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Growing Olives and Other Tree Species in Marginal Dry Environments

With Examples from the Khanasser Valley, Syria

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Foreword

Olives have been grown in the Mediterranean areas for over five thousand years and yet there is renewed interest in these and other tree crops for the marginal areas of the dry lands. The need to increase water-use efficiency and to diversify income generation and household food security of the rural people are the main driving forces behind this trend.

The livelihoods of the rural poor are increasingly threatened by land degradation, climate changes, and liberalization of trade markets that lower the competitiveness of products from marginal areas. There is a need to develop more options and higher quality products in order to compete both nationally and internationally. For the harsh environments of the dry lands there is a need for robust crops that can endure the extreme droughts and temperature fluctuations along with soils of low fertility.

Thus, this book is a timely addition to the literature on the potentials for marginal dry areas. Although focusing mainly on olives, the reader can find information on other tree crops such as pistachio, fig, almond, pomegranate, cactus pear, jojoba, grape, and mulberry.

This edition reflects the diversification of crop research at ICARDA. We hope it will be the first of many such editions as ICARDA increases the range of options available to the rural poor of the CWANA region.

Prof. Dr Adel El-Beltagy
Director General
ICARDA

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Contents

About ICARDA and the CGIAR

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is governed by an independent Board of Trustees. Based in Aleppo, Syria, it is one of 15 centers supported by the Consultative Group on International Agricultural Research (CGIAR).

ICARDA serves the entire developing world for the improvement of lentil, barley and faba bean; all dry-area developing countries for the improvement of on-farm water-use efficiency, rangeland, and small-ruminant production; and the Central and West Asia and North Africa region for the improvement of bread and durum wheats, chickpea, forage legumes, and farming systems. ICARDA's research provides global benefits of poverty alleviation through productivity improvements integrated with sustainable natural-resource management practices. ICARDA meets this challenge through research, training, and dissemination of information in partnership with the national agricultural research and development systems.

The results of research are transferred through ICARDA's cooperation with national and regional research institutions, with universities and ministries of agriculture, and through the technical assistance and training that the Center provides. A range of training programs is offered, from residential courses for groups to advanced research opportunities for individuals. These efforts are supported by seminars, publications, and specialized information services.

CGIAR

The CGIAR is an international group of representatives of donor agencies, eminent agricultural scientists, and institutional administrators from developed and developing countries who guide and support its work. The CGIAR receives support from many country and institutional members worldwide. Since its foundation in 1971, it has brought together many of the world's leading scientists and agricultural researchers in a unique South–North partnership to reduce poverty and hunger.

The mission of the CGIAR is to promote sustainable agriculture to alleviate poverty and hunger and achieve food security in developing countries. The CGIAR conducts strategic and applied research, with its products being international public goods, and focuses its research agenda on problem-solving through interdisciplinary programs implemented by one or more of its international centers, in collaboration with a full range of partners. Such programs concentrate on increasing productivity, protecting the environment, saving biodiversity, improving policies, and contributing to the strengthening of agricultural research in developing countries.

The World Bank, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), and the International Fund for Agricultural Development (IFAD) are cosponsors of the CGIAR. The World Bank provides the CGIAR System with a System Office in Washington, DC. A Science Council, with its Secretariat at FAO in Rome, assists the System in the development of its research program.

Chapter One

Introduction

To complement a long, rich tradition of work on its mandate crops (e.g., durum wheat, barley, chickpea), the International Center for Agricultural Research in the Dry Areas (ICARDA) is now examining the possibility of working on other crops that have been grown in Central and West Asia and North Africa (CWANA) for thousands of years and are still of major importance, as they sustain the livelihoods of entire communities in the region (Harlan, 1987). It is therefore of prime importance that these crops be taken into account when addressing issues of income generation, poverty alleviation, and natural resource management, especially in the drier areas where people are struggling to survive.

One such crop is olive (*Olea europaea* L.), which is attracting increasing interest in many areas of the world (Fernández and Moreno, 1999; Nuberg and Yunusa, 2003). In Syria, the number of olive trees reached 71 million in 2002 (MAAR, 2002): this is expected to rise to 85 million by the year 2010. The reasons for the popularity of the species are not only agronomic, but are also related to environmental and human health concerns. It is robust and can often grow and produce in hilly and rocky areas where other trees cannot. The tree's tolerance to drought and its capacity to grow in shallow, poor-quality soils make the species among the best adapted for cultivation in semi-arid areas.

The olive groves in Sfax, Tunisia, have given very good results, despite an average annual rainfall of less than 200 mm. In this region, the olive has pushed back the desert and brought reasonable prosperity to a population that once used to be decimated by famine (Pansiot and Rebour, 1961). Its adaptation to poor local environments is enhanced by the fact that, despite its tolerant characteristics, the tree shows a remarkable response to any improvement in cropping conditions. For example, under dry conditions, olive yield can be substantially increased by applying small amounts of water (Fernández and Moreno, 1999). This, together with its relative salt tolerance, makes olive one of the very few profitable crops in extensive areas of the world with moderately saline soils and a scarcity of water for irrigation. If properly managed, olive is one of the most rewarding cultivated species in terms of soil conservation. Olive, which is mainly grown in areas exposed to erosion and desertification, plays a major role in minimizing soil erosion, by means of its evergreen dense canopy and superficial root proliferation (Silvestri *et al*., 1999). In hot climates, it reduces air temperature and dryness by providing shade and through transpiration.

As the pressure for good arable land increases, those efforts which aim to increase the olive acreage in Mediterranean countries are focusing mainly on marginal dry lands where the growth of other crops is limited and/or uneconomical. Moreover, many other countries (e.g., Argentina, Australia, Chile, China, India, Pakistan, and Saudi Arabia) have recently begun to introduce olive to their marginal dry (arid or semi-arid) zones.

Such efforts to expand olive growing beyond its natural habitat face edapho-climatic conditions that may be too harsh for olive growth. The marginal dry lands are defined as those where productivity (biological and economic) is low due to unfavorable environmental conditions (i.e., low precipitation-evapotranspiration ratios, low soil fertility, and sloping land). A good example of the marginal dry areas where olive growing is spreading is Syria's Khanasser Valley, located 70 km southeast of Aleppo, near the steppe area (Fig. 1). The environmental and socioeconomic conditions found in the valley are representative of those found throughout 5% of the CWANA region. Because it lies in a transitional zone between arid and semi-arid areas, the Khanasser Valley is characterized by long dry summers and cool winters, with an average annual rainfall of around 200 mm. Rainfall is irregularly distributed over the season and its amount varies from year to year, thus rendering water the most important limiting factor to crop production in the valley. Most of the soils in the area are poor and prone to degradation due to water and wind erosion and salinization. The challenge in this area lies in making the best use of the limited resources, in order to secure livelihoods, maximize income for farmers, and protect the land from degradation. ICARDA has conducted various research activities in the valley over the years. An

