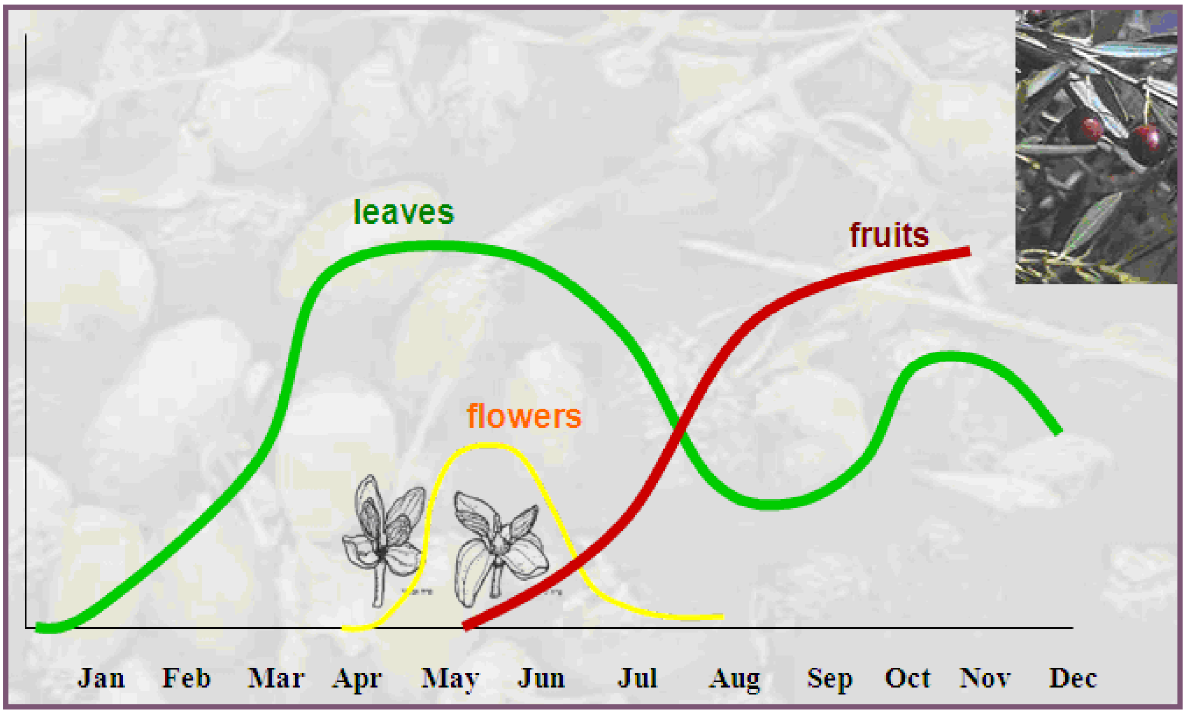


Figure 3.2: Seasonal changes in requirements of olive trees for nutrients, by organ

3.4 Main plant nutrients, their rates in olive leaves, deficiency symptoms and application rates and methods

Nitrogen (N)

Nitrogen is one of the essential nutrients needed by plants, mainly as a building block of all proteins in the cytoplasm and the enzymes of the organism, and for chlorophyll buildup associated with the photosynthetic activity. Nitrogen uptake and metabolism is a key factor for olive roots to change the pH of their surrounding solution, which facilitates nutrient uptake by increasing their availability to the plant.

Functions

Nitrogen is one of the primary nutrients absorbed by olive roots, preferably in the form of the nitrate (NO3 -) ion. Nitrogen is a constituent of amino acids, amides, proteins, nucleic acids, nucleotides and coenzymes, hexosamines, etc. This nutrient is equally essential for good cell division, growth and respiration.

Because olives usually require larger amounts of nitrogen than other mineral nutrients, this is the most commonly applied fertilizing element in olive orchards.

The composition of virgin olive oil is affected by cultivar, fruit ripeness, agro-climatic conditions and growing techniques. Several studies have shown the effects of nitrogen fertilization on oil composition. Annual applications of nitrogen influence olive oil quality, especially fatty acid composition and antioxidant compounds.

Timing of side dressing

For highest uptake of nitrogen by the tree, and optimal effect on floral induction, nitrogen should be in the root zone just before the period of greatest uptake, i.e., just ahead of shoot growth and bloom in the early spring to early summer.

In dry farming orchards, nitrogen fertilizer is added to the soil in the fall to mid-winter, in order to have available nitrogen during the critical period. Where low rainfall prevails, nitrogen should be applied at the beginning of the floral induction period, while in regions enjoying higher rainfall, it is a common practice to apply nitrogen at the end of this period.

The total annual rate in bearing orchards is 0.5 – 1.0 kg / tree, (1 – 2 lbs. / tree).

- If only broadcasting is possible, it is best to apply half in January and half in October, to moderate alternate bearing.
- If fertigation systems are available, it is best to apply some 25% of the annual rate after fruit-set in order to contribute to vegetation and high yield in the next year.

Excessive amounts of nitrogen before fruit-setting may lead to high fruit load, resulting in small size fruits and alternate bearing (see Table 3.2).

Table 3.2: The effect of N rates on yield & size at a heavy crop year, cv. Mission, Palermo, Ca.

N application rate		Yield		Share of yield fit for canning
lbs. / tree	kg / tree	lbs. / tree	kg / tree	%
Unfertilized	Unfertilized	49	22.1	97
1/2 lb.	0.225	172	77.4	92
1 lb.	0.45	196	88.2	63
3 lbs.	1.35	226	101.7	43

Source: H.T. Hartmann, UC Davis

Over-fertilization of nitrogen causes the accumulation of nitrogen in fruit, which negatively affects some components. Excessive nitrogen reduces polyphenol content, thereby lowering the main natural antioxidants, the oxidative stability of the oil and its bitterness.

Foliar application of nitrogen

If nitrogen application was not done by soil application ahead of time, it can also be applied in the critical stages by foliar fertilization. Urea gives good results at a concentration of up to 3% – 4%. Foliar fertilization is effective in dry farming orchards where the absorption of nitrogen through the root system is very restricted.

Nitrogen-containing fertilizers:

Fertilizer	% N
Urea	46
Ammonium nitrate	33.5
Ammonium sulfate	20.5

Fertilizer	% N
Potassium nitrate	13
Magnesium nitrate	11
Calcium nitrate	15.5

Symptoms of nitrogen deficiency

- Small, yellowish leaves
- Poor shoot growth
- Sporadic bloom
- Poor fruit-set

Figure 3.3: N deficiency symptoms: pale color, lack of new growth

Phosphorus (P)

Functions

Phosphorus is one of the three primary nutrients and is absorbed by olive roots mainly in the form of orthophosphate ($H_2PO_4^-$). An adequate supply of phosphorous at early growth stages is important for producing healthy rhizome and a strong root system, root growth and development of reproductive parts. It plays a key role in reactions involving ADP & ATP, essential for energy storage and transfer for subsequent use in growth and reproductive processes. In fact, almost every metabolic reaction of any significance in plants proceeds via phosphate derivates. Phosphorus is also an important structural component, as it is a component of sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid, and more.

This element is necessary for many life processes such as photosynthesis and metabolism of carbohydrates. It helps plants, speeds-up the maturity process, and increases disease- and drought-stress resistance. It also influences flower setting and general vegetative growth.

Phosphate fertilization is especially necessary in acid soils and soils containing high amounts of calcium carbonate. The same applies to orchards planted in shallow, infertile soils or in new, irrigated olive orchards (1 – 10 years old) in which ample nitrogen is used every year.

Some P deficiency symptoms are similar to those of nitrogen deficiency, such as small leaf size, but without: leaf deformity, red leaf, light green leaf tips or dark green color (Figures 3.4 & 3.5).

The characteristic visual symptom of phosphate deficiency is widespread chlorosis of the leaves.

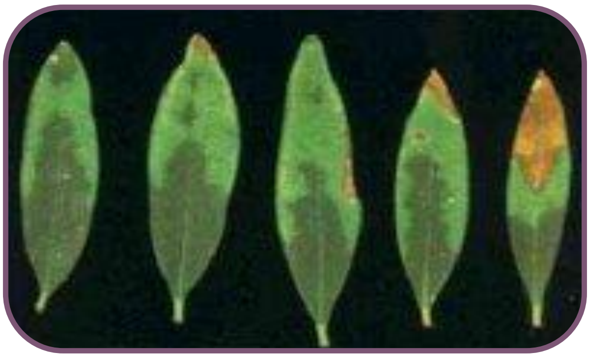


Figure 3.4: Gradual P deficiency stages

Figure 3.5: Severe P deficiency

However, it is not a safe diagnostic criterion because it is often confused with other causes (e.g., nitrogen deficiency). Safe diagnosis can be done by chemical leaf analysis.

When phosphate fertilization is necessary, it should not exceed 20% – 30% of the amount of nitrogen added. So, if 1 kg / tree of N is added (e.g., 5 kg ammonium sulfate), the corresponding amount of phosphate should not exceed 200 – 350 g / tree of P_2O_5 (e.g., 1.0 – 1.7 kg of SSP, 0-20-0). As a rule of thumb, it is suggested to add 500 g / tree of P_2O_5 (e.g., 2.5 kg of SSP) in a two-year period.

In a case of severe phosphate deficiency, an amount of 4 – 5 kg / tree of P_2O_5 (e.g., 20 – 25 kg SSP) is added in trees at the full production stage. For younger trees, smaller amounts (1 – 8 kg SSP) are added, depending on age and development stage.

Source: Oliveoilsindia.com 2009-2010

Specialized laboratories can test for soil-P in three different ways – Mehlich III, Bray II, and Olsen – to optimize soil management. Thus, total P, the immediately available P, the amount in reserve that can become available, and the amount in the soil that is unavailable can be assessed. Hence, it is advisable to perform a soil test every other year, and apply P to the soil only if it is needed, avoiding excessive P build-up in the soil. It is perfectly fine to apply P fertilizer only once every two - three years, depending on testing results.

For soil application it is suggested to use SSP, Single superphosphate (0-20-0), or TSP, Triple superphosphate (0-46-0).

For application by nutrigation, fully soluble fertilizers are suggested, such as:

- Mono-ammonium phosphate (12-61-0)
- Di-ammonium phosphate (21-53-0)
- Mono-potassium phosphate, MKP (0-34-52)

Potassium (K)

Potassium is not concentrated and does not form a constitutional part of any unique tissue or organ in the plant, but plays an important role in a multitude of physiological activities within the plant cell as well as in the coordination between tissues and organs in the whole plant.

Functions

Potassium is required as a cofactor for over 40 enzymes. It has a role in stomatal movements by maintaining electro-neutrality in plant cells. It is required for many other physiological functions, such as formation of sugars and starches, synthesis of proteins, normal cell division and growth, neutralization of organic acids and involvement in enzymatic reactions. Potassium affects transpiration rate by regulating stomata opening and closure, where a high transpiration rate increases nutrient absorption. Regulating stomata opening and closure also regulates carbon

dioxide supply and improves efficiency of sugar use, increases water uptake and is consequently helpful in cell expansion. It also increases plant resistance to biotic and abiotic stresses such as frost tolerance, by decreasing the osmotic potential of cell sap due to higher ratio of unsaturated / saturated fatty acids. In addition, it assists in drought resistance, regulation of internal water balance and turgidity, regulation of Na influx and / or efflux at the plasmalema of root cells, chloride exclusion by rough selectivity of fibrous roots for K over Na and imparting salt tolerance to cells by increasing K holding capacity in the vacuole against leakage when Na is incurred in an external medium. Sub-optimal potassium status reduces nitrogen uptake.

A few instances of the major role of potassium in the water management systems of the olive tree are cited below.

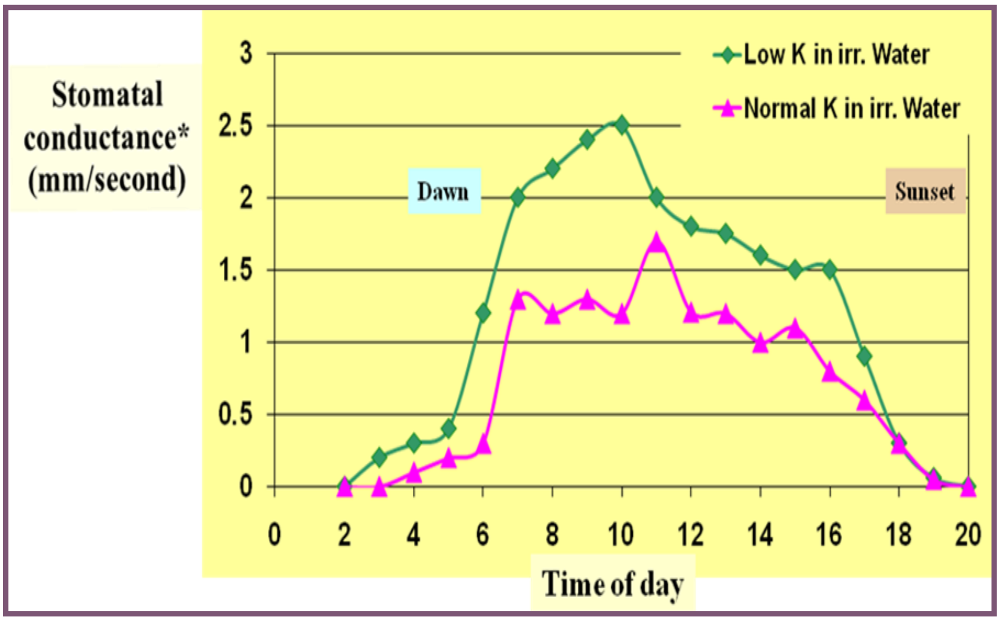


Figure 3.6: Potassium deficiency increases stomatal conductance in olive trees
Cultivar: 'Chemalali de Sfax'. Source: Arqero, Barranco & Benlloch (2006)