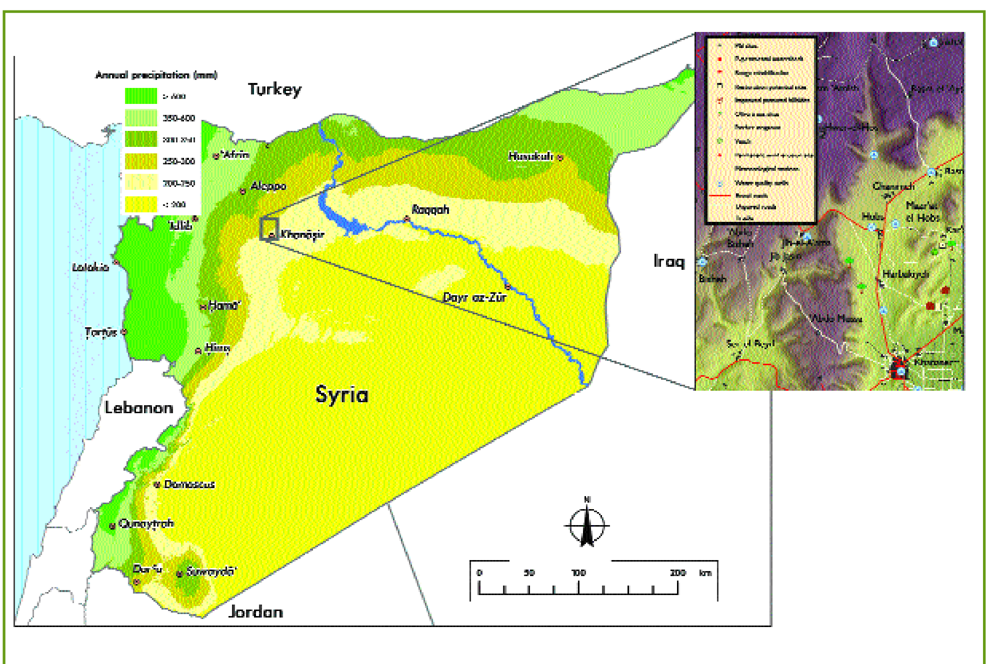


Fig. 1. Precipitation map of Syria showing the Khanasser area at the border of the steppe, which receives average annual rainfall of about 200 mm.

integrated project was launched in 2001 by ICARDA in cooperation with the Atomic Energy Commission of Syria (AECS), the University of Bonn (Germany), and local agricultural services (the Olive Bureau of Syria, the Directorate of Extension, and Jabal al-Hoss Rural and Agricultural Development Projects). The project aims to assess and solve, in an integrated way, the main problems confronting the development of the valley. Achieving this objective involves short- and long-term integrated strategies that focus, simultaneously, on higher productivity and the rehabilitation, conservation, and sustainable management of land, water, and range resources, thus leading to better living conditions.

Olives were not traditionally grown in the Khanasser Valley. A few olive groves existed in the flat area in the middle of the valley and at homesteads, the oldest of which was established in the late 1970s. ICARDA researchers started work with farmers on the establishment of olive trees on the hillsides of the Khanasser Valley in 1998. According to farmers, olive production in this area would mainly be for consumption by families while any surplus would provide an extra income.

Today, the main olive-growing area of the valley (80-90% of the valley's olive trees) lies in its western part, around the villages of Raheb, Roweheb, Habs, Harbakiyeh, and Mogherat. In mid 2003, there were more than 11,000 trees, grown both on hillsides and on the valley floor (Fig. 2). More than 90% of these trees were planted between fall 1997 and spring 2003. Some farmers established their orchards in two or three steps, due to limited financial resources. Young olive trees under summer irrigation are already producing on a commercial scale at a few sites in the Khanasser Valley (mainly around Khanasser town), while older groves flourish under irrigation in villages situated 30 km to the northwest of the valley.

Despite the relative popularity of olives in the valley, the experience of local farmers in olive growing and management is limited. In addition to the harsh environment, this lack of experience can be considered to be the main factor limiting any expansion of olive growing in the valley. Therefore, it is important to identify the main environmental and agricultural conditions and management practices required for the successful establishment of commercially sound olive groves in this area (as a model for other dry environments in the CWANA region). All available information should be collected to assess the risks involved in this investment and to ensure that farmers receive a sustainable return on the investments they make.

This document is not intended to cover all aspects of olive growing, which have already been discussed in detail in other books (e.g., Morettini, 1950; Pansiot and Rebour, 1961; and Ferguson *et al*., 1994). Rather, it focuses on aspects specific to areas drier than the prime traditional olive-growing regions. Olive's adaptation to harsh edapho-climatic conditions and water management in olive groves receive a great deal of attention in this book. This review aims, therefore, to achieve the following objectives:

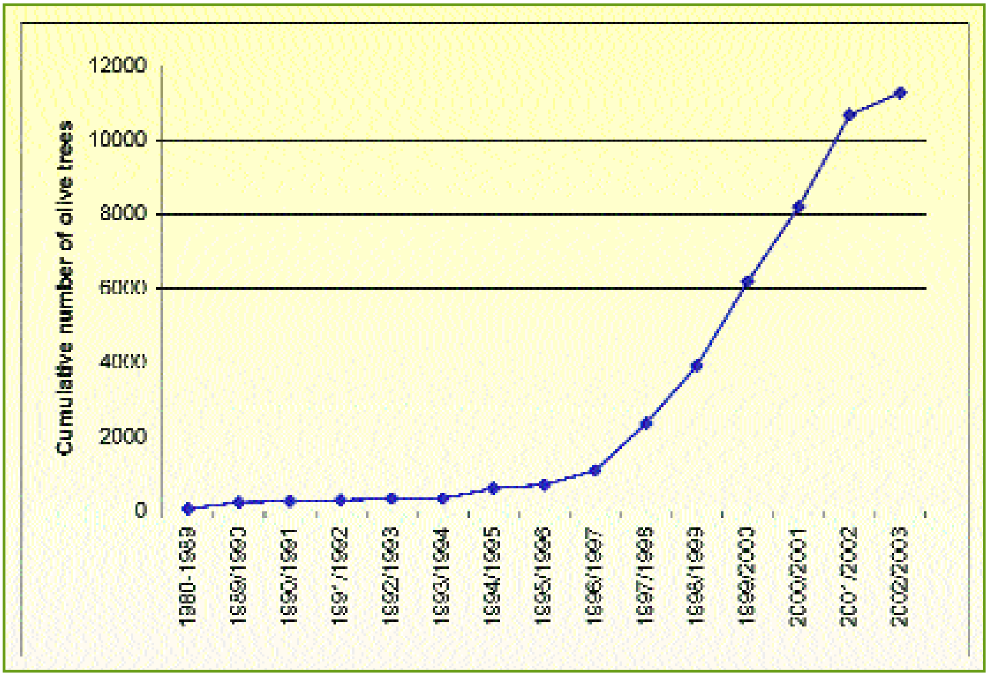


Fig. 2. Cumulative number of olive trees planted during the period 1980-2003 in the villages of Raheb, Roweheb, Habs, Harbakiyeh, and Mogherat (Khanasser Valley, Syria).

1. Present a review of the agro-ecological requirements and the limiting factors affecting olive-tree production in marginal dry areas.
2. Identify olive varieties that are best adapted to the harsh environment in these areas.
3. Formulate recommendations for irrigation and management practices that may improve olive production under the prevailing socioeconomic and bio-physical conditions in marginal dry areas, while ensuring efficient use of available natural resources.
4. Provide recommendations for alternative tree species that may be suitable for the pedo-climatic conditions in marginal dry areas.
5. Identify research gaps and provide recommendations on research strategies.

The appendices contain a summary of available information on the world's most important olive varieties. For each of the varieties, the botanical description of the tree and the fruit, yield parameters, and tolerance to drought, cold, salinity, and pests are given.

Information on olive grove management and varieties was collected from olive growers in the villages mentioned above. We also interviewed an experienced olive grower originating from a traditional olive-growing region in northwest Syria (Salkin), who has dedicated the seven hectares of land he owns near to the project entirely to olive growing. The farmers interviewed are from different socio-economic categories; but, most of them belong to medium- to large-scale households in terms of land owned since their properties range from 4.5 to 300 ha. Most olive growers in the Khanasser Valley produce other crops and only use a small proportion of their land to grow olive (the highest amount used being 45%). The cautious level of investment made in this crop is mainly due to a lack of information on olive requirements and productivity in the region and the farmers' modest experience in olive growing and management skills. Moreover, olive trees represent a long-term investment, as they usually need at least 4-5 years before they start producing fruit on a commercial scale and 10 years before they achieve full-capacity production. For these reasons, olive growing is still considered a sideline activity in the valley, although its importance is rising steadily. Farmers in the valley depend on traditional crops and/or livestock. The main crops grown are wheat, barley, and cumin in the winter, and vegetables, on a small scale, in the summer. Limited numbers of horticultural trees (such as pistachio, pomegranate, and fig), and grape vines, can also be found.

Chapter II

General Characteristics of the Olive Tree

The Olive Tree: History and Culture

Man first cultivated the olive tree in prehistoric times. Its long history is coupled with its religious importance, as the tree is mentioned both in the Bible and the Koran in the context of certain religious events.

The products of this tree are well established in the diets of the Mediterranean peoples. Olives and olive oil represent a major ingredient in almost all the dishes throughout the Mediterranean. The tree has heavily influenced the habits and the cultures of the people in this region of the world: since Roman times it has been considered to be a symbol of peace. In southeastern France, the olive has been called “the rich crop of the poor lands” while in the Near East it is called “the tree of lazy people”, because of its ability to endure harsh conditions and its low input requirements.

Origin and Geographical Distribution

The genus *Olea*~~,~~ belongs to the Oleaceae family, which also includes some other genera such as *Forestiera*, *Forsythia*, *Fraxinus*, *Jasminum*, *Ligustrum*, and *Syringa*. The genus *Olea* comprises about 35 species, spread from southern Africa northward through eastern Africa and Arabia, also found in Australia, western China, India, Malaysia, and Pakistan.

- *Olea europaea* L. The olive tree. This cultivated variety is often classified under the subspecies sativa and has close similarities to the wild oleaster subspecies (*Olea europaea oleaster* Hoffmanns & Link), widely distributed in the eastern Mediterranean countries.
- *Olea chrysophylla* Lamarck. This wild species is a possible ancestor of *Olea europaea*. In Africa, it is referred to as *Olea africana* Miller and occurs in Kenya, Uganda, Ethiopia, eastern Sudan, Yemen, and parts of Saudi Arabia. It is also present in southeast Iran, Pakistan, and western China where it is called *Olea ferruginea* Royale.
- *Olea laperrinei* Battandier & Trabut. This Saharan olive found in areas of the Hoggar mountains (southern Algeria) seems to have characteristics which fall between those exhibited by *O. chrysophylla* Lamarck and *O. europaea* L. (Chevalier, 1948). *O. laperrinei* Battandier & Trabut is said to be the immediate ancestral stock of *O. europaea* L. (Turrill, 1951).

Olive-tree cultivation began in the eastern Mediterranean around 3000 BC, where the first olive groves were established in Palestine and coastal parts of

Syria and Turkey (De Candolle, 1883), from where it spread to Italy in around 1000 BC and extended westwards to Spain because of the Greco-Roman and, later, Arab-Islamic presences and trade routes.

Figure 3 shows the present distribution of olive-growing areas in the Mediterranean basin. In the European Mediterranean regions, olive cultivation extends north to a latitude of 45°. Low winter temperatures and spring frosts make it difficult to grow olives farther north. In the eastern Mediterranean regions, the 30° line of latitude represents the southern limit of olive cultivation, especially in Jordan and Egypt. In the Maghreb countries, olive is limited to the coastal areas (including the mountains). The scarce rainfall, high temperatures, and very low humidity levels that characterize the Saharan climate in the far south of Tunisia, central and southern Algeria, and southern Morocco do not allow olive trees to be grown in these areas (Pansiot and Rebour, 1961).

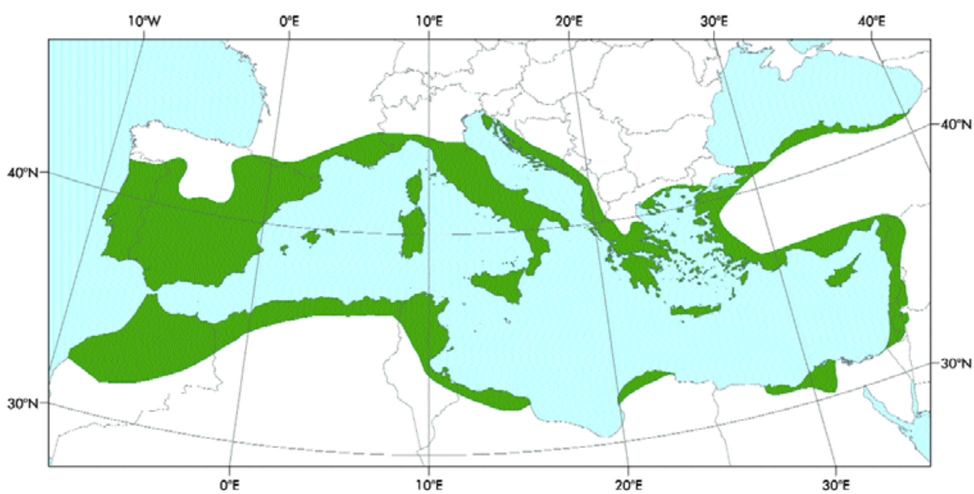


Fig. 3. Olive-growing areas in the Mediterranean basin (based on the map of Morettini, 1950).

In high-altitude areas, the upper limits of olive distribution range from 700 to 800 m above sea level on north-facing slopes, and from 900 to 1000 m on south-facing slopes. Olive trees may be found at up to 1200 m or more, but their productivity is not steady (Pansiot and Rebour, 1961).

The average annual total world production of olives for the years 1998-2001 amounted to 15,090,620 tonnes (FAOSTAT, 2003). Mediterranean countries account for more than 98% of world olive production. Spain is the world's leading olive producer, accounting for more than 30% of this amount, followed by Italy and Greece; Syria, accounting for 4% of world production, is placed sixth (Fig. 4).