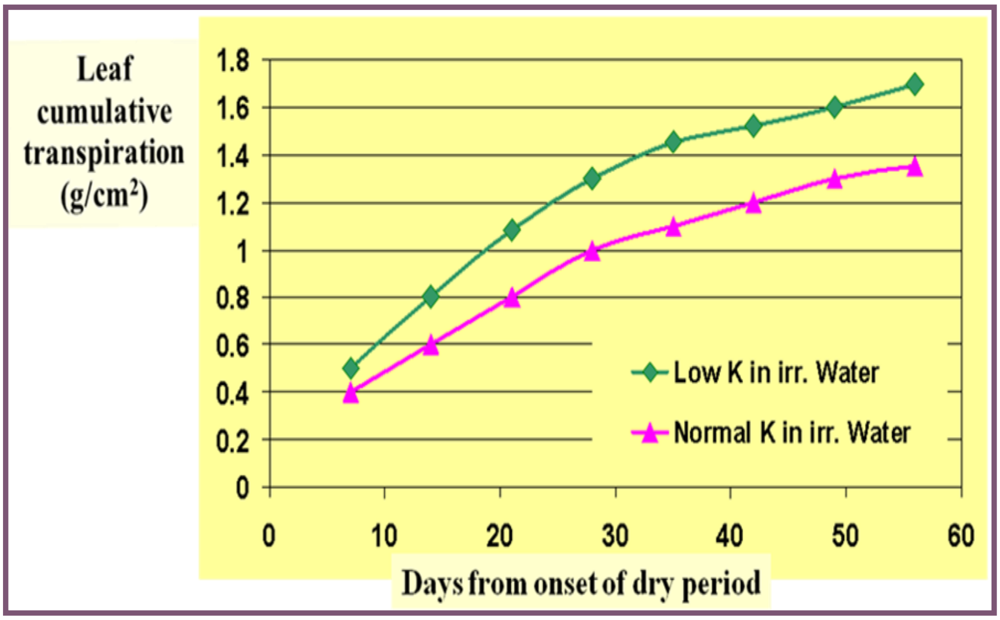


Figure 3.7: Potassium deficiency increases transpiration rate of olive trees
Cultivar: ''Lechin de Granada'.
Source: Benlloch-Gonzalez, Arqero, Fournier, Barranco & Benlloch (2008)

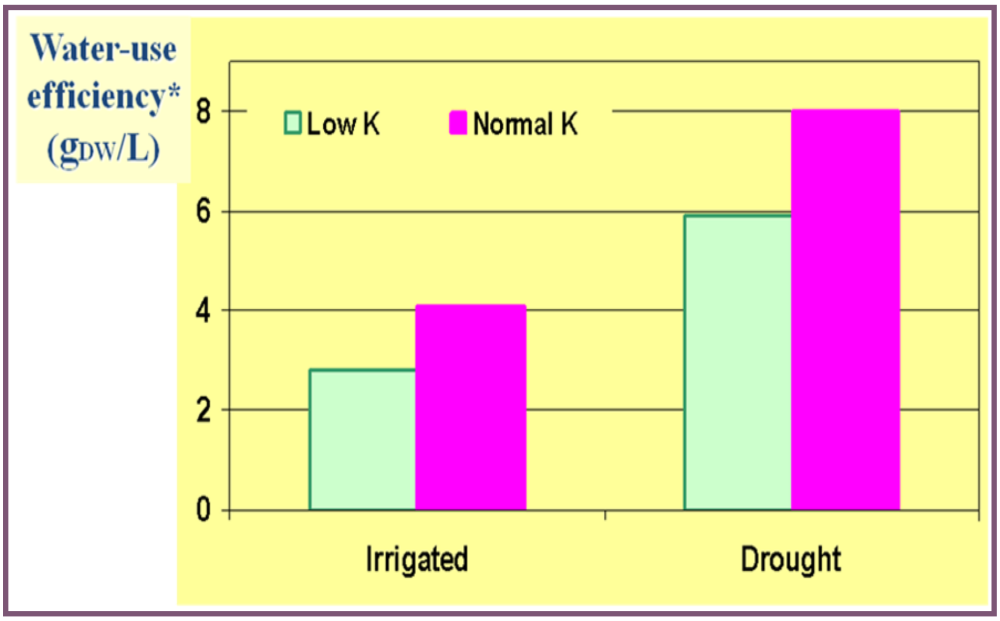


Figure 3.8: Potassium deficiency reduces water-use-efficiency in olive trees Cultivar: 'Chemalali de Sfax'. Source: Arqero, Barranco & Benlloch (2006)

Olive trees demand this nutrient. High amounts of potassium are removed from the soil with fruit harvest and pruning, particularly in high yield seasons. Regular potassium fertilization is required in order to maximize yield and quality (see Table 3.3), especially in orchards where no potassium fertilizer has been added for several years.

Potassium is a mobile nutrient and thus deficiency is most clearly shown in older leaves. They present pale chlorotic patches with the appearance of "burns" (necrosis) at the leaf tips and edges. These areas of dead tissue progress from the tip to the base, and from the leaf margin towards the intervein area. The leaf tip tends to curve downwards.

Potassium deficiency diagnosis is not safe on the basis of these symptoms, and must be further confirmed by leaf analysis. Deficient leaves contain about 0.1% – 0.3% potassium (on a dry basis), whereas the content of well-supplied leaves ranges from 0.4% – 1.7%.

Table 3.3: Tree response to potassium fertilizer

	Yields (kg / tree)	% Canning fruit		
	4 year mean	1st year	2nd year	3rd year
Unfertilized	16.3	20	19	5
K+ mass dose	68.9	70	62	33

Source: H.T. Hartmann, UC Davis

Potassium deficient leaves (Figures 3.9 – 3.12) are light green and, in cases of severe deficiency, show tip burn as well as dead areas in the leaves. Continuous deficiency will cause twig die-back, reduced fruit number and smaller fruit size.

Figures 3.9 - 3.12: Potassium deficiency symptoms in olive leaves in order of severity, including twig die-back

The following potassic fertilizers are available:

- **Potassium chloride** (Muriate of potash), 0-0-60. Highest in potash content, but also carries high chloride that may accumulate in the soil and bring about chloride toxicity. See more on chloride toxicity at the end of this chapter.
- **Potassium sulfate**, 0-0-50. Non-chloride potassic fertilizer, with relatively low solubility.
- **Potassium nitrate**, 13-0-46. Highly soluble, carries with it a considerable amount of nitrogen, in the nitrate form, which is highly available and nutritious for the tree in most stages. This fertilizer is also the preferred one where soil pH is somewhat low. The absorption of the nitrate component will increase soil pH.
- **Mono-potassium phosphate** (MKP) 0-32-54. Highly soluble, carries with it a considerable amount of phosphate that is nutritious to the tree in several growth stages.

The amount of applied potassium should be determined in combination with nitrogen. In olive orchards in which no potassium has been used in the past, it is preferable to add twice as much potassium as nitrogen. For example, if 0.5 kg / tree of N (i.e., 2.5 kg ammonium sulfate) is applied, then 1 kg / tree of K (i.e., 2 kg potassium sulfate) must be added. Later on, potassium dosage is adjusted to be equal to nitrogen. After high yield seasons, it is preferable to increase potassium to supplement the amount that is being removed. Leaf analysis, wherever possible, may give better direction for potassium fertilization.

Many times, potassium deficiency is due to low soil moisture (drought); potassium is fixed by clay minerals in the soil and thus trees cannot take it up from the soil. The problem can be relieved by selecting cultivating techniques that enhance the growth of the root system and ensure adequate soil moisture. In this case, larger amounts of fertilizer are added, usually 10 – 15 kg of potassium per tree. Alternatively, half of the above-mentioned amount can be added in the winter in the form of potassium sulfate, and the remaining amount in the form of potassium nitrate through the irrigation system. Potassium nitrate is applied through the irrigation system at a dose of 300 – 500 g / tree after fruit-setting.

Potassium should be applied to the soil at the rate of 2.3 – 4.6 kg (5 – 10 pounds) of pure potassium per tree, or about 280 – 560 kg / ha (250 – 500 pounds / acre). The smaller rates correspond to sandy, or light-textured soils, while the greater rates apply to heavier soils. Where there is no fertigation system it is recommended to apply the potassium fertilizer once a year between December to January (northern hemisphere) to be washed into the soil by winter rainfall. In such cases, the potassium fertilizer should be banded alongside the row of trees or in a circle around the tree, where it would be absorbed by the soil by the drippers / sprinklers/ jet emitters. Broadcasting of the fertilizers where there is no active root zone will be of no avail. In drip-irrigated plots, application can be made under the emitters. The best would be to acquire a fertigation system and the fertilizer should be dissolved and distributed via the irrigation system (fertigated). **Regular K inputs maximize yield and quality**.

When potassium is notably deficient, a foliar spray of 1.2% (e.g., 10 pounds per 100 gallons) potassium nitrate, such as Multi-K, can quickly correct the deficiency. The new vegetation in the spring will absorb it very quickly and results will start to be obvious within a week.

Potassic fertilizers (e.g., Multi-K), should be applied in irrigated orchards in the spring and during the entire growing season.

Maintaining soil acidity at the right pH level (in the region of 6.5) is critical for facilitating the optimal uptake of other nutrients. Multi-K, due to the presence of nitrate-nitrogen, increases soil pH of acidic soils in the root zone.

Magnesium (Mg)

Functions

Magnesium is a secondary plant-nutrient, absorbed as Mg2+. Magnesium is a crucial constituent of the chlorophyll molecule. It is required, nonspecifically, by a large number of enzymes involved in phosphate transfer. It is involved in photosynthesis, carbohydrate metabolism, synthesis of nucleic acids, related to movement of carbohydrates from leaves to upper parts, and stimulates P uptake and transport in addition to being an activator of several enzymes.

The main symptom of magnesium deficiency is the chlorosis of leaves that begins from the top or the edges of the leaf and spreads gradually to the whole leaf area. Other symptoms include severe leaf shedding and a poor vegetative cycle.

Magnesium deficiency is best controlled by soil application, or foliar spray of magnesium sulfate ("Epsom salt") or magnesium nitrate (11-0-0-16MgO), such as Magnisal™.

Sulfur (S)

Functions

Sulfur, also a secondary plant nutrient, is essential for protein formation as a constituent of the three amino-acids cystine, cysteine and methionine. Sulfur is required for the formation of chlorophyll and for the activity of ATP-sulfurylase. These essential functions enable the production of healthy and productive plants, which are preconditions for high yields and superior quality.

Sulfur is best supplied by ammonium sulfate and potassium sulfate.

Source: Producing Table Olives, By Stan Kailis, David Harris

Calcium (Ca)

Functions

Calcium is also one of the secondary plant nutrients, absorbed by plant roots as Ca2+. Calcium is a constituent of the middle lamella of cell walls as Ca-pectate. Calcium is required as a cofactor by

some enzymes involved in the hydrolysis of ATP and phospholipids. It is an important element for root development and functioning, a constituent of cell walls and is required for chromosome flexibility and cell division.

Calcium deficiencies take place only in soils lacking this element, e.g., washed soils in tropical regions. The main symptom of calcium deficiency is the chlorosis starting at the tips of the leaves, like in boron deficiency, but in this case the veins in the chlorotic area of older leaves become white. Other deficiency symptoms are general poor growth, especially in the roots and shoots. Unlike boron deficiency, there is a lack of young shoots (Figure 3.13).

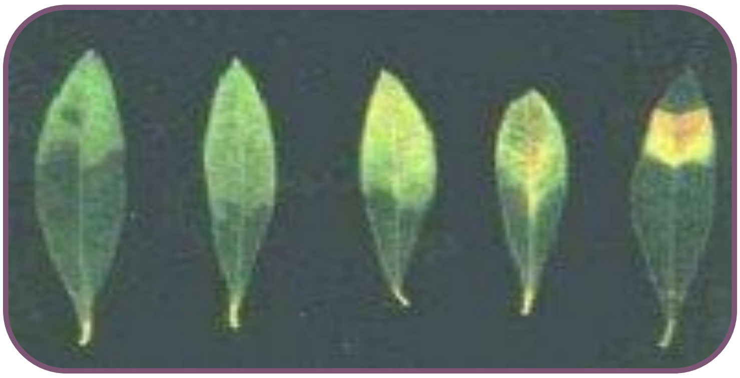


Figure 3.13: Calcium deficiency

Calcium deficiency is corrected rather easily by adding 5 – 10 kg of calcium oxide per tree. To avoid calcium deficiency, soil pH must be determined before planting a new orchard. The amount of calcium added must be determined after soil analysis.

Calcium nitrate (15.5-0-0-26.5), e.g., Multi-Cal, is an optional calcium fertilizer that, due to its excellent solubility, can be used in fertigation systems.

Trace elements

Major sources: Producing Table Olives, by Stan Kailis; David Harris, 2007.

The olive tree requires small amounts of boron, zinc, manganese, copper and molybdenum. A deficiency in any of these elements can reduce growth and fruiting. Deficiencies of trace elements are commonly associated with alkaline, lime-rich (calcareous) soils, where they are retained in an oxide form. Lowering soil pH by adding elemental sulfur, which is converted to an acid form by microorganisms, can overcome this problem. Sulfur in the form of sulfate is not an acidifying material.

Boron (B)

Sources: http://www.summerlandolives.com.au/; http://www.oliveoilsource.com/

Functions

Boron plays a role in cell wall development and is important in pollination, fruit development and the translocation of sugars. An adequate supply of boron is important for flowering. The quality of olive fruit is affected if boron is deficient.

Within plants, boron is relatively immobile. It is not readily relocated from old to young plant tissue. Plants are therefore dependent on a continuous uptake of boron during the growing season. In this respect, its behavior in plants is very similar to calcium (both are immobile) and deficiency symptoms can be confused.

Boron deficiency symptoms

Boron deficiency occurs more commonly in dry weather. Microbial activity in the soil is reduced, and the movement of boron in the soil solution to plant roots is restricted. Boron is not very mobile, so deficiency appears in the young leaves.