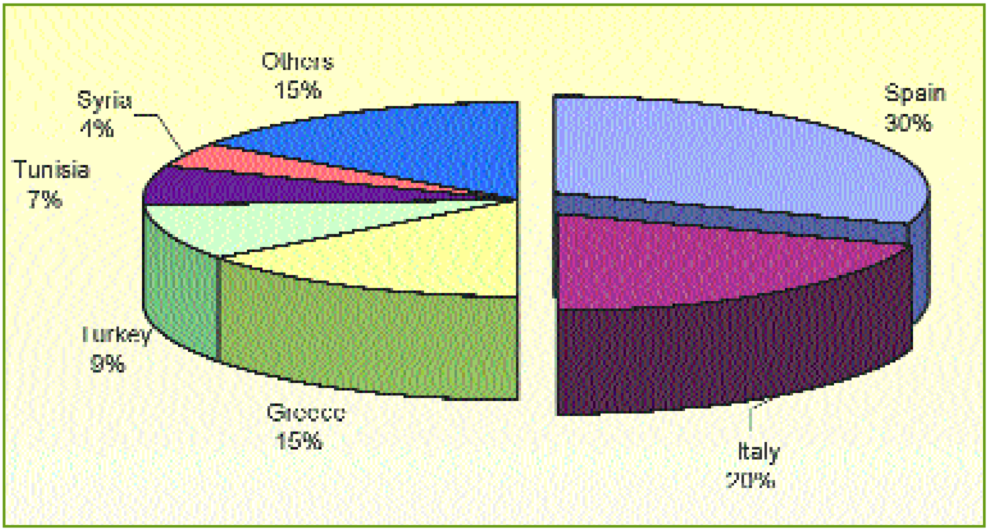


Fig. 4. Four-year (1998-2001) average contribution of main olive-producing countries to world production (FAOSTAT, 2002).

At present, the 2% of the world's olive trees which grow outside the Mediterranean basin are distributed throughout the following areas: South America, where olive was introduced by Spanish colonialists in the sixteenth century; North America, especially California where the olive tree was supposedly planted by Franciscan monks late in the eighteenth century; Australia, where stocks from Italy were introduced early in the nineteenth century; and in southern Africa, Iraq, the Islamic Republic of Iran, and Afghanistan. Efforts are still ongoing to introduce olive trees to new regions in Chile, Western Australia, and China, where considerable planting programs have taken place over the last two decades.

Botanical Description

Olive is a medium-sized to tall evergreen tree that can reach more than 15 m if left unpruned. It is a robust tree capable of regenerating promptly if cut or injured above the ground, and can live for centuries while maintaining good productivity. Its leaves are dark green, thick, leathery, lanceolate, and oppositely arranged; they are connected to the branch by a short petiole. The monoecious olive tree produces small yellow-green flowers in inflorescences with 15-30 small flowers. Fruits usually develop on shoots produced in the previous year.

Most olive varieties are self-fertilizing (see Appendices 1 and 2). The remaining self-sterile varieties imply the need for cross-pollination from other usually local varieties to ensure reasonable yields. Cross-pollination is generally known to increase yields in olive even for self-fertilizing varieties (Lavee, 1986).

Tree Growth and Life Cycle

Renowned for its longevity, an olive tree may live for several centuries. In Palestine, olive trees (usually those of the 'Nabali baladi' traditional variety) are often called "Roman", since it is believed by the local population that some trees of this variety are still alive since the Roman era, some 15 centuries ago.

The olive tree grows slowly; under the best possible conditions it only bears some fruits 3-4 years after planting and only begins economically viable production after 8-10 years. The tree does not reach full development until it is 20 years old. The mature stage extends between the ages of 35 and 150, during which the tree produces at full capacity. Thereafter, the tree ages and starts to bear irregular crops, unless it is rejuvenated by cutting back. When the trunk is cut away completely, shoots sprout at the base from which a new stem emerges, thus earning its reputation as an "immemorial tree".

Under normal conditions in its natural habitat, the annual growth cycle of the olive may be divided into the following periods (Fig. 5) although dates may change slightly depending on the variety, climate, and management options:

- Fall: fruit harvest and fall vegetative growth.
- Winter: dormancy followed by winter chilling for vernalization, and flower bud differentiation (in mid winter).
- Spring: leaf bud differentiation, flowering (between April and June), and new growth flush.
- Summer: early development of the fruit (June), pit hardening (July), fruit growth and ripening (August until harvest in early fall), and summer rest.

The olive tree produces a large number of flowers, of which only 1-5% give fruits. Flower and fruit abscission that takes place in the five to six weeks following full bloom is responsible for the small percentage of fruit retained to maturity (Rallo and Fernández-Escobar, 1985). According to Troncoso *et al.* (1978), the peak of fruit abscission in 'Manzanilla de Sevilla' occurs when the fruits are 3 to 4 mm in diameter, while the final number of developing fruits is reached about six to seven weeks after full bloom.

Fruit ripening involves a gradual change of color: from green to violet and, eventually, to a deep purple or black. Oil formation or 'lipogenesis' occurs during this process. Starting from October, the fruit can be harvested at various stages, depending on the variety, area, and final product (table olives or oil).

Biennial-Cropping

Naturally, the number of olive fruits produced in a given year is determined by two physiological phenomena: the alternate-bearing habit and the massive fruit abscission in the post-bloom period. Olive fruit production depends on the course of the vegetative and reproductive processes during a biennial cycle (Fig. 5). The