The main symptoms are:

- Leaves with deficiency contain less than 20 ppm boron, while those from healthy trees have more than 20 ppm (on a dry basis).
- Leaves around the terminal bud turn light green at their tip and eventually fall off.
- Gradually, the same symptom appears on leaves near the base of the shoots, which appear dry at their edges.
- Later growth shows small and distorted leaves that are stunted, fragile and finally drop off. If a small piece of the stem is cut off with a sharp knife, a brown discoloration shows due to necrosis of the cambium.
- Chlorosis (yellowing) and death of the growing points.
- Trees suffering from boron deficiency appear chlorotic from a distance and delay entering the vegetative stage.
- Distortion, thickening and cracking of stems. The stems may be hollow or brittle.
- Formation of rosettes, growth of auxiliary buds (side shooting), bushy growth and multiple branching. Shortened internodes and secondary shoot production at the tree base.
- Thickening, twisting and failure of roots to spread out or develop properly. In some cases the roots may show excessive branching.
- Dropping of buds or blossom. Poor fruit-set.
- Fruits and seeds may also be affected. Brown sunken areas may develop in fruit, in a symptom called "Monkey-face".

Figure 3.14: Boron deficiency - leaves with dead tips and a yellow band, but still green at the base, and with a rosette form

Figures 3.15 & 3.16: Boron deficiency symptoms on olive leaves

Figure 3.17: Boron deficiency effect on fruits: the "monkey face" symptom and premature fruit drop

Correcting boron deficiency

Boron is taken up by plants as undissociated boric acid H3BO3.

Boron deficiency is corrected by broadcasting 113 – 225 g (0.25 – 0.5 pound) of a 14% – 20% boron fertilizer per tree, or 28 – 56 kg / ha (25 – 50 pounds / acre) on the soil surface within the drip line during winter. One treatment will last for several years, but because of its mobility in the soil and susceptibility to leaching, annual applications of boron are recommended in most situations. Frequent applications at low rates also minimize the risk of toxicity.

BE VERY CAREFUL not to apply too much since toxicity may occur.

A fast correction of boron deficiency in a specific season can be achieved by a foliar spray of 0.05% – 0.1%, (i.e., 7 – 14 ounces per 100 gallon of water) of Borax. Spray should be applied until runoff is achieved. Such applications prior to flower bud initiation or immediately prior to flowering significantly improve fruit-set, even in trees with no visible symptoms and low, but not deficient leaf boron levels.

Boron fertilizers

Borax, (11% B) is a fine crystalline product for dry soil application, or by application in solution to the soil or foliage.

Granubor, (15 % B) and Borate Granular, (14.3 % B) are granulated fertilizers, which makes them more suitable for dry application by machine to the soil. They can be used on their own or in blends with other fertilizers. Granubor and Borate Granular do not dissolve, hence are unsuitable for foliar application.

Solubor, (20.5 % B) is a fine, soluble powder for application in solution through a boom-spray to the soil or foliage. Application rate is 1 – 1.5 g / L. Solubor is more soluble than Borax, especially in cold water, and is the recommended choice for foliar applications or ground applications in solution.

The marketplace for boron products also offers high analysis Boron solutions, designed to rapidly correct boron deficiencies in all crops in both soil and foliar applications. Some of them allow enhanced foliar and root uptake due to formulation with organic acids, which assist with assimilating the boron in the plant. They can be applied as a foliar spray, or by fertigation, .e.g., AgroDex Boron, (10%). Application rate: 1 – 2 L / ha.

Boron toxicity symptoms

Olives are classified as "somewhat tolerant" of boron in irrigation water, accepting water levels of boron of 1 to 2 mg / liter (roughly equivalent to 1 – 2 ppm). Water with 12 ppm will cause problems for olives that are not tolerant to high levels of boron. A soil analysis would be the only way to determine if there is a soil problem. One of the most common causes is over-fertilization with or poor placement of boron fertilizer.

Toxicity symptoms

In the early stages, the symptoms of boron toxicity are normally expressed as marginal and tip chlorosis of the older leaves. Moderate to severe toxicity produces progressive leaf necrosis, beginning at the tip or margins and gradually covering the whole leaf, resulting in premature leaf drop.

Zinc (Zn)

Functions

Zinc activates a number of enzymes and is important in the biosynthesis of auxins, such as IAA.

Zinc levels are adequate in the olive tree if zinc concentration is higher than 10 ppm on a dry weight basis.

Zinc deficiency symptoms

Yellow spots may appear on adult leaves, small pale-green leaves, with interveinal chlorosis. Otherwise, signs are similar to iron- and manganese-deficiency – reduced shoot growth resulting in rosette formation (see Figure 3.18).

Figure 3.18: Zn deficiency in olive leaves

Correcting zinc deficiency

Replenishment of Zn is especially important in early spring. Correction of zinc deficiency can be done by foliar spray with 0.1% zinc sulfate or by zinc-containing fungicides if these are planned for actual fungal diseases.

Iron (Fe)

Functions

Iron, a micronutrient, is a constituent of cytochromes and non-haeme iron proteins. It is involved in photosynthesis and N2 fixation and respiratory linked dehydrogenases. Iron is also involved in the reduction of nitrates and sulfates and in reduction processes by peroxidase and adolase.

Iron deficiency can occur even though the soil has an abundant amount of iron, but it is unavailable due to a high pH of the soil or irrigation water. Competition with other ions, such as manganese, zinc and potassium, can also contribute to iron deficiency by displacing iron from chelating agents in the soil.

Iron deficiency symptoms include yellowing of immature leaves, with the mid-rib and veins greener than inter-vein areas. Fruits tend to be pale-yellow rather than green-yellow.

Correcting iron deficiency

Iron deficiency can be corrected by foliar spray of iron chelates, e.g., EDTA-Fe, which contains 12% Fe, and should be applied at 50 g / L of water. Foliar sprays of iron are quick acting, but are not long lasting. The same product can be applied by fertigation to the soil for a longer effect. Other treatments are drenching the soil with iron sulfate (20% iron), and should be applied at 20 g / m2 in water, or injecting iron sulfate or iron citrate directly into the tree trunks. Other commercial iron chelates are EDDHA-Fe, (e.g., Multi-micro EDDHA Fe 6%), and DTPA.

Manganese (Mn)

Functions

Manganese is required for the activity of dehydrogenases, decarboxylases, kinases, oxidases, peroxidases, and non-specifically by other divalent cation-activated enzymes. It is required for photosynthetic evolution of O2, besides involvement in production of amino acids and proteins. Manganese has equally essential roles in photosynthesis, chlorophyll formation and nitrate reduction.

The concentration of metallo-enzyme peroxidase in the leaf is considered to be the best marker of Mn deficiency.

Manganese deficiency symptoms

Starts with interveinal chlorotic mottling of immature leaves, similar to that seen in iron deficiency. Flower buds often do not fully develop, turn yellow and abort.

In severe deficiency, new growth is yellow in color but, in contrast to iron deficiency, necrotic spots usually appear in the interveinal tissue.

Correcting manganese deficiency

Manganese is absorbed by the plant roots in the form of Mn2+. Mn deficiency can be corrected by:

- Application of acidifying fertilizers such as elemental sulfur and ammonium sulfate.
- Foliar spraying with manganese sulfate at 0.2%, or manganese-containing fungicides.
- Waterlogging of the soil that depletes soil oxygen, releasing high amounts of soluble ferrous and manganese cations, could be considered, but excessive concentrations may be toxic to the roots. Also, olive trees are intolerant to waterlogged soil, so this method should be ruled out!

Copper (Cu)

Functions

Copper plays an active role in some enzymes performing key functions like respiration and photosynthesis, e.g., cytochrome oxidase, diamine oxidase, ascorbate oxidate, phenolase, leccase, plastocyanin (a protein having ribulose biphosphate carboxylase activity), ribulose biophosphate oxygenase activity, superoxide dismutase, plant acyanin and quinol oxidase. Copper is also a constituent of cytochrome oxidase and heme in equal proportions. Cu-proteins have been implicated in lignification, anaerobic metabolism, cellular defense mechanism, and hormonal metabolism. Copper proteins exhibit electron transfer and oxidase activity. It also acts as a terminal electron acceptor of the mitochondrial oxidative pathway.

Copper deficiency symptoms

Copper deficiency symptoms are often found in sandy soils. This problem is exacerbated if excessive amounts of phosphorus fertilizers are used. Copper deficiency symptoms are stunted growth, distorted leaves, leaf rosettes and pale yellow-white leaves.

Correcting copper deficiency

Application of copper sulfate at 0.25 – 0.5 kg / tree to the soil, or foliar sprays as Bordeau mixture, or copper sulfate at 0.05%.

Beware of over-application of copper. It can be toxic to the tree and to soil microorganisms.

Molybdenum (Mo)

Deficiencies are rare but more likely in acid soils due to low bioavailability. Symptoms often consist of interveinal chlorosis in older leaves. Young leaves may be severely twisted.

Chloride (Cl)

Functions

Chloride is required by all plants in very minute amounts, similar to iron, whose normal concentration is about 100 ppm.

- Chloride is essential for the proper function of the plant stomata, thus controlling internal water balance.
- It also functions in photosynthesis, specifically the water splitting system.
- It functions in cation balance and transport within the plant.
- Research has demonstrated that chloride diminishes the effects of fungal infections in an undefined way.
- It is well documented that chloride competes with nitrate uptake, tending to promote the use of ammonium N. This may be a factor in its role in disease suppression, since high plant nitrates have been associated with disease severity.

Although chloride is classified as a micronutrient, it is generally applied in very high rates by irrigation water. Additionally it is often supplied by commodity fertilizers, e.g., potassium chloride (MOP) and calcium chloride, resulting in a very marked uptake that will bring its concentration to the level of a secondary element such as sulfur, namely ~0.5%, which is about 5,000-fold of the required rate!

It was found in an experiment that increasing the salinity of soil solution results in accumulation of Na and Cl in leaf, shoot and root tissues of olive trees. Simultaneously, K and Ca concentration are decreased, but Mg content is not affected by the salinity stress.

Source: Al-Absi, Qrunfleh, & Abu-Sharar, 2002.

Chloride toxicity

Chloride accumulation to these high rates can develop into a serious problem. The chloride anion markedly reduces plant vigor and tends to accumulate in the leaf margins, producing leaf-edge scorching and necrosis (tissue death), that stems from concentration levels of up to 3%! Such leaves are prone to premature leaf abscission and reduced photosynthesis activity.

Therefore, the use of high chloride water, especially when there is a Ca / Cl ratio of less than 2:1 in the irrigation water, is highly risky. A water test is important. For obvious reasons, don't use fertilizers high in chloride or that contain much muriate of potash (MOP; potassium chloride) or calcium chloride.

Chloride toxicity symptoms

Typical salt toxicity symptoms are dead leaf edge, leaf drop and necrosis of stem tip. Toxicity symptoms appear above 50 mM of NaCl, and become more severe at high salinity levels.

Figure 3.19: Typical salt toxicity symptoms in the olive tree are dead leaf edge, leaf drop and necrosis of stem tip
Source: Chartzoulakis, 2005

4. Fertilization practices

4.1 Soil amelioration

Correcting acidic soil pH

As noted above, olive trees are quite tolerant when it comes to soil pH. When soils are overly acidic, lime is commonly used to correct the pH. The amount required varies with soil texture. The approximate amount of finely ground limestone needed to raise the pH of an 18 cm (7 inch) layer of soil by one pH unit from an initial pH of 4.5 or 5.5 ranges from about 2 MT / ha (0.5 short ton / acre) for sandy soil to about 8 MT / ha (2 short tons / acre) for a clay loam. Usually, only the surface becomes acidic enough to require liming.

Correcting sodic and alkali soils and sodic irrigation water

Sodic soils can be corrected by the application of gypsum. Application rate can be determined by a lab analysis. After the gypsum is applied, the displaced sodium must be leached below the root zone. Organic materials such as manure, cover crop or crop residues may help improve the soil structure for leaching. In established orchards, heavy irrigation during the dormant period minimizes the damage to tree roots from lack of aeration.

There is a close association between the composition and concentration of soil salts and salts in irrigation water. When used for irrigation, water with high sodium relative to calcium and magnesium is likely to result in a sodic soil, and therefore needs to be treated before use, or it may jeopardize the long-term wellbeing of the orchard.

Source: http://www.oliveoilsource.com/page/fertilizers-and-amendments

As mentioned above (Chapter 3, "The mineral nutrition of olive trees"), alkali soils may be acidified to the norm required by olive trees by the application of elemental sulfur. Sulfur in the form of sulfate is not an acidifying material.

It is advisable to acidify the soil gradually, over several years. Two small applications of acidifying material a year apart are better than a single, large application. Soil acidification reactions may take a year or more to complete, so check soil pH annually to monitor the change. Check pH at the same time each year, as soil pH varies seasonally.

Acidification before planting

The most effective approach is to add elemental sulfur over a period of years, monitor soil pH and wait until the desired pH is reached before planting. Add elemental S according to the clay content of soil. Mix the sulfur into the soil. Examples for application rate:

- For sandy soil, add 450 – 900 kg of elemental S per 1ha.
- For clayey soil, add 1.8 – 2.25 ton of elemental S per 1ha.
- Soil with high organic matter content also requires more elemental S than sandy soil, to achieve the same pH decrease.
- Soils with combined high organic matter and medium clay content, need 1.8 – 2.25 ton elemental S per 1ha. A logical approach is to apply S in the fall and test the soil pH in the spring. The process should be repeated if the desired pH has not been attained.

Acidification of the soil of an existing orchard

Dig a minimum of 4 holes per tree, (preferably 8 – 12), at least 30 cm deep, and 10 – 20 cm in diameter, near the drip line. Mix ~60 g elemental S with the soil removed from each hole. Refill the holes with the soil and water sparingly. Keep the soil around the plant moist, but not wet. This procedure can be performed at any time of the year, but fall is best.

4.2 Fertilization as a means to assure high soil fertility

The fertilization practices in traditional, extensively-cultivated olive orchards are based mainly on tradition, repeating the same fertilization program every year, enriched by neighbors' testimonials. This practice leads to arbitrary application of excessive rates of some fertilizers, mainly N and, at the same time, to a lack of other nutrients that could be necessary at this growing stage. Also, the excessive application of non-required fertilizers may cause environmental degradation and negatively affect productivity and olive oil quality.

From a modern, rational point of view, any amount of a nutrient must be supplied only when there are solid proofs, such as visual and laboratory test results, showing that it’s really needed. For this purpose, leaf-nutrient analysis provides an indication of tree nutritional status, featuring an important tool for determining fertilization requirements.

Fertilization rate can be estimated by the amount of nutrients taken up by the trees and removed from the soil by fruits and pruned branches that are taken away from the plot and by tree mass growth where, although the tree remains in the plot, its nutrients are not available for further growth. All these nutrients need to be returned to the soil in order to retain its fertility for further growth and fruit production.

4.2.1 Nutrient uptake / removal

Table 4.1: Nutrient demand / uptake / removal in main olive producing countries

Nutrient uptake - macronutrients				
		g / tree / year		
Country	Source	N	P_2O_5	K_2O
Tunisia	Rey	578	67	502
France	Bouat, 1968	300	60	200
Spain (Jaen)	Llamas, 1983	310	75	560
Italy	Pantanelli	276	142	488

Source: World Fertilizer Use Manual, IFA, 1992

Table 4.2: Macro plant nutrients removed by 1 ton of fruit

N	P	P_2O_5	K	K_2O
Kg				
9.8	11.3	25.9	10.3	12.4

Source: Kinoch: RSA

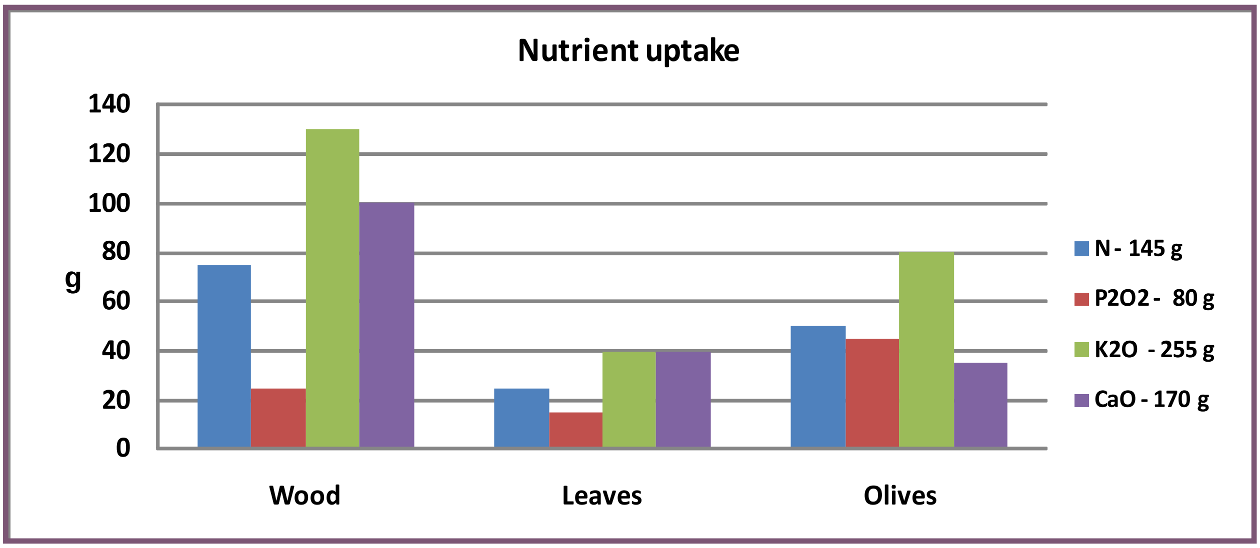


Figure 4.1: Uptake of plant nutrients by different parts of olive tree

Table 4.3: Nutrients taken up by the plant and removed by crop (5 ton / ha)

	Plant nutrient requirements (kg/ha)				
	N	P_2O_5	K_2O	CaO	MgO
Available from recycled previous crop	8	2	14	3	3
Uptake by whole plant	78	19	98	53	25
Removed by crop	40	7	60	15	4

Source: Haifa Chemicals website – NutriNet™

As is clear from Figure 4.1, potassium is taken up by all tree organs, including wooden parts, leaves and fruits, in a larger amount than any other plant nutrient.

But, when calculating the needed fertilization, only the amount of plant nutrients removed from the field should be taken into account, such as fruits and pruned branches. These nutrients need to be returned to the soil in form of fertilizers in order to maintain its fertility and so that it should not be continuously exploited.

Some researchers recommend, as a rule of thumb, an annual application of fertilizers equivalent to 2 – 3 fold the amount removed by the harvested crop.

4.2.2 Soil and leaf analysis

As explained at the beginning of chapter 3, soil analysis can serve in a very limited way to assess soil fertility for olive trees, while leaf analysis is the preferred method for this purpose. Table 3.1 in chapter 3 details the deficiency, sufficiency and toxicity values of all mineral elements required for olive production.

4.3 Application of fertilizers

Nitrogen (N), phosphorus (P), potassium (K) and boron (B) are generally the most critical nutrients in the mineral nutrition of olive orchards. Concentration of any of these nutrients can be correctly detected through leaf analysis, which is the best diagnostic method to determine the nutrient status and to plan fertilizer applications.

4.3.1 N application

Young orchards

Table 4.4: Recommended nitrogen application rate for young olive trees

Year	Annual nitrogen application rates		Distribution along the growth season			Root zone diameter (meters)
	Per tree* (g)	Per hectare* (with > 400 trees)	Spring	Early summer	Late summer	
1	100 – 200	50 kg	25%	33%	42%	0.9
2	140 – 280	70 kg	27%	36%	37%	2.7
3	200 – 400	100 kg	30%	35%	35%	3.7
			Winter	Spring	Summer	
4	300 – 600	150 kg	30%	33%	37%	4.5
5	300 – 600	150 kg	30%	33%	37%	6
Bearing	800 – 1,000	200 – 250 kg	According to leaf analysis			

* The above-mentioned application rates should be used as a guideline that should be corrected according to annual leaf analyses, considering the dynamic trends of the values as well as the absolute values.

** If the trees are bearing at this stage, use the values given below for bearing trees.

Source: Producing Table Olives, by Stan Kailis, David Harris, 2007

Bearing orchards

In traditional, extensively grown and rain-fed orchards, nitrogen is usually applied to the soil at
0.5 – 1.5 kg / tree, once a year, towards the end of the winter, using urea, ammonium sulfate, or ammonium nitrate; and augmented by foliar spray in the spring, using urea solution at 4%. Other nutrients are applied on an inconsistent basis.

In intensively cultivated orchards, phosphorus, potassium and boron, as well as other secondary- and micro-nutrients are applied simultaneously throughout the year. Where Nutrigation (fertigation) systems are available, the use of fully soluble nitrogen fertilizers is very common and the following fertilizers are in wide use:

- Urea (46% N)
- Ammonium nitrate (34% N
- Potassium nitrate (13% N & 46% K2O)
- Calcium nitrate (15.5%N & 26.5% CaO)
- Mono-ammonium phosphate (12% N & 61% P2O5)

4.3.2 N-P-K application

As mentioned, in bearing orchards the basic demand for N-P-K is supplied by application of these nutrients as shown in Table 4.5. To this, traditional growers add, whenever available, organic manures at a rate of 50 kg / tree every 2 – 3 years, applied at the foot of the tree. In this way, they add all nutrients and improve soil structure and infiltration capacity.

Table 4.5: Application of basic essential nutrients for olive tree maintenance

	Annual application rates	
	Per tree (g)	Per hectare (with > 400 trees) (kg)
Nitrogen	800 – 1,000	200 – 350
Phosphorus (P_2O_5)	200 – 300	50 – 70
Potassium (K_2O)	1,000 – 1,200	400 – 500
Boron	200 – 400	2.5 – 5.0

As seen in Table 4.2, potassium removal by the fruit is somewhat higher than that of nitrogen, which commands an appropriate compensation by fertilization.

This compensation concept is becoming common in many major olive producing Mediterranean countries, such as Spain (Jaen), Morocco and Tunisia (Sfax). But a further step needs to be taken in order to fully implement this concept, namely, the higher the fruit yield removed from the field, and the higher the expected yield for next year, the higher should be the application rate of these nutrients as well as all others that were not included in the basic table above (Table 4.5). For a comprehensive list of these nutrients and their application rates please read Haifa's recommendations in the next chapter.

4.3.3 Soil application for rain-fed bearing orchards

As shown above, traditionally cultivated olives that are not equipped with an irrigation system, usually yield an inferior amount of fruit The application rate of nitrogen, phosphorus and potassium can therefore be relatively modest, e.g., 100, 30 – 40, 200 kg / ha respectively.

This application should be done in the second half of the winter and completed before the end of the rainy season, in order to make sure that the minerals are absorbed in the soil but stay in the active root zone, to be encountered by the tree roots without being leached too deep in the soil.

The following N and K application plan is based, therefore, on fully-soluble fertilizers, e.g., urea
(46-0-0) and potassium nitrate (13-0-46), e.g., Multi-K®. The P should be applied only if indicated by leaf analysis of the previous summer, by broadcasting of a commodity fertilizer such as SSP (single superphosphate) 0-20-0 in late fall. All fertilizers should be applied only under the leaf canopy of the trees.

Table 4.6: N-P-K application rates and forms for rain-fed, bearing orchards at yields up to 10 ton / ha (25 kg / tree).

Nutrient	N	K_2O	P_2O_5
Rate (kg / ha)	100	200	30-40
Recommended fertilizers	Urea	Potassium nitrate	SSP
Fertilizer rate (kg / ha)	44	435	150 – 200
Application method & timing	2 – 3 broadcasting applications during rainy season		1 broadcasting application during late fall

An important factor affecting yield is **tree density** that has many variations in the form of High-Density planting, as well as Super-High Density planting. Clearly, plant nutrient removal is directly affected and thus is presented in the following table:

Table 4.7: The effect of planting density on the yield and on plant nutrient requirements

Density	Yield		Plant nutrient requirements (kg / ha)		
Trees / ha	kg / tree	Ton / ha	N	P_2O_5	K_2O
417	10	4.2	150	50	145
556	9	5.0	160	55	155
1,250	6	7.5	170	60	165
1,905	5	9.5	180	65	175

A detailed program translating these values to specific fully-soluble products can be found in Table 5.7 in the next chapter.

4.3.4 The effect of irrigation on fruit yield and fertilizer application

Should the orchard have an irrigation, but not a fertigation system, it is generally more fruitful and therefore needs higher amounts of fertilizers to compensate for the nutrients exported from the soil. The progressive nutrient application rates should then be followed as specified in Table 4.8.

These nutrients should be applied by broadcasting under the trees canopy.

Table 4.8: N-P-K application rates and forms, for irrigated, but not fertigated bearing orchards with yields from 6 ton / ha to over 20 ton / ha.

Yield		Nutrient rate recommendations* (g / tree)			
		Winter (by end of winter, before start of vegetative growth)			Autumn
kg / tree	Ton / ha	N	P_2O_5	K_2O	N
< 15	< 6	250	150	250	250
15-30	6 – 12	330	200	250	250
30-50	12 – 20	500	300	300	300
> 50	> 20	630	370	350	350

* If manure is added, rates should be reduced proportionally to the mineral content of the manure.

A detailed program translating these values to specific fully-soluble products can be found in Table 5.4 in the next chapter.

4.3.5 The effect of fertigation on fruit yield and fertilizer application

Should the orchard have an irrigation and a nutrigation (fertigation) system, it is generally even more fruitful and therefore needs higher amounts of fertilizer to compensate for the nutrients exported from the soil. The progressive nutrient application rate should then be followed as specified in Table 4.9. Naturally, the nutrigation system allows for a fully flexible nutrient application program that can be easily changed, based on leaf and soil analyses, tree morphology, pest situation, climatic and irrigation-water conditions, market opportunities and threats regarding fruit prices as well as fertilizer prices. The full flexibility of the nutrigation system enables fertilizer application even in the winter months, when a rain-fed orchard is generally not fertilized. It goes without saying that the nutrients are applied by the water emitters of the orchard.

The following application program is a real case that represents the considerations taken while planning a fertigation program in a Mediterranean-type cultivation region. The program is detailed by application months.

Intended use: Oil extraction

Trees density: 500 trees / ha

Soil type: Light to medium

Expected yield: 30 MT / ha

As can be seen, the fertilizer rates are indicated per month, and the grower is able to further divide the monthly rates into weekly amounts. Clearly, the rates recommended need to be adjusted according to leaf analysis results.

Table 4.9: Fertigation schedule under Mediterranean growing conditions

Application by month	N	P_2O_5	K_2O
	kg / ha		kg / ha
February	25	91.5	0
March	38	61	0
April	48	57	0
May	76	57	12
June	89	29	35
July	85		58
August	45		90
September	26		92
October	26		92

A detailed program translating these values to specific fully-soluble products can be found in Table 5.6 in the next chapter.

4.3.6 Fertilization by means of foliar feeding

Foliar spraying and feeding is a unique application method, helpful in satisfying plant requirements promptly and with high efficiency. Nitrogen and potassium are easily absorbed in the plant and distributed into the plant when applied to the leaves. Foliar feeding is a useful solution, especially for rain-fed orchards in arid zones where the scarcity of water in the summer drastically reduces nutrient absorption from the soil, hence making it difficult to correct deficiencies, exactly when the trees may also lose a great deal of their productivity due to drought conditions.

Additionally, foliar fertilizer applications are also important under normal growth conditions, by supplementing nutrient requirements at peak demand periods. Olive nutrition is of critical importance in the spring (when flowering and vegetative growth take place), and at the end of the summer, before harvesting. Foliar applications help accelerate vegetative growth and reproductive development, encouraging shoot growth, improving fruit-set and reducing alternate bearing.

Therefore, if foliar feeding is the only source for application during peak demand, several applications should be carried out.

The olive fruit is very efficient at removing nutrients from the leaves. Foliar sprays help enrich the leaves at these high nutrient demand periods. Foliar sprays during this period will help increase yield and improve the nutritional quality of the oil.

The following part of this chapter will supply a lot of scientific information describing the achievements of foliar feeding in olives in different parts of the world.

Israel – Poly-Olive™

A field trial was conducted in Israel on the Barnea cultivar, which was treated with 4 foliar applications of Poly-Olive™ 15-7-30+2MgO enriched by micro nutrients including 4,500 ppm boron at 2%. (For product details see the special paragraph in chapter 5 after Table 5.9.) This resulted in larger fruit size and better ripening (Figure 4.2).