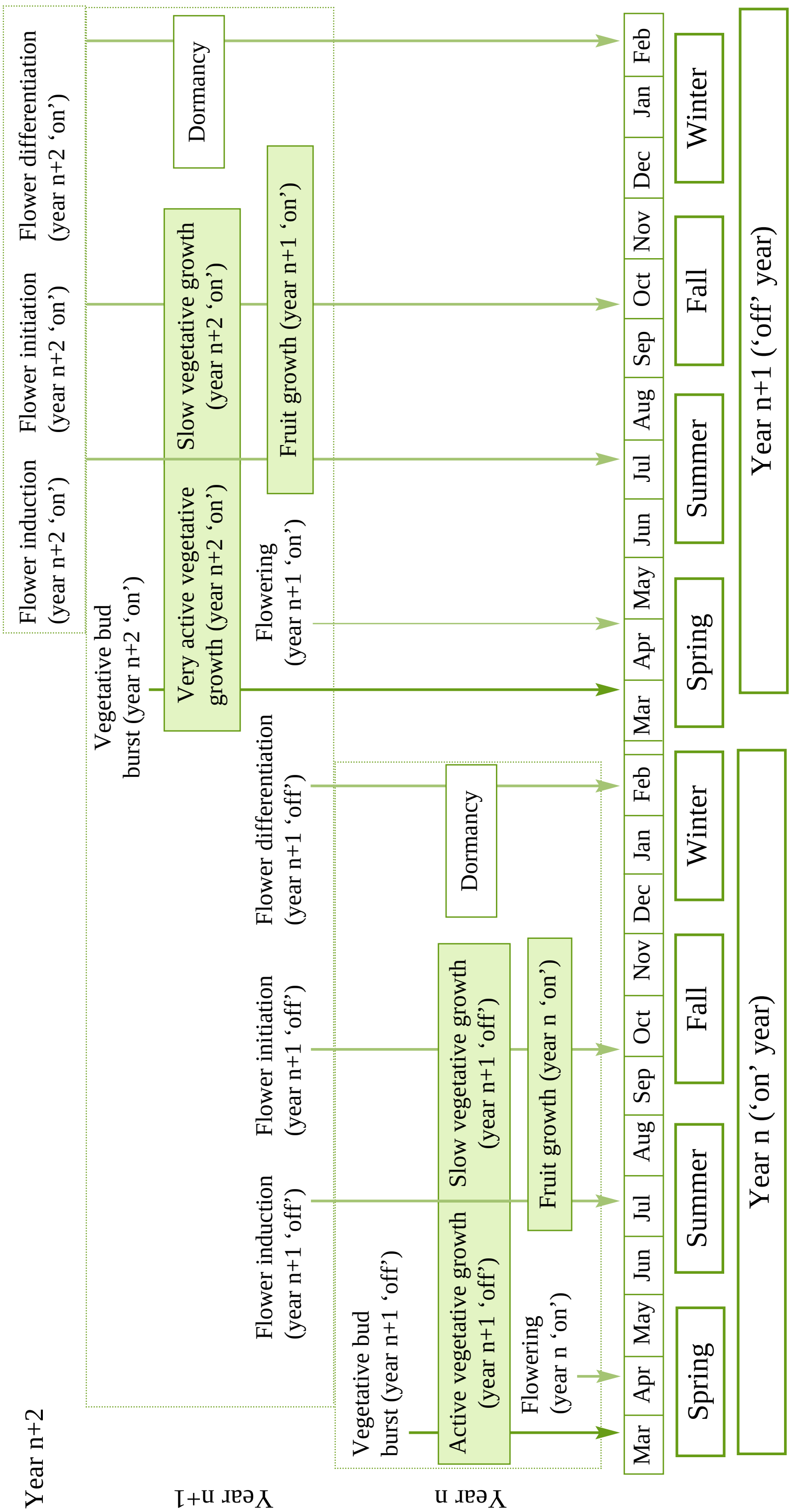


Fig. 5. Biennial cycle of the olive tree in the northern hemisphere (text in parentheses indicates the year in which buds will develop into floral or vegetative organs). Dates may change slightly according to varieties and climatic conditions.

biennial-cropping (also called alternate-bearing) pattern is defined as 'the full production of olive every second year'. The full production year is called the "on year", while the year with little or no production is called the "off year".

Vegetative buds burst in the spring (March) and continue to grow until summer (July). A second, less important, vegetative flush occurs in the fall (October) if soil moisture is adequate and temperature is warm. This vegetative growth is negatively correlated with the simultaneous fruit load and will determine the amount of fruit production in the following year.

The biennial-cropping phenomenon seems to be a result of the complex influence on tree biology of extrinsic factors (such as water management, soil, climate, and cultural operations) and intrinsic physiological factors related to varieties (Androulakis, 1998). This phenomenon is encountered in most varieties (Appendices 1 and 2) although it's severity varies from one variety to another. In recent years, some mechanisms involved in the biennial bearing habit have been identified. Inhibition of floral induction by seeded developing fruits is the major factor in this phenomenon (Rallo *et al.*, 1994). Because the intense biological activities due to vegetative and reproductive development coincide, competition for nutrients occurs between these two types of organs (Androulakis, 1998).

Rallo *et al*. (1994) reported that there is a period of endodormancy in which natural chilling is equal to or more efficient than constant temperatures in releasing floral buds from dormancy. Within the period that dormancy was breaking (mid-late January), there was a linear relationship between the percentage of floral bud burst and chilling (average 13.8°C). However, subsequent floral bud development was not influenced by chilling when these treatments were applied after 25 January.

Alternate-bearing can be reduced through controlled pruning, to prevent overcropping and to keep a balance between vegetative growth and fruit production. Proper irrigation management can also play a role in reducing this phenomenon. For instance, irrigation in early fall may stimulate vegetative growth, thus promoting the formation of vegetative buds rather than flower buds.

Studies of physiological and bio-climatological factors have shown that, among the factors affecting the biennial pattern, nutrition holds a key position (Poli, 1986). Both the nutrients available to the olive tree and the intensity of its internal metabolism vary greatly according to water uptake. Although the balance of the three main elements required (nitrogen, phosphorus, and potassium) can apparently be determined for a given region with specific pedo-climatic characteristics, the situation becomes complicated when considering important minor elements and micronutrients. A shortage of nutrients during the period of vegetative and reproductive development can affect not only the vigor of the new shoots and the size of the fruits but also the quantity and quality of the return bloom the following spring. Therefore, fertilization, coupled with pruning, helps to uphold the physiological balance of the tree and so diminish, to some extent, the variation in production that is due to the biennial-cropping phenomenon.

Germplasm

There are hundreds of olive varieties originating from the Mediterranean basin. These varieties differ in their morphology and physiology. In fact, differences can be found in tree, leaf and fruit shape; oil content and characteristics; edapho-climatic requirements; productivity; ability to self-fertilize; susceptibility to certain diseases, etc.

The wild olive trees surviving harsh conditions in different areas of the Mediterranean represent a promising stock for cultivars tolerant to drought and other environmental stresses.

Before selecting a variety to grow, it is of prime importance to consider the adaptation of the variety to the local environment, production parameters, and fruit and oil characteristics. Some important aspects used to classify olive varieties are given below:

Tree shape: Erect (up-right branch growth), Spreading (branch growth is mainly lateral), or Drooping (branches are bending downwards).

Age (after planting) at first production: Early (3-4 years), Medium (4-5 years), or Late (6-7 years).

Time of flowering: This is the time when 50% of flowers are open. This is a relative parameter that can change according to climatic conditions and geographical area. Varieties are classified into Early-, Medium-, or Late-flowering.

Fruit size and weight: This is based on fresh weight when the fruit is ready to be harvested. Although classes are not always distinct, main classes can be divided as follows: Small (<2 g), Medium (2-4 g), Big (4-6 g), or Very big (>6 g).

Time of fruit ripening: This is the time when the fruit reaches its peak oil content and its final color (usually black or dark-purple) although table-fruit varieties can be harvested before this stage. Varieties are divided into 3 classes: Early (October), Medium (November), or Late (December).

Fruit oil content: This is computed on a fresh weight basis. Oil content can vary according to management practices and climatic conditions. Classes are: Low (<18%), Medium (18-22%), or High (23-33%).

Alternate-bearing habit: This parameter reflects the difference between average productivity for 'on' and 'off' years. Varieties can be divided into three classes with respect to this character; Slight (the difference is usually less than 30%), Intermediate (the difference is 30-60%), or Significant (the difference is higher than 60% and can reach 100% in some severe cases).

Appendices 1 and 2 give a synthesis of available information on the main olive varieties compiled from many different sources. Details of other varieties can be found in the World Catalogue of Olive Varieties, published by the International Olive Oil Council in Madrid, and through the FAO Olive Germplasm Website *(http://www.fao.org/scripts/olivo/query/olcoll2.idc).*

Olive varieties usually fall into one of two commercial-use categories: oil and table (also called pickling or canning) although many varieties are dual purpose. Oil varieties have a high oil content (23-33%) in comparison to table olive (10-18%). Table olive requires special fruit characteristics in order to make it suitable for pickling or canning. For instance, fruit size in table olive should be large; this trait is not so important in oil varieties. The most well-known oil and table varieties are listed in Table 1.

Main Olive Varieties in Syria

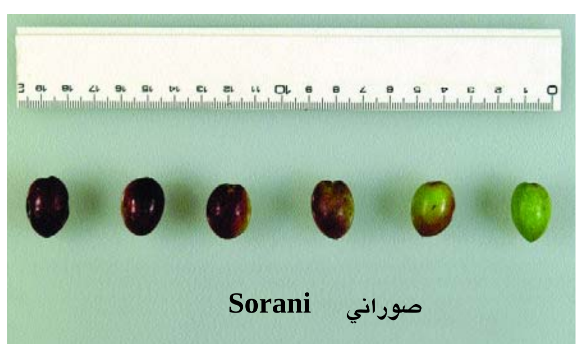
Because it is located in the heart of the original habitat of the olive tree, Syria has many wild and cultivated olive varieties which originate from different parts of the country. Although the cultivated indigenous varieties may be as many as 70 (M. Abdeen, 2003, Olive Bureau, Idleb, Syria, personal communication), the main commercially grown varieties are relatively few. The main varieties grown in the major olive-producing governorates (Aleppo and Idleb) are 'Sorani', 'Zeiti', and 'Qaisi', while in the coastal area (from Lattakia to Tartous), 'Do'ebli' and 'Khodeiri' are the most popular. In the arid inland areas of Palmyra and

Table 1. Most important olive varieties of the major olive-producing countries.

Country	Variety	
	Oil or dual-purpose	**Table**
Greece	'Koroneiki'	'Kalamata'
Italy	'Frantoio', 'Moraiolo', 'Leccino', 'Pendolino'	'Ascolano'
Spain	'Picual', 'Cornicabra', 'Hojiblanca', 'Arbequina', 'Empeltre'	'Manzanilla', 'Gordal' (syn. 'Sevillano' in California and 'Queen' in Australia)
Syria	'Sorani', 'Zeiti', 'Qaisi'	'Jlot', 'Moussa'abi'
Tunisia	'Chemlali', 'Chetoui'	'Barouni', 'Meski'
Turkey	'Ayvalik'	'Domat'
California and Australia	'Mission'	'Sevillano'

Damascus, the 'Dan', 'Jlot', and 'Abu-Satl' varieties are cultivated under irrigation. Many other less important varieties ('Mossa'abi', 'Homsi', 'Safrawi', 'Abu-Shokeh', etc.) grow elsewhere in the country. Foreign varieties are not very common in Syria, although the Turkish 'Trilye' and the Italian 'Frantoio' varieties were imported in the 1980s due to a shortage in the production of the seedlings of local varieties which occurred at that time. Characteristics of the main Syrian varieties are given below.

- **'Sorani'**, also called 'Ma'ari', is considered the most important variety in Syria, because of its drought and disease tolerance and its adaptation to most of the country's environments. The number of trees of this variety amounts to 17 million, grown mainly in Idleb governorate and in some new plantation areas. While it is mainly used for oil production, it is also considered to be a good table olive variety, especially its black olives. This vigorous variety is characterized by moderately dense leaves and a spreading growth habit. It is self-fertilizing and has a low ovary

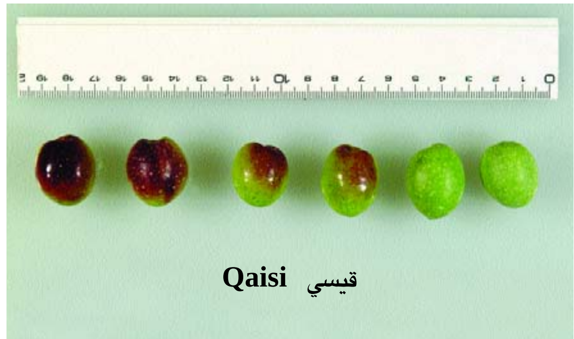


abortion rate. The tree starts to produce 5-7 years after planting, which is considered late. The fruits are medium-sized, ovoid, and slightly asymmetrical. Fruit ripening time is medium, and the fruit turns a dark purple when ripe. It has a medium level of production, of alternate habit. The tree is resistant to many pests (e.g., olive beetle and leopard moth) but is susceptible to *Verticillium* wilt. The fruit's oil content is around 30%.

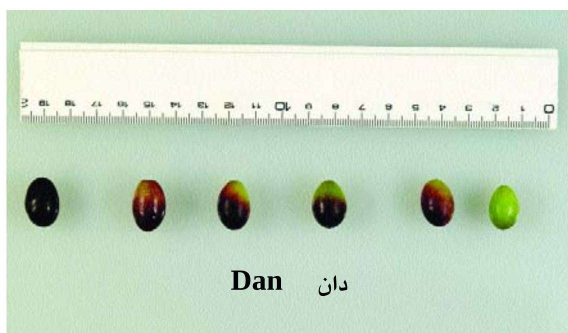
- **'Zeiti'**, also called 'Kurdi' and 'Assil'. It is mainly cultivated in the north-western part of Aleppo governorate; the 21 million trees grown represent, alone, more than 30% of the olive trees in the country. 'Zeiti' gained its name (which means oily in Arabic) from its high oil content that reaches 32% under favorable conditions in

its natural habitat. It is therefore considered as the most rewarding of the Syrian varieties in terms of oil content. The tree is vigorous and demonstrates a rapid initial growth rate. Its canopy is moderately dense with drooping branches. The tree is self-sterile, produces a high percentage of male flowers (over 50%) and has a high rate of ovary abortion, leading to the production of a large number of very small fruits. The age at which the tree begins producing fruit, 3-4 years after planting, is considered early. Flowering and fruit ripening are early. Its small to medium-sized fruits are dark-purple when ripe. This tree is sensitive to drought, high temperatures, and insects. It is characterized by a good alternate productivity.
- **'Do'ebli'**, also called 'Dremalali' and 'Tamrani', is considered to be the main variety grown in the Syrian coastal areas (7 million trees). The tree is self-fertilizing and has a low rate of ovary abortion. Its fruits are ovoid and slightly asymmetrical. This is a dual-purpose variety, as its fruit is good for the table when it turns black. It is resistant to olive knot and *Verticillium* wilt, but is susceptible to peacock spot. It is suitable for humid climates, and is a high-yielding variety with an alternate cycle. The tree begins producing fruits at a medium-late age (5-6 years after planting). The fruit has an oil content of 22-25%.
- **'Khodeiri'** is mainly grown in the coastal governorates of Lattakia and Tartous, but is also planted in some western parts of Homs and Hama; 7 million trees of this variety are grown in Syria. It is susceptible to peacock spot, but is a good bearer with a slight alternate cycle. It is used for oil and canning (when green), and the oil content of its fruit is 24-26%.
- **'Qaisi'** (or 'Kaissy'), is also known as 'Khalkhali' in some areas and is mostly grown in the new plantations to the east of Aleppo, where average

annual rainfall is around 300 mm per year. The number of trees of this variety grown in Syria exceeds 5 million. The tree is vigorous but slow growing. Its canopy is dense, with an upright growth habit. The variety is self-fertilizing and has a very low ovary abortion rate. Production starts, albeit at an insignificant rate, at a young age (3-4 years after planting) and its flowering time is medium. The fruits are ovoid-spherical and medium-sized to big (4-6 g), having clear white spots (lenticels). The fruit ripens early. This variety is both highly resistant to drought and high temperatures and fairly resistant to low temperatures. It is also resistant to tuberculosis; but sensitive to olive beetle. It gives a good level of production with a significantly alternate cycle, and is a good dual-purpose variety. The fruit's oil content ranges from 18-22%.