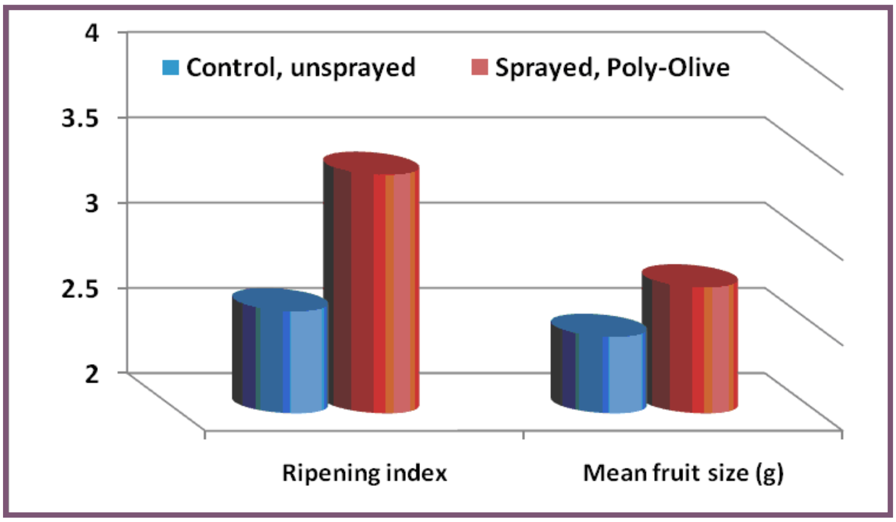


Figure 4.2: Effect of Poly-Olive™ 15-7-30+2MgO with micro nutrients on fruit ripening

A field trial was conducted in Israel, on the Barnea cultivar, when the trees were 8 years old, under intensive cultivation. Tree spacing was 3 x 7 m; average yield in the three years prior to the trial was 15 T / ha / year. Despite massive soil fertilization, deficiencies of macro- and micro-nutrients were apparent. Trees were treated with Poly-Olive™ 15-7-30+2MgO+ME, at 2% or 4%.

To study the effect of application timing, foliar nutrition was applied at three different phenological stages: at inflorescence, after fruit-set and after stone hardening.

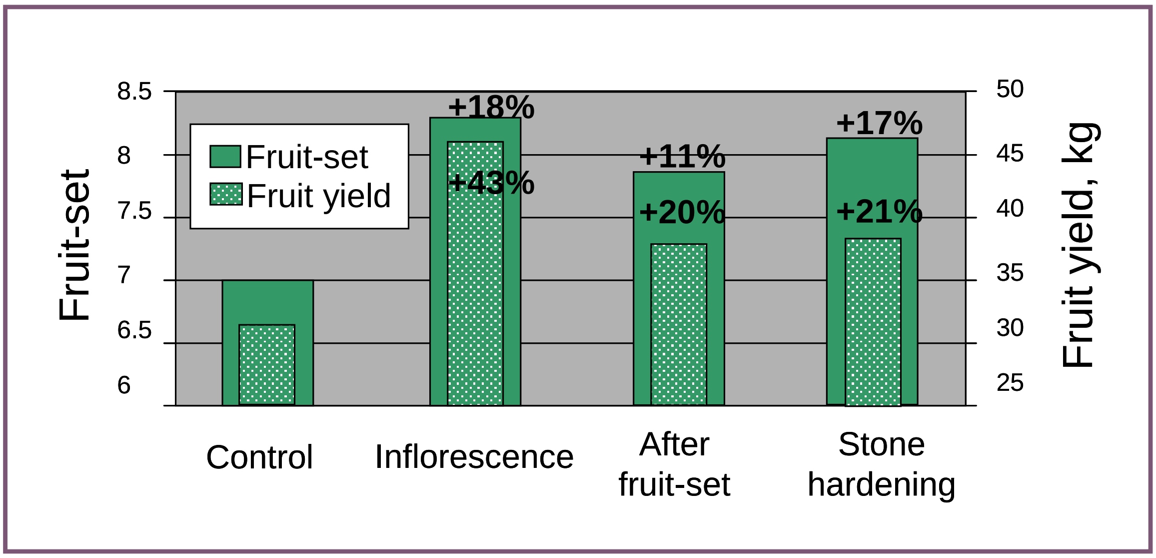


Figure 4.3: The effects of foliar application of 2% Poly-Olive™ on fruit-set and fruit yield as measured in the second year of the trial

Results

- Poly-Olive™ application at all three phenological stages checked, significantly increased fruit-set and fruit yield when compared to the control. The earliest application (before inflorescence) resulted in the highest percentage of fruit-set, and consequently highest fruit yield.
- The experiment was carried out during two consecutive years, and the mean value of fruit-set rate for the entire experiment was highest when Poly-Olive™ was applied latest in the season (after stone hardening). Probably this treatment, when nutrients are translocated to the developing fruits, prevents deficiencies and balances the nutritional condition of the tree, thus creating the basis for high yields in the succeeding year. Alternate bearing may thus be restrained.
- Spray concentration at 4% was not superior to 2%.

Tunisia - potassium nitrate (Multi-K)

In Tunisia, (Sfax region) potassium requirement of rain-fed Chemlali trees was estimated based on a yield of 200 kg / tree. Two rates of potassium nitrate (Multi-K) were applied by foliar spray as follows:

Treatment rates		
Control, unsprayed		
F50	Foliar spray	50% of estimated tree requirement
F100	Foliar spray	100% of estimated tree requirement

The foliar feeding of each treatment was distributed to three applications as follows:

- 30% - during flower bud swell
- 40% - during second fruit development stage
- 30% - at the beginning of the fruit color change

Results: Leaf area, leaf mineral content and fruit indices at harvest

The leaves of the two foliar treatments had a higher leaf area than the control (Figure 4.4). Moreover, these leaves were also richer in the minerals applied, i.e., N and K, and did not change the contents of other minerals; data not shown (Figure 4.5).

These increases have enhanced leaf photosynthetic capacity, having a remarkably positive effect on fruit development and value (Figure 4.6)

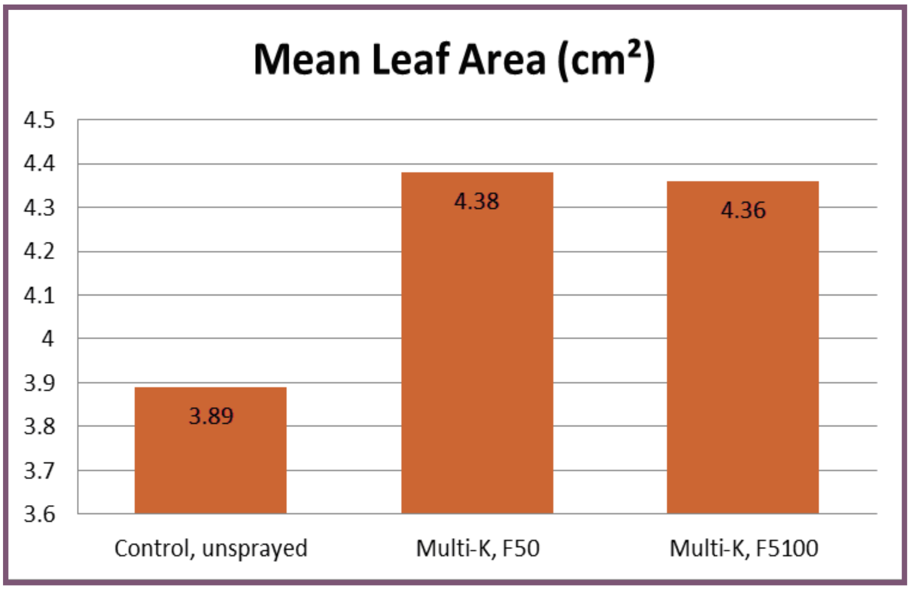


Figure 4.4: The effect of different rates of potassium sprays on olive leaf areas
Statistics analysis by Duncan's test

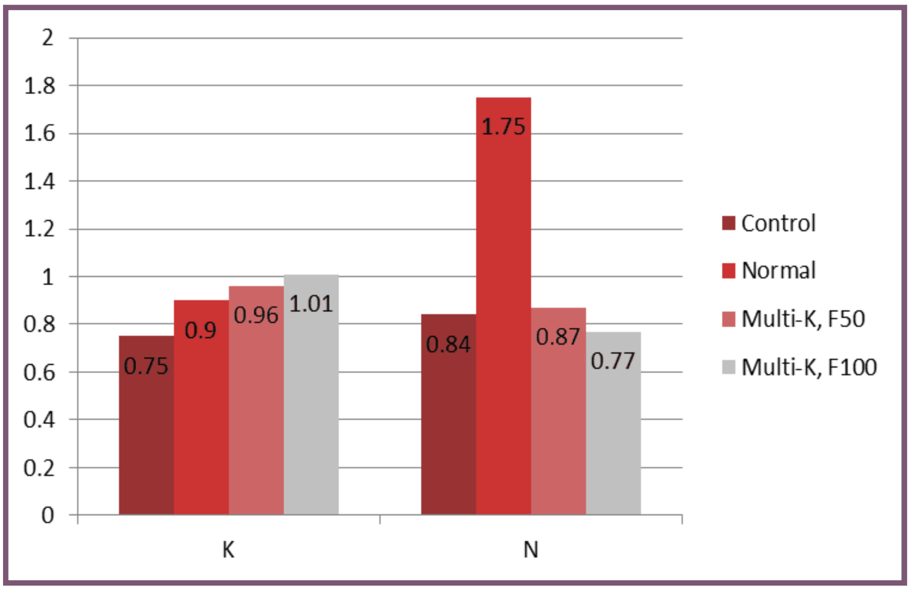


Figure 4.5: The effect of different rates of potassium nitrate sprays on leaf mineral composition compared to Freeman et al. (1994) norms. Statistics analysis by Duncan's test

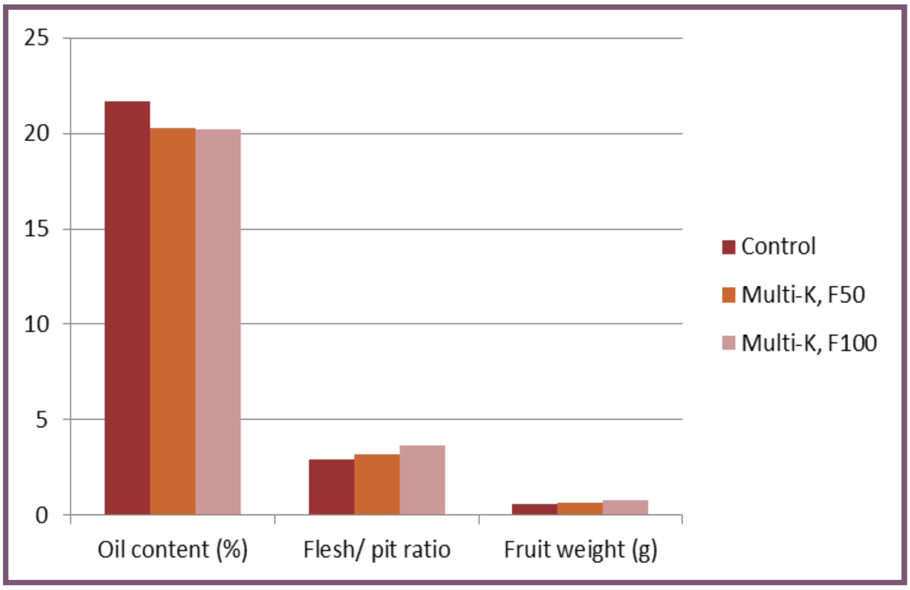


Figure 4.6: The effect of different rates of potassium nitrate sprays on the pomological characteristics of olive fruits. Statistics analysis by Duncan's test

Figure 4.6 shows that flesh / pit ratio and fruit weight were highest in the Multi-K F100 treatment, statistically significantly lower in the Multi-K F50 treatment and, again, statistically significantly lower in the control treatment. Fruit growth was more intensive during stage 3 for the Multi-K F100 treatment (data not shown).

Conclusions

- Potassium nitrate (Multi-K) enhanced leaf area and leaf analysis of nitrogen and potassium, thereby reducing their deficiencies, and significantly enhanced fruit mass and flesh / pit ratio.
- Treatment Multi-K F100 generally produced higher effects and better results than were observed with Multi-K F50. Both treatments were generally better than the unsprayed control.

Turkey

Foliar application of potassium nitrate is a well-known and recommended procedure in olive orchards in Turkey, due to low potassium contents in many local soils. In a study carried out by Dikmelik, Puskulku & Altug of the Olive Research Institute at Ege University, Turkey, in 1998, with the important cultivar "Memecik", four foliar sprays were done at 4%. Two foliar feeding treatments (20 days apart) were done after fruit-set (May); two additional sprays (20 days apart) were done after pit hardening (August). The sprays were done as 4% potassium nitrate at 1,000 L / ha, sometimes combined with urea. These foliar treatments were compared with the local commercial habit of the growers of side dressing with potassium-sulfate (SOP).

Table 4.10: Comparison between soil application of SOP, and foliar feeding of potassium nitrate

	Side dressing with SOP	Foliar feeding with potassium nitrate
K contents in the leaves (% in D.M.) in December	0.61	0.81 (+ 33%)
K contents in the fruit pulp (% in D.M.) at maturity	1.56	1.65 (+ 6%)
Mean mass of 100 fruit units (g)	217.5	278.7 (+ 28%)
Pulp/pit weight ratio	2.90	3.54 (+ 22%)
Oil content in D.M.	47.8%	52.9% (+ 11%)

Conclusions

Foliar applications of Multi-K, carried out from the first rapid growth period of fruit (summer) till maturity (end of early fall), were found to have highly positive effects on the nutrition status of the trees that suffered from insufficient potassium. The quality of the treated table olives was highly improved due to increase in size, higher pulp / pit ratio and higher oil content.

Crete

The effect of the eight factorial combinations of summer soil and spray application of two levels of N and two levels of K on the mineral composition of olive leaves was studied in an irrigated olive orchard (cv. Manzanillo) in Crete.

Potassium nitrate in the form of Multi-K was sprayed at 4% four times during July and August.

N and P contents of the leaves were increased by potassium nitrate spray applications. The applications of urea, shortly before the potassium nitrate sprays, significantly enhanced the uptake of K in the leaves.

5. Haifa's recommendations for comprehensive mineral nutrition of olive orchards

5.1 Pre-planting soil amelioration

As mentioned in the previous chapter, before loading the soil with nutrients that will serve the plantation for the first years of its life, soil properties need to be adequate for growing olives. After performing a thorough soil test, the grower should ascertain that the soil is not too acidic, nor too basic or sodic. Should the soil test show a need for soil amelioration, the following means need to be taken.

Correcting acidic soil pH

Usually only the surface, i.e., top 18 cm (7 inch) layer becomes acidic enough to require liming. The amount of finely ground limestone required varies with soil texture. In order to raise the pH of the said layer by one pH unit from an initial pH of 4.5 or 5.5, the following rates are needed:

- In sandy soil: about 2 MT / ha (0.5 short ton / acre)
- In a clay loam soil: about 8 MT / ha (2 short ton / acre)

Correcting alkali soils

Alkali soils may be acidified by application of elemental sulfur. Sulfur in the form of sulfate is not an acidifying material. It is advisable to acidify the soil gradually, over several years. Two small applications of acidifying material a year apart are better than a single large application. Soil acidification reactions may take a year or more to complete, so check soil pH annually to monitor the change. Check pH at the same time each year, as soil pH varies seasonally. Monitor soil pH and wait until the desired pH is reached before planting. Add elemental S according to the clay content of soil. Mix the sulfur into the soil. Examples for application rates:

- For sandy soil, add 450 – 900 kg of elemental S per 1ha.
- For clayey soil, add 1.8 – 2.25 ton of elemental S per 1ha.
- Soil with high organic matter content also requires more elemental S than sandy soil, to achieve the same pH decrease.
- Soils with combined high organic matter and medium clay content, need 1.8 – 2.25 ton elemental S per 1ha. A logical approach is to apply S in the fall and test the soil pH in the spring. If the desired pH has not been attained, repeat the process.

Correcting sodic soils

Sodic soils can be corrected by the application of gypsum. Application rate should be determined by a lab analysis. After the gypsum is applied, the displaced sodium must be leached below the root zone by high rates of irrigation. Organic materials such as manure, cover crop, or crop residues may help improve the soil structure for leaching. In order not to again build up a high sodium load, irrigation water should have a high ratio of calcium and magnesium versus sodium.

5.2 Pre-planting base dressing + side dressing

The following program is recommended for situations where the intended plot is not equipped with irrigation and fertigation systems, the soil is not fertile, and no previous crop residues can be recycled. In such situations the following nutrients, fertilizers and rates are recommended:

Nutrients	N	P_2O_5	K_2O	CaO	MgO
Rates (kg/ha)	4	87	40	16	13
Fertilizers	Ammonium nitrate (34% N)	Superphosphate (25% P_2O_5)	Potassium sulfate (50%)	Dolomite (26%)	Magnesium sulfate (16%)
Rates (kg/ha)	12	350	80	62	81

In the next two years, it is enough to apply nitrogen only, at app. 11 kg / ha (e.g., 32 kg / ha of AN) per year, while all other nutrients will be supplied by the aforementioned side-dressed fertilizers.

5.3 Pre-planting base dressing + irrigation & fertigation

Example: Plant density: 500 trees / ha

Soil type: Light to medium

Pre-planting base dressing is done the same way as in paragraph 5.2.

Nutrients	N	P_2O_5	K_2O	CaO	MgO
Rates (kg/ha)	4	125	40	16	13
Fertilizers	Ammonium nitrate (34% N)	Superphosphate (25% P_2O_5)	Potassium sulfate (50%)	Dolomite (26%)	Magnesium sulfate (16%)
Rates (kg/ha)	12	500	80	62	81

Once planted, apply by fertigation a 1:1 ratio of N & K, as shown in the following table. Start applying phosphorus based on leaf analysis from the third year and on.

Table 5.1: Fertilization schedule of non-bearing olive trees

Orchard age (years)	Required nutrients		Recommended fertilizers	
	N	K_2O	Urea	Multi-K®
	(kg / ha)			
1	50 - 80	50 -70	78 - 130	110 - 150
2	80 - 120	70 -120	130 - 170	150 - 260
3	120 - 150	120 - 145	170 - 240	260 - 315

5.4 No base dressing, but nutrition can be done by fertigation or side dressing programs from planting to fruit-bearing

This program is based on Haifa's product Poly-Feed® 17-10-27 + micro nutrients, a fully water-soluble fertilizer that contains all essential plant nutrients. The following table suggests application timing and rates of this product, assuming that planting takes place in spring.

Table 5.2: Fertilization program for newly planted olive trees

Age of tree (years)	Season	Poly-feed® 17-10-27+M (g / tree)	Root zone diameter (m)
1	Spring	83	0.6
1	Early summer	99	0.9
1	Mid summer	99 - 124	1.2
2	Spring	217	2.1
2	Summer	236	2.7
2	Late summer	168	1.8
3	Winter	246	3.4
3	Spring	276	3.7
3	Summer	295	4.3
	Apply fertilizer in response to leaf and soil analysis.		

5.5 Recommendations for an extensively cultivated, rain-fed, olive-bearing orchard yielding up to 10 ton / ha (25 kg / tree)

Table 5.3: N-P-K application rates and forms

	N	K_2O	P_2O_5
Nutrient rate (kg / ha)	100	200	30-40
Recommended fertilizer	Urea	Multi-K	SSP (20% P_2O_5)
Fertilizer rate (kg / ha)	44	435	150 – 200
Application method & timing	2-3 broadcasting applications during rainy season		1 broadcasting application during late fall

5.6 Recommendations for a rain-fed, olive-bearing orchard yielding from 6 to 20 ton / ha (25 kg / tree)

This program is based on Haifa's product Poly-Feed 17-10-27 + micro nutrients, a fully water-soluble fertilizer that contains all essential plant nutrients. If manure is added, rates should be reduced according to the analysis of the manure.

Table 5.4: A program for a rain-fed, olive-bearing orchard

Expected yield		Autumn		End of winter (before start of vegetative growth)			
kg / tree	Ton / ha	Nutrient	Recommended fertilizer	Nutrients			Recommended fertilizer
		N	Urea 46-0-0	N	P_2O_5	K_2O	Poly-Feed® 17-10-27+ ME
< 15	< 6	250	550	270	160	430	1,600
15-30	6 – 12	250	550	370	220	550	2,200
30-50	12 – 20	300	650	500	300	800	2,950
> 50	> 20	350	760	630	370	1,000	3,700

5.7 Recommendations for irrigated but not fertigated, olive-bearing orchard, yielding 3-5 ton / ha

The total amount of nutrients should be split into 4 – 6 side-dressing applications, from early spring till early summer.

Plant nutrients (kg / ha)			Recommended fertilizer (kg / ha)
N	K_2O	P_2O_5	Poly-Feed® 17-10-27+ME
190	300	50-100 (if required by leaf analysis)	1,100

5.8 Recommendations for nutrigated (fertigated) olive-bearing orchard

The programs are based on the general uptake curves of the different plant organs depicted in Figure 5.1.

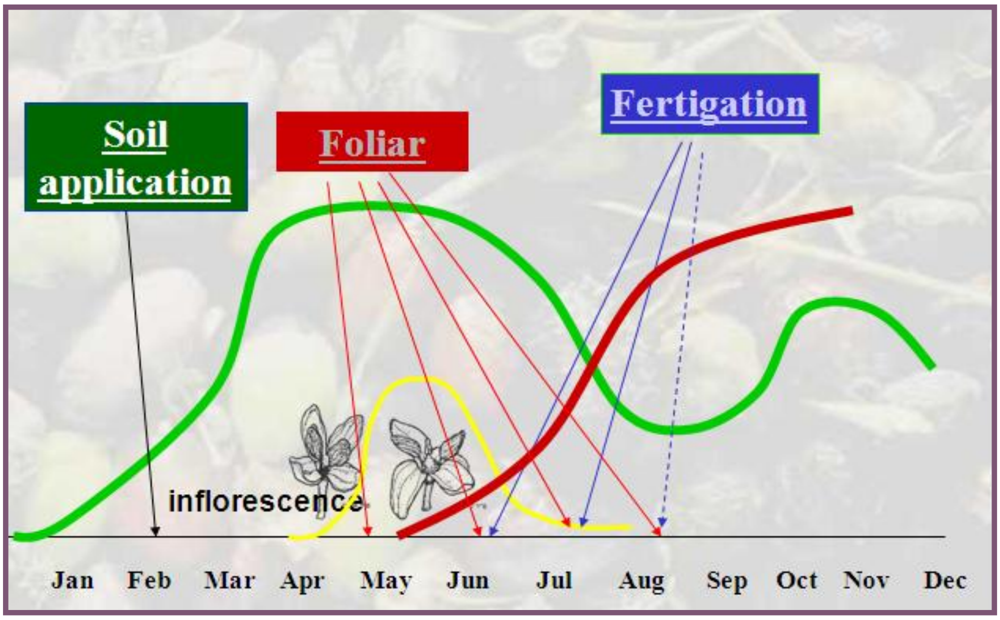


Figure 5.1: A scheme of the nutritional requirements of leaves (green curve), flowers (yellow curve) and fruits (red curve)

Situation A: For orchards yielding ~30 ton / ha

Plant density: 500 trees / ha

Soil type: light to medium

Side-dressing equipment is not available

Foliar spraying equipment is not available

Option I

Table 5.5: Fertigation schedule according to season and physiological stage of olive trees

Application time	Nutrients			Fertilizers		
	N	K_2O	P_2O_5	Multi-K*	Haifa-MAP**	Ammonium nitrate
	(kg / ha)			(kg / ha)		
Spring - early summer	125-185	200-240	246-300	540-650	320-390	190-200
Post harvest	75-115	-	150-180	330-400	-	50-130
Total	200-300	200-240	395-480	870-1,050	320-390	240-330

* Multi-K® – Potassium nitrate (13-0-46)

** Haifa MAP – Mono ammonium phosphate (12-61-0)

Ammonium nitrate (34-0-0)

General instructions

End fertigation 50 days prior to harvest.

Divide nutrigated rate into weekly doses.

Adjust fertilized rate according to leaf analysis data.

Option II - Nutrigation™ schedule detailed by months:

Same orchard conditions as in Option I.

Table 5.6: Fertigation schedule under Mediterranean growing conditions

Application by month	Multi-K®*	Haifa MAP®**	Ammonium nitrate
	(kg / ha)		
February	0	150	21
March	0	100	78
April	0	94	111
May	26	94	183
June	75	47	219
July	125	0	205
August	195	0	60
September	200	0	0
October	200	0	0

* Multi-K® – Potassium nitrate (13-0-46)

** Haifa MAP® Mono ammonium phosphate (12-61-0)

Ammonium nitrate (34-0-0)

Divide monthly rates into weekly doses.

Adjust fertilized rates according to leaf analysis data.

Option III – a program based on Nutrigation only, at various tree densities

Table 5.7: The effect of tree density on yield and plant nutrient removal

Planting density	Yield		Plant nutrient requirements			Recommended fertilizers	
			N	P_2O_5	K_2O	Poly-Feed 17-10-27+ME	Urea 46-0-0
Trees / ha	kg / tree	kg / ha	kg / ha			kg / ha	
417	10	4,2	150	50	145	537	168
556	9	5,0	160	55	155	574	136
1,250	6	7,5	170	60	165	611	144
1,905	5	9,5	180	65	175	648	152

Situation B: For orchards yielding 2.4 – 3.2 ton / ha (60 – 80 kg / tree)

Side-dressing equipment is available

Foliar spraying equipment is available

Table 5.8: An olive orchard nutrition program based on side dressing, nutrigation and foliar feeding

Time (northern hemisphere)	Application method	Products	Rates	
			kg / tree	kg / ha
February	Side dressing	Multicrop 17-6-12 + 0.5B	3 - 5	1,200 - 2,000
May	Foliar	Poly-Feed Foliar 21-21-21 + ME	1% @ 1,000 L/ha	
June	Nutrigation	Poly-Feed 25-0-25 + 2Mgo	1	400
June	Nutrigation	Multi-K 13-0-46	1	400
June	Foliar	Poly-Olive 15-7-30+ 2MgO+ ME + 0.45B	1% @ 1,000 L/ha	
July	Nutrigation	Poly-Feed 17-0-34 + 2Mgo	1.5	600
July	Foliar	Poly-Olive 15-7-30+ 2MgO+ ME + 0.45B	1% @ 1,000 L/ha	
August	Nutrigation	Multi-K 13-0-46	1	400
August	Foliar	HaifaBonus 13-2-44	4 - 5% @ 1,000 L/ha	

The latest above-mentioned case illustrates the marked role that foliar sprays can play in the mineral nutrition of olive orchards. We will now elaborate on the subject.

5.9 Foliar feeding with Haifa products

Foliar feeding is a fast, highly effective method of providing nutrients when used as a supplement to administer fertilizers through the soil. It is an ideal feeding method under certain growth conditions in which absorption of nutrients from the soil is inefficient, due to temporal or continuous conditions limiting nutrient absorption from the soil, such as uncontrolled weeds, a nematodes attack, water-logging, etc. Precision-timed foliar sprays are also a fast-acting and effective method for treating nutrient deficiencies and plant and fruit growth and improving quality.

Here are some operational tips for best results from Haifa's foliar products:

- The best time to spray is early in the morning or in the evening, when temperatures are lower and relative humidity is comparatively high. High temperature and low humidity increase the susceptibility of the plants to injuries from sprayed chemicals. Crops must be well irrigated and must not be under water stress when the actual spraying takes place, in order to allow the plants to keep their stomata fully open to absorb the active ingredients of the spray.
- The recommendations should be regarded as a general guide only. The exact fertilization program should be determined according to specific crop needs and the grower's experience.

Haifa offers a special fertilizer line for foliar applications: HaifaBonus™, Poly-Feed® Foliar, and Poly-Olive™. These high-K foliar formulae contain a specially developed adjuvant for better adhesion to the leaf surface, improved absorption and prolonged action.