- **'Dan'** is the main variety used for oil extraction in Damascus Ghoota. Its fruits can also be used for table when black. This vigorous tall tree (8-10 m) is resistant to *Verticillium* wilt. Fruit production starts at a medium age (5-6 years after planting). Its fruit has an oil content of around 22%.



- **'Abou-Satl'**, also known as 'Mohazzam', is the main table variety grown in Palmyra. The tree is vigorous and demonstrates tolerance to drought, cold, and salinity. Fruit production is good and alternate starting at an early age (4 years after planting). The fruit's oil content ranges from 10-12%.
- **'Jlot'** is mainly grown in the region around Damascus. The tree is vigorous with a dense canopy and up-right growth. Its fruits are elongated and medium-sized to large (5-7 g) used for table. It is highly resistant to drought. Fruit production starts at a medium age (5-6 years after planting). Its fruit has an oil content which ranges from 10-15%.
- **'Mossa'abi'** is another important variety grown in the region of Damascus and Dara'a. The tree starts bearing fruits at a late age (6-7 years after planting). It is good for canning; its fruits have an oil content of 8-10%.

Drought-Tolerant Syrian Olive Varieties

Different olive varieties demonstrate varying degrees of adaptation to local environments according to their physiology (which is strongly related to their geographical origin) and growing conditions. Examples of such adaptation are physiological and morphological traits such as cutin-layer thickness, the ability to conserve moisture in the stem or in the root, and the ability to make use of dew. Such traits differ from one variety to another, determining the degree to which the different varieties are adapted to drought (Morettini, 1950). Generally, local varieties are more adapted to a given climate than exogenous varieties.

From environmental and economic points of view, opting for varieties suited to the local climate is crucial for the establishment of a successful olive grove. In a study conducted at the Izra' research station of the Arab Center for Studies of Arid Zones and Dry Lands (ACSAD) in southern Syria (rainfall around 300 mm), Nseir *et al*. (1985) investigated drought resistance in five olive varieties ('Manzanilla de Sevilla', 'Picholine', 'Qaisi', 'Sorani', and 'Jlot') of local and European origins. The varieties were grown in a clay loam soil with a planting distance of 8 m × 8 m (156 trees per hectare). These authors showed that 'Qaisi' and 'Jlot' demonstrated the best growth in terms of trunk diameter after 12 years of growth under rainfed conditions in this area. Calculations of average production over 4 years (1980-84) showed 'Jlot' to be the most productive variety, followed by 'Manzanilla de Sevilla', 'Picholine', 'Qaisi', and 'Sorani' (Table 2).

Table 2. Four-year average production, oil content, and pulp/pit ratio of different olive varieties as reported by Nseir *et al*. (1985).

Variety	Production (kg $tree^{-1}$)	Production (t ha^{-1})	Oil content (%)	Pulp/pit ratio
'Jlot'	24.0	3.74	10.6	5.7
'Manzanilla de Sevilla'	22.2	3.46	24.9	3.3
'Picholine'	21.4	3.38	22.6	4.3
'Qaisi'	18.6	2.90	20.0	4.6
'Sorani'	10.5	2.10	28.4	3.8

The pulp/pit ratio was highest in 'Jlot', followed by 'Qaisi', 'Picholine', 'Sorani', and 'Manzanilla de Sevilla'. The low oil content of 'Jlot' should be considered when planning to grow olives. Taking all growth and production parameters into consideration, 'Qaisi' was the variety which performed best when grown under these conditions, especially in terms of oil production.

This study by Nseir *et al.* (1985), together with the recommendations of local extension services, shows that 'Qaisi', and to a lesser extent 'Sorani', are the most drought-tolerant varieties adapted to Syrian inland conditions. However, other varieties that have shown promising results in other parts of the Mediterranean (e.g., 'Nabali Muhassan' in Jordan and Palestine, 'Chemlali' and 'K20' in Tunisia, 'Moroccan Picholine', 'Cornicabra' in Spain) could be tested.

Two trees growing in an olive grove in Hwer-al-Hoss, a village situated on the Jabal-al-Hoss hill range at the western limit of the Khanasser Valley, Syria. These pictures show the importance of selecting suitable varieties for a given environment. The picture on the left shows a heavy production of high-quality fruits on a tree that belongs to a drought-tolerant variety. The one on the right shows a few wilting fruits on another tree, which is sensitive to drought and to high temperatures.

Olive varieties grown in the Khanasser Valley

Many olive varieties are grown in the Khanasser Valley olive groves: it is possible to find as many as 10 varieties in the same grove. However, 'Zeiti', 'Qaisi', and 'Sorani' are the predominant ones.

'Zeiti', which is present in practically all the groves in the valley, represents 77% of the total number of trees in the Khanasser Valley. It remains the most popular among olive growers in this area, thanks to its high oil content and its reputation in the main olive-growing area of Afrin (to the northwest of Aleppo), where farmers from Khanasser work as wage-laborers. Nevertheless, there are some indications that the oil content of this variety is less than 25% under local conditions in the Khanasser Valley, compared to its 32% potential under Afrin growing conditions. The variety is not very well adapted to drought and high temperatures, which characterize the valley. It should be noted that the trees of this variety show water-shortage symptoms much earlier than drought-tolerant varieties such as 'Qaisi' or 'Sorani'. Furthermore, many farmers in the Khanasser Valley complained that their trees did not bear fruit even though they saw a large number of inflorescences. After diagnosis, it was discovered that some areas where this variety is grown are exposed to a dry hot wind, coming from the steppe, which desiccates inflorescence, hence reducing fruit set. In addition, this variety is known for its high rate of ovary abortion and requires cross-pollination from other varieties. It should be noted that almost all the groves made up of this variety are grown under irrigation.

Promoted by national extension services, ‘Qaisi’ is the second important variety in the area. In fact, extension services do not recommend the expansion of other varieties (particularly ‘Zeiti’) in this marginal area. ‘Qaisi’ is present, in small or large numbers, in 65% of the groves in the valley. We observed that ‘Qaisi’ trees tolerated the warm spring wind and produced fruits, while the trees of other varieties failed to produce due to desiccation of their flowers.

Constituting 8% of the trees of the valley, ‘Sorani’ is the third important variety. It is found in 38% of the groves in the valley. However, this variety has great potential for expansion, since it has the two main characteristics local farmers look for: high oil content and drought tolerance.

Some foreign varieties are also present in the valley. The Turkish ‘Trilye’ variety was imported through official channels in the 1980s. It found its way into the valley because farmers mistook it for ‘Zeiti’. This variety occupies fourth place among the varieties grown in the valley.

There are also some other less important local varieties, such as ‘Mossa’abi’, ‘Mawi’, and ‘Abu-Satl’, which are grown in insignificant numbers by a few farmers.

It is pertinent to stress that many farmers in the valley mistakenly believe that the variety they have is ‘Zeiti’ when it is actually ‘Sorani’ or ‘Trilye’ in most cases. The lack of knowledge and experience that characterizes olive growers in the the Khanasser Valley could generate problems. For instance, choosing the wrong olive varieties may result in complete crop failure, which was the case with several farms in the valley due to the desiccation of inflorescence by dry hot wind.