Haifa Bonus

Haifa Bonus is completely and readily soluble in water at all concentrations recommended for foliar applications. Haifa Bonus contains 100% nutrients and is free of potentially harmful elements. It is therefore unlikely to scorch the leaves when sprayed according to recommendations.

Haifa Bonus is highly compatible with most pesticides used in olives. It is also compatible with other plant nutrients used for correcting common deficiencies such as magnesium, zinc and boron. It is advisable to confirm compatibility of your intended mix by preparing a sample of the spray materials at their recommended concentrations in order to rule out the possibility of a detrimental cross reaction. This mixture should be sprayed onto small area a week prior to the commercial treatment, in order to assess whether an adverse effect occurs.

It is recommended to apply 2 - 4 spray applications of Haifa Bonus, from early spring to late summer, 3 – 4 kg Haifa Bonus / 100 liters of water (3% – 5% concentration), at a rate of 8 – 10 liters / tree (according to tree size).

Compatibility

Usually, no compatibility problems should be expected while tank-mixing Haifa Bonus with copper fungicides and with insecticides, but hydrolysis may occur with dimethoate as it may break down, at pH 8 or higher, in one hour or less. Thus, a pH range of 5-6 should be maintained. An acidifying **surfactant / adjuvant** should be added to prevent alkaline hydrolysis of the pesticides and to assure nutrient uptake. Read surfactant instruction label for best results. Haifa MAP, also used as a plant nutrient, can be added to lower the pH of spray solution.

Table 5.9: Recommended foliar applications with HaifaBonus

Time of spray	No. of applications	Spray concentration	Spray volume (Liter / tree)
Early spring - late summer	3 - 4	3 - 5%	8 - 10

Adding Magnisal® (Mg source) and boron to Haifa Bonus are preferable for the spring treatment while plain Haifa Bonus is recommended for the second spray.

Poly-Olive™ 15-7-30+2MgO+Micronutrients

Poly-Olive™ is an ideal fertilizer to enhance vegetative development and fruit production in olive trees.

Product analysis

Total nitrogen (N)	15%
Nitrate nitrogen (N-NO_3)	8.5%
Ammoniacal nitrogen (N-NH_4)	1.5%
Ureic nitrogen (N-NH_2)	5.0%
Phosphorus (P_2O_5)	7%
Potassium (K_2O)	30%
Magnesium (MgO)	2%

Micronutrients	
Iron (Fe)	1000 ppm
Manganese (Mn)	500 ppm
Zinc (Zn)	150 ppm
Boron (B)	4500 ppm
Copper (Cu)	110 ppm
Molybdenum (Mo)	70 ppm
Iron (Fe)	1000 ppm

- High potassium and nitrogen content to encourage shoot growth and to enhance fruit development.
- High concentration of boron (B) to enhance fruit-setting.

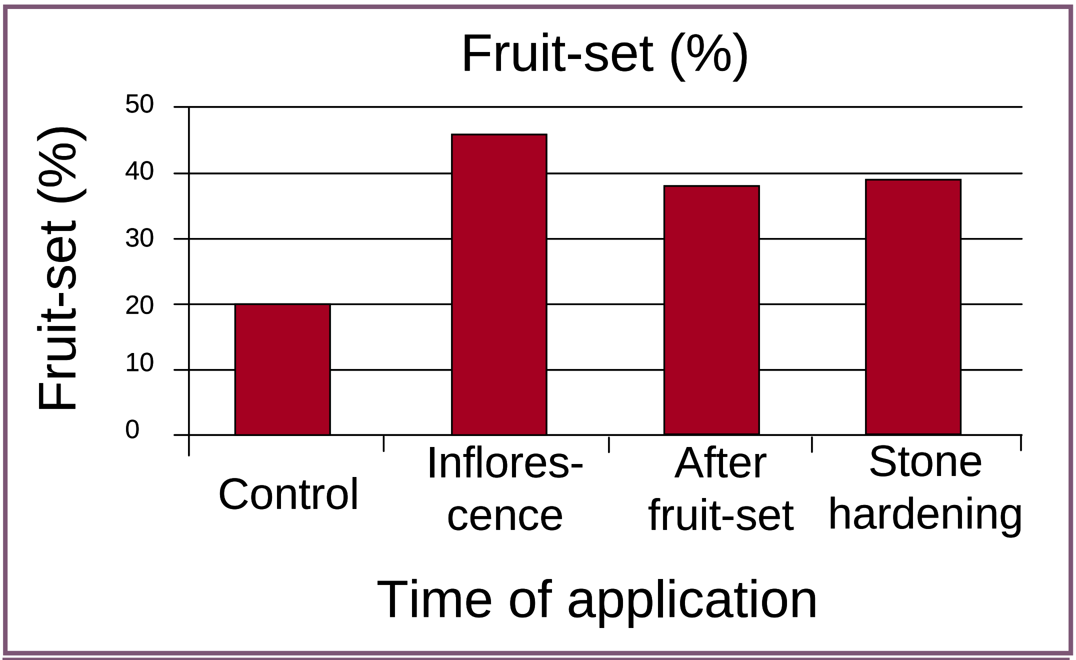
It is recommended to apply Poly-Olive™ at the stage of inflorescence development, before flowering, and during the main stage of fruit development (August – September).

Recommended program for foliar feeding with Poly-Olive:

Table 5.10: Recommended foliar applications with Poly-Olive 15-7-30+2MgO+ME

Growth phase	Spray volume (L / ha)	Spray concentration	No. of applications	Intervals
Inflorescence	500-700	1% - 2%	1 – 2	2 – 3 weeks
Fruit development	500-1000	1%	2	2 – 3 weeks

Proven results



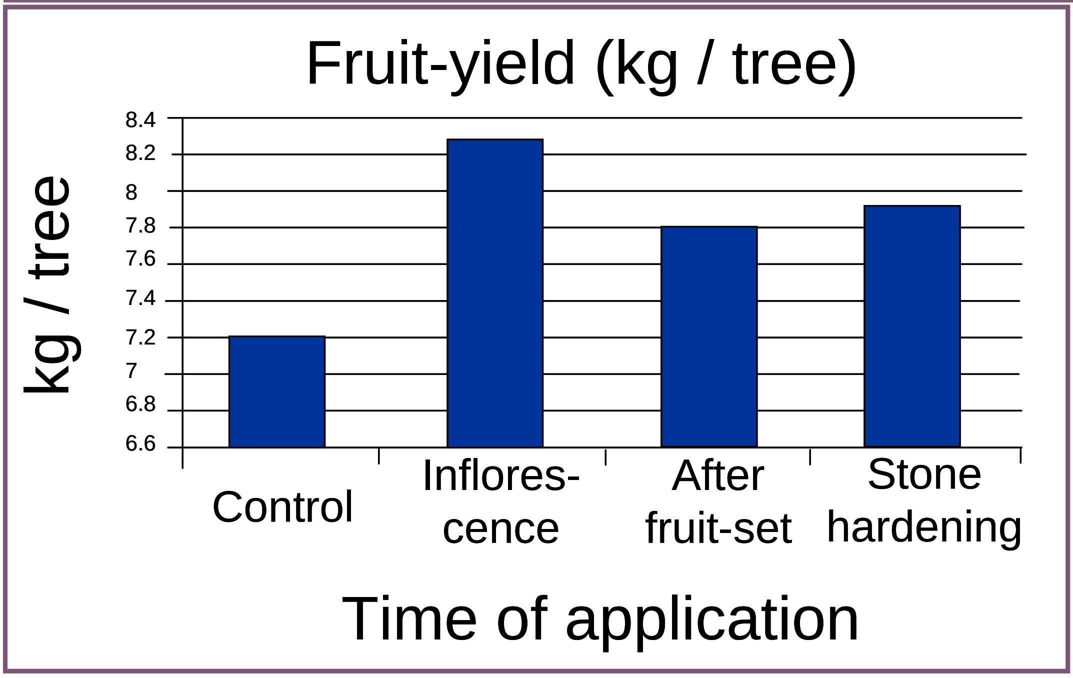


Figure 5.2: The effects of spraying Poly-Olive™ 15-7-30+2MgO+ME on fruit-set ratio and on fruit yield in olive trees

Please note that Haifa has also the following products in its foliar-feeding products portfolio:

Haifa MAP, Haifa MKP, Haifa Cal and Haifa Micro are also suitable for foliar application.

5.10 OliveDrop™ – for enhanced mechanical harvesting

Haifa Chemicals has developed a new double action product, OliveDrop™, which not only acts as an abscission agent, but also supplies plant nutrients. OliveDrop™ contains macro plant nutrients, N-P_2O_5-K_2O, at nutrient ratios of 9-41-27, respectively, that also includes a special adjuvant. OliveDrop™ reduces pedicel strength, resulting in markedly higher efficiency of mechanical harvesting, especially when tank-mixed with Ethrel® (which is converted in the leaves into the

natural plant growth substance ethylene, which promotes natural fruit abscission in olives). Another advantage of OliveDrop™ is that it has practically no adverse defoliation effect, unlike other abscission agents tested and compared to OliveDrop™ (Figure 5.3; Table 5.11).

It is recommended to foliar-spray a tank-mix of 5% OliveDrop™ with 0.1% Ethrel and 0.5% paraffinic oil, at a spray volume of 2,000-3,000 L / ha, 11 – 14 days prior to the intended harvest.

Table 5.11: The effect of several products on abscission forces, shaking percentage and defoliation percentage, as measured 67 days after foliar treatment

Treatment	FRF* g / fruit			Harvest (%) **	Defoliation (%)
Dates	11 Nov.	14 Nov.	19 Nov.	23 Nov.	17 January
Control	517	459	509	76.3 b	6.5 c
Ethrel® 0.3% + Triton 0.05 + Urea 1%	517	192	110	92.3 a	52.2 b
HarvestVant® 4% + Urea 1%	517	228	123	91.1	60.2 ab
HarvestVant® 4% + Urea 1% + Damoil*** 0.5%	517	241	98	95.7 a	77.2 a
OliveDrop™ 5% + Ethrel® 0.1%	517	240	152	87.4 ab	13.0 c
OliveDrop™ 5% + Ethrel® + Damoil*** 0.5%	517	265	156	93.1 a	9.7 c
Ethrel® 0/3%+Triton 0.05+Urea 1%+Damoil 0.5%	517	158	42	94.8 a	70.7 ab

* FRF (Fruit Retention/Release Force), g / fruit

** Statistically significant as per JMP software according to Tukey-Kramer at 0.05 level

*** Damoil - Paraffinic Oil %98

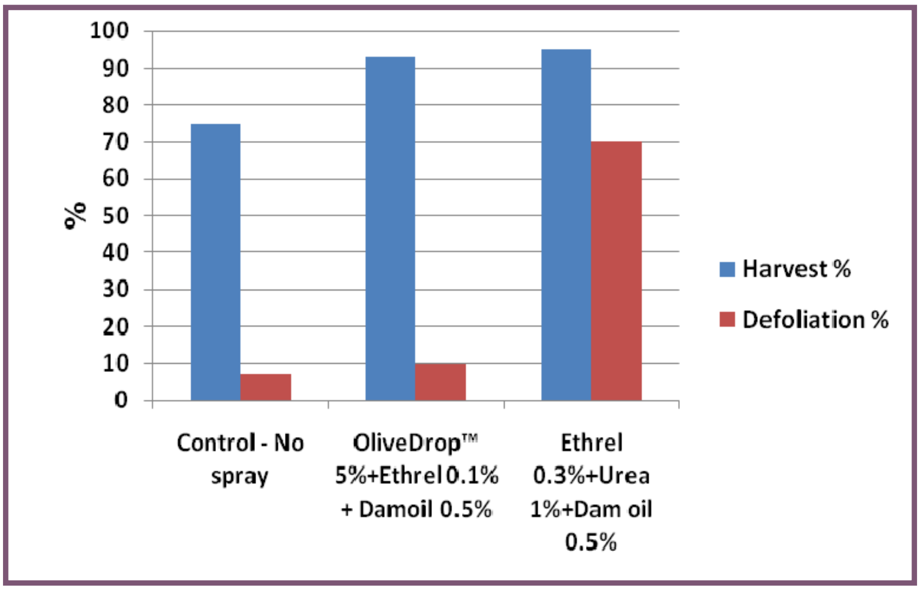


Figure 5.3: The effect of several foliar treatments on harvest efficiency and on defoliation of the treated trees

5.11 Nutrigation™ (fertigation)

Nutrigation™ (fertigation) is a technique that combines irrigation with fertilization. During the several decades since this technique was developed, it has become well established as a potent method in modern agriculture, resulting in higher yields and improved crop quality.

Suitable water-soluble and chloride-free fertilizers

Application of top-quality water-soluble fertilizers through the irrigation system is the optimal method for providing balanced plant nutrition throughout the growth season. A balanced Nutrigation™ regime ensures that essential nutrients are placed precisely at the site of intensive root activity and are available in exactly the right quantity - when plants need them.

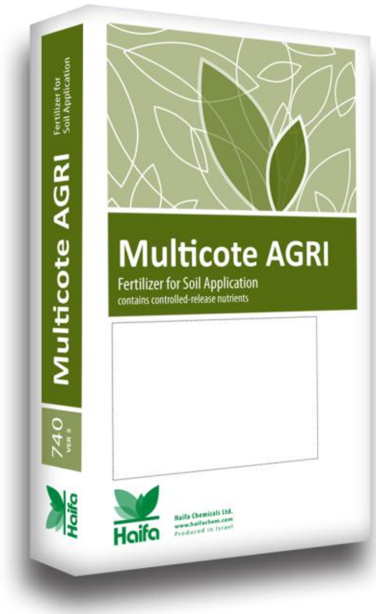
Haifa offers a wide range of water-soluble fertilizers for Nutrigation™. All products contain only pure plant nutrients and are free of sodium and chloride.

Multi-K®	A binary fully soluble fertilizer composed of the two most important macronutrients, at an advantageous proportion
Poly-Feed®	Soluble NPK fertilizers enriched with secondary and micro-nutrients
Haifa MAP	Mono-ammonium phosphate
Haifa MKP	Mono-potassium phosphate
Magnisal	Haifa's original magnesium nitrate fertilizer
Haifa Cal	Fully soluble calcium nitrate fertilizer
Haifa Micro	Water-soluble chelated micronutrients
Haifa ProteK	A high P systemic fertilizer

5.12 Soil application - controlled-release nutrition

The concept of Teaspoon-Feeding™ applies also to Multicote® AGRI products composed of polymer-coated nitrogen, phosphorus and potassium, with release longevity of **2-8 months.** This line of products releases plant nutrients gradually and steadily according to an olive tree's needs throughout the growing season. See additional information in Appendix I.

The benefits of Multicote® AGRI products



Nutrients are supplied in accordance with specific olive tree needs which assure **optimal tree development.**

Single application per season - This results in a drastic reduction of field labor and application costs, as well as considerably less soil compaction.

Minimized losses through leaching, volatilization or fixation in the soil

- Availability of nutrients throughout the growth cycle is ensured.
- More efficient use of fertilizers without wastage, allowing for reduced application rates.
- Ecologically superior (no soil or air pollution).
- Salt accumulation in the soil is prevented.

Fertilization totally independent of irrigation

- No need to maintain sophisticated dosing systems
- No need for technical irrigations

It is recommended that olive plantations use Multicote® AGRI 17-9-16+2MgO, a product based on 35% nitrogen derived from Multicote®, as follows:

- Rain-fed grown olives – by the end of the winter – before vegetative growth starts (end of February – mid March); apply Multicote® AGRI at 3 – 7 kg / tree.
- Irrigated olives – (intensive and super-intensive grown olives) - by the end of the winter – before vegetative growth starts (end of February – mid March), apply Multicote® AGRI at 300 – 400 kg / Ha.

5.13 Haifa NutriNet™ - online fertilization and Nutrigation™ programs

Haifa fertilization recommendations are also available online and can be accessed through Haifa's website, www.haifa-group.com. Click on Haifa **Know-how** tab, or directly at:

http://www.haifa-nutrinet.com and enter into NutriNet™, a unique software program that will assist you to work out the recommended fertilizer rates according to the expected yield of olives under your growing conditions.

Soil-applied fertilization schedule and fertigation rates may vary according to cultivar, climatic conditions, growth stages and expected yield. By using the Haifa NutriNet™ online program, you can obtain Haifa's recommendations most suitable to your growing conditions by selecting the expected yield, growing method and growth stages.

The following is an example of recommendations for two expected yield levels (2 and 6 T/ ha) of fresh olive fruit, as determined by NutriNet™:

I – Expected yield: 2 ton / ha

Once you enter the expected yield in the table, the recommended application rates will be displayed (Table 5.12).

Table 5.12: Nutrient requirements - olives

Expected yield:	2		Tons / ha	
Nutrient requirements (Kg / Ha)				
N	P_2O_5	K_2O	CaO	MgO
16	3	24	6	2
Uptake by whole plants				
37	10	45	27	14
Available nutrients from recycled previous crop				
8	2	14	3	3
Recommended application rates				
36	95	31	11	11

In the example below (Table 5.13), the assumption is that the fertilization in the following olive grove is applied partially by top-dressing (Table 5.14), and partially by Nutrigation™ (fertigation) (Table 5.15). However, any other application methods can be selected and the recommendations may vary accordingly.

Table 5.13: Fertilization – olive (kg / ha)

Irrigation method:	Drip				
Fertilization method:	Top dressing + Nutrigation™				
	N	**P_2O_5**	**K_2O**	**CaO**	**MgO**
NPK required Kg / Ha	36	95	31	11	11
Top / side dressing	11	57	12	9	9
Nutrigation™	25	38	19	2	2
Total	36	95	31	11	11

Table 5.14: Top / side dressing - olives

All nutrient and fertilizer values are in Kg / Ha					
	N	**P_2O_5**	**K_2O**	**CaO**	**MgO**
Fertilization method:	Top dressing + Nutrigation™				
NPK required Kg / Ha	36	95	31	11	11
Top / side dressing	11	57	12	9	9
Nutrigation™	25	38	19	2	2
Total	36	95	31	11	11

All nutrient and fertilizer values are in Kg / Ha					
	N	**P_2O_5**	**K_2O**	**CaO**	**MgO**
Suggested top / side dressing	11	57	12	9	9
Suggested fertilizers	Ammonium nitrate (33%)				7
	Superphosphate (45%)				127
	Multi-K (46%)				26
	Calcium nitrate (26%)				35
	Magnesium sulfate (16%)				56

Table 5.15: Water soluble and chloride-free fertilizers rates for Nutrigation™

All nutrient and fertilizer values are in Kg / Ha					
	N	**P_2O_5**	**K_2O**	**CaO**	**MgO**
Suggested Nutrigation™	25	38	19	2	2
Suggested fertilizers	Ammonium nitrate (33%)				29
	Multi M.A.P. (12-61-0)				62
	Multi-K (13-0-46)				41
	Multi Cal (26%)				8
	Magnisal				12

II - Expected yield: 6 ton / ha

Once you enter the expected yield in the table, the recommended application rates will be displayed (Table 5.16).

Table 5.16: Nutrient requirements - olives

Expected yield:	6		Tons / Ha	
Nutrient requirements (Kg / Ha)				
N	P_2O_5	K_2O	CaO	MgO
48	9	72	18	5
Uptake by whole plants				
91	23	115	61	29
Available nutrients from recycled previous crop				
8	2	14	3	3
Recommended application rates				
101	110	101	28	26

In the example below (Table 5.17), the assumption is that the fertilization in the following olive grove is applied partially by top-dressing (Table 5.18), and partially by Nutrigation™ (fertigation) (Table 5.19). However, any other application methods can be selected and the recommendations may vary accordingly.

Table 5.17: Fertilization – olive (kg / ha)

Irrigation method:	Drip				
Fertilization method:	Top dressing + Nutrigation™				
	N	**P_2O_5**	**K_2O**	**CaO**	**MgO**
NPK required Kg / Ha	101	110	101	28	26
Top / side dressing	30	66	40	22	21
Nutrigation™	71	44	61	6	5
Total	101	110	101	28	26

Table 5.18: Top / side dressing - olive

All nutrient and fertilizer values are in Kg / Ha					
	N	**P_2O_5**	**K_2O**	**CaO**	**MgO**
Suggested top / side dressing	30	66	40	c22	21
Suggested fertilizers	Ammonium nitrate (33%)				18
	Superphosphate (45%)				147
	Multi-K (46%)				87
	Calcium nitrate (26%)				85
	Magnesium sulfate				131

Table 5.19: Water soluble and chloride-free fertilizer rates for Nutrigation™

All nutrient and fertilizer values are in Kg / Ha					
	N	**P_2O_5**	**K_2O**	**CaO**	**MgO**
Suggested Nutrigation™	71	44	61	6	5
Suggested fertilizers	Ammonium nitrate (33%)				116
	Haifa NAO (12-61-0)				72
	Multi-K (13-0-46)				133
	Haifa Cal (26%)				23
	Magnisal				31

Appendix I: Haifa specialty fertilizers

Pioneering solutions

Haifa develops and produces potassium nitrate products, soluble fertilizers for Nutrigation™ and foliar sprays, and controlled-release fertilizers. Haifa's agriculture solutions maximize yields from given inputs of land, water and plant nutrients for diverse farming practices. With innovative plant nutrition schemes and highly efficient application methods, Haifa's solutions provide balanced plant nutrition at precise dosing, composition and placing. This ultimately delivers maximum efficiency, optimal plant development and minimized losses to the environment.

Potassium nitrate

Haifa's potassium nitrate products represent a unique source of potassium due to their nutritional value and contribution to plant health and yields. Potassium nitrate has distinctive chemical and physical properties that are beneficial to the environment. Haifa offers a wide range of potassium nitrate products for Nutrigation™, foliar sprays, side-dressing and controlled-release fertilization. Haifa's potassium nitrate products are marketed under the Multi-K® brand.

Multi-K® products

Pure Multi-K®	
Multi-K® Classic	Crystalline potassium nitrate (13-0-46)
Multi-K® Prills	Potassium nitrate prills (13-0-46)
Special grades	
Multi-K® GG	Greenhouse-grade potassium nitrate (13.5-0-46.2)
Multi-K® pHast	Low-pH potassium nitrate (13.5-0-46.2)
Multi-K® Top	Hydroponics-grade potassium nitrate (13.8-0-46.5)
Enriched products	
Multi-npK®	Enriched with phosphate; crystalline or prills
Multi-K® Mg	Enriched with magnesium; crystalline or prills
Multi-K® Zn	Enriched with zinc; crystalline
Multi-K® S	Enriched with sulfate; crystalline
Multi-K® B	Enriched with boron; crystalline or prills
Multi-K® ME	Enriched with magnesium and micronutrients; crystalline

Nutrigation™

Nutrigation™ (fertigation) delivers pure plant nutrients through the irrigation system, supplying essential nutrients precisely to the area of most intensive root activity. Haifa's well-balanced Nutrigation™ program provides the plant with its precise needs according to seasonal changes. Decades of experience in the production and application of specialty fertilizers for Nutrigation™ have made Haifa a leading company in this field. Haifa constantly keeps up to date with contemporary scientific and agricultural research, in order to continuously broaden its product line to better meet the requirements of crops and cropping environments.

Haifa offers a wide range of water-soluble fertilizers for Nutrigation™. All products contain only pure plant nutrients and are free of sodium and chloride

Multi-K® products	Comprehensive range of plain and enriched potassium nitrate
Poly-Feed®	Soluble NPK fertilizers enriched with secondary and micro-nutrients
Haifa MAP	Mono-ammonium phosphate
Haifa MKP	Mono-potassium phosphate
Haifa Cal	Calcium nitrate
Magnisal®	Our original magnesium nitrate fertilizer
Haifa Micro	Chelated micronutrients
Haifa VitaPhos-K™	Precipitation-proof poly-phosphate for soilless Nutrigation™
Haifa ProteK	Systemic PK fertilizer

Foliar feeding

Foliar feeding provides fast, on-the-spot supplementary nutrition to ensure high, top quality yields and is an ideal feeding method under certain growth conditions in which absorption of nutrients from the soil is inefficient, or for use on short–term crops. Precision-timed foliar sprays are also a fast-acting and effective method for treating nutrient deficiencies. Foliar application of the correct nutrients in relatively low concentrations at critical stages in crop development contributes significantly to higher yields and improved quality. Haifa offers a selection of premium fertilizers for foliar application.

Haifa Bonus High-K foliar formulas enriched with special adjuvants for better absorption and prolonged action.

Poly-Feed® Foliar NPK formulas enriched with micronutrients specially designed to enhance the crop performance during specific growth stages.

Magnisal®, Haifa MAP, Haifa MKP, Haifa Cal and Haifa Micro are also suitable for foliar application.

Controlled-release nutrition

Multicote®, Haifa's range of controlled release fertilizers includes products for agriculture, horticulture, ornamentals and turf. Multicote® products provide plants with balanced nutrition according to their growth needs throughout the growth cycle. Multicote® products enhance plant growth, improve nutrient use efficiency, save on labor and minimize environmental impact.

Single, pre-plant application controlled-release fertilizer can take care of the crop's nutritional requirements throughout the growth season. Controlled release fertilizers are designed to feed plants continuously, with maximal efficiency of nutrient uptake. Controlled release fertilizers save labor and application costs. Their application is independent of the irrigation system, and does not require sophisticated equipment.

Taking advantage of MulticoTech™ polymer coating technology, Haifa produces the Multicote® line of controlled-release fertilizers.

Multicote® products

Multicote® for nurseries and ornamentals; NPK formulae with release longevities of 4, 6, 8, 12 and 16 months.

Multicote® Agri / Multigro® for agriculture and horticulture

CoteN® controlled-release urea for arable crops

Multicote® Turf / Multigreen® for golf courses, sports fields, municipals and domestic lawns

Appendix II: Conversion tables

From	To	Multiply by
P	P_2O_5	2.29
P	PO_4	3.06
H_3PO_4	H_2PO_4	0.9898
K	K_2O	1.20
Ca	CaO	1.40
Mg	MgO	1.66
S	SO_3	2.50
S	SO_4	3.00
N	NH_4	1.28
N	NO_3	4.43

From	To	Multiply by
P_2O_5	P	0.44
PO_4	P	0.32
H_2PO_4	H_3PO_4	1.38
K_2O	K	0.83
CaO	Ca	0.71
MgO	Mg	0.60
SO_3	S	0.40
SO_4	S	0.33
NH_4	N	0.82
NO_3	N	0.22

From	To	Multiply by
Acre	Hectare	0.405
Kilogram	Lbs	2.205
Gram	Ounces	0.035
Short Ton	MT	0.907
Gallon (US)	Liters	3.785
Kg/Ha	Lbs/acre	0.892
MT/Ha	Lbs/acre	892

From	To	Multiply by
Hectare	Acre	2.471
Lbs	Kilogram	0.453
Ounces	Gram	28.35
MT	Short Ton	1.1
Liters	Gallon (US)	0.26
Lbs/acre	Kg/Ha	1.12
Lbs/acre	MT/Ha	0.001

1 meq	Correspondent element (mg)
NH_4^+	14 mg N
NO_3^-	14 mg N
$H_2PO_4^-$	31 mg P
HPO_4^{2-}	31 mg P
HPO_4^{2-}	15.5 mg P
K^+	39 mg K
Ca^{2+}	20 mg Ca
Mg^{2+}	12 mg Mg
SO_4^{2-}	16 mg S
Na^+	23 mg Na

1 mmol	Correspondent element (mg)	Weight of ion
NH_4^+	14 mg N	18 mg NH_4^+
NO_3^-	14 mg N	62 mg NO_3^-
$H_2PO_4^-$	31 mg P	71 mg P_2O_5
HPO_4^{2-}	31 mg P	35,5 mg P_2O_5
K^+	39 mg K	47 mg K_2O
Ca^{2+}	40 mg Ca	28 mg CaO
Mg^{2+}	24 mg Mg	20 mg MgO
SO_4^{2-}	32 mg S	48 mg SO_4
Na^+	23 mg Na	–
Cl^-	35.5 mg Cl	–