Chapter III

Water Management in Olive Groves

In dry areas, where olive is mainly grown, water shortage is the main factor limiting agricultural production. We will therefore discuss olive water requirements and management before treating other aspects related to soil and orchard management.

The olive tree can survive in a variety of climates. The olive-growing region around the Mediterranean Sea is characterized by considerable variability in annual rainfall, ranging from less than 200 mm in the driest areas to more than 1300 mm in the more humid ones (Pansiot and Rebour, 1961). Furthermore, olive possesses higher tolerance to salinity and drought than other temperate fruit trees. It is grown in areas far from its natural habitat, such as Argentina, Australia, Chile, China, and India. However, yield cannot be optimal if pedo-climatic conditions are not favorable. For instance, intense rain, extremely high temperatures and dry wind are deleterious to good fruit set since olives are wind pollinated (Bradley *et al*., 1961; cited in Tous and Ferguson, 1996).

Drought Resistance of the Olive Tree

Olive is one of the most drought-tolerant fruit trees, and its water-use efficiency in good soil water conditions is higher than most other fruit tree species (Xiloyannis *et al*., 1996; cited in Xiloyannis *et al*., 1999). The first drought-adaptation characteristic is the high amount of cuticular wax covering the leaves, which significantly increases the diffusion resistance of the cuticular membrane, thus controlling water loss (Leon and Bukovac, 1987). In addition, olive stomata are present on the lower leaf side and completely covered by shovelled trichomas, which reduces their exposure to sun and controls transpiration (Boujnah *et al.*, 1998).

Moreover, olive possesses physiological mechanisms (such as reducing water loss by closing stomata) which enable it to withstand long periods of drought. This is more evident in young current-year leaves than in one-year-old leaves (Fernández *et al*., 1997). Olive is also able to resist water stress by lowering the water content (Abd El-Rahman *et al*., 1966) and water potential (Xiloyannis *et al*., 1999) of its tissues. This mechanism permits the plant to establish a high potential gradient between leaves, roots, and soil, therefore allowing it to utilize soil water at potentials as low as -2.5 MPa (Dichio *et al*., 1994; Xiloyannis *et al*., 1999), which is far below permanent wilting point (-1.5 MPa). Similarly, Abd El-Rahman *et al*. (1966) noticed, in 'Chemlali' olive trees grown under semi-arid conditions (150 mm rainfall) in northwest Egypt, a marked increase in osmotic potential throughout the dry season, which enables its roots to extract water from drying soil. These active and passive osmotic adjustments play an important role in maintaining cell turgor and the leaf activities that depend on it (Xiloyannis *et al*., 1999; Chartzoulakis *et al*., 1999).

Under water stress, the olive tree stops shoot growth while reducing stomatal conductance, enabling photosynthetic activity to continue at lower rates (Xiloyannis *et al*., 1999; Chartzoulakis *et al*., 2000). Xiloyannis *et al*. (1999) showed that net assimilation at a pre-dawn leaf water potential of -6 MPa was only 10% of that of well-watered plants. This allows the continued production of assimilates as well as their accumulation in various plant parts, in particular in the root system, creating a higher root/shoot ratio in comparison with well-watered plants.

In addition to these physiological changes, anatomical differentiation can also increase drought resistance

The 'Chemlali Sfax' trees are able to withstand drought and low rainfall in Tunisian coastal areas by making use of high relative humidity and extracting water from dew.

This olive tree, although rooted in a very shallow soil (<30 cm), is growing well during a very dry, hot, summer without irrigation. The soft limestone parent material retains moisture in the dry environment of the Khanasser Valley better than the soils prevailing in these hillsides. Notice the bedrock outcrop in the central lower part of the picture.

in olive trees. Varieties that exhibit different levels of adaptation to drought differ in their anatomical characteristics. Comparing two Greek varieties, Chartzoulakis *et al*. (1999) discovered that leaf and mesophyll thickness were lower in the variety 'Mastoidis' than in 'Koroneiki', which maintained, under drought conditions, higher photosynthetic rates and lower stomatal conductance. Furthermore, the surface area of mesophyll cells exposed to intercellular spaces per unit leaf area appeared significantly greater in 'Koroneiki', which leads to higher photosynthetic rates. The effects of water stress on the growth and development of olive trees at different phenological stages are summarized in Table 3.

Table 3. Effects of water stress at different phenological stages on growth and production of olive trees.

Organ or phenological stage	Period of the year[1]	Effect of water stress	Reference
Root growth	From spring to fall	Stimulated root secondary growth, thicker roots	Fernández *et al*., 1994
Shoot growth	Mainly spring (February to June), and fall (September to December)	Reduced shoot growth, higher root/canopy ratio	Celano *et al*., 1999
Flower bud development	February to April	Reduced flower formation	
Bloom	April to May	Incomplete flowering	Beede and Goldhamer, 1994
Fruit set	May or June	Poor fruit set and increased alternate bearing	Beede and Goldhamer, 1994
Fruit growth due to cell division	June to July	Reduced fruit size. Stone size will be reduced if stress occurs in June or early July before stone hardening	Lavee *et al*., 1990
Fruit growth due to cell enlargement	August to harvest	Reduced fruit size	
Oil accumulation	September to harvest	Reduced fruit oil content	Inglese *et al*., 1999
Fruit ripening	October to December	Enhanced pre-harvest fruit drop	Inglese *et al*., 1999

[1] The time of the year applies to the olive's natural habitat.

Root distribution and density play an important role in the ability of olive to resist drought, as they are correlated with the soil volume explored, and hence with water absorption. In light deep soils, olive roots may extend 12 m laterally and 6 m deep. In addition to genetic factors, root distribution and density are affected by soil conditions, water regime, and irrigation method.

After a period of water stress and subsequent rehydration of the soil, olive, like other tree species, demonstrates a period of inertia in its leaf activity. This is not due to a lack of cell turgor but to other causes related to both the tree's hormone balance and the conductivity of its xylem system. How fast leaf functionality is restored depends on the previously reached level of stress (Xiloyannis *et al*., 1999).

Water Requirements of Olive

Water requirements of olive depend on the type of cultivar, the physiology of each individual tree, and the pedo-climatic and grove conditions to which it is subject, particularly tree density and pruning (Fernández and Moreno, 1999). Despite the drought-tolerant character of olive, additional water almost always has a positive effect on olive yield. Many authors (e.g., Moreno *et al*., 1996; Villalobos *et al.*, 2000; Girona *et al*., 2002; Palomo *et al*., 2002) have tried to determine the water requirements of olive and to study the effect of water on tree growth and production.

Soil moisture measurements and plant-stress indicators can assist with the scheduling of irrigation. Soil moisture measurements give a direct indication of the water use and needs of the crop. However, this method is laborious and multiple observation locations are needed to account for the variability of the soils and trees. Plant-water measurements, although they provide a direct indicator of plant-water needs, are difficult to interpret, due to the highly dynamic nature of plant-water status (Goldhamer and Fereres, 2001).

Rainfall in the Khanasser Valley

As in most semi-arid regions, rainfall in the Khanasser Valley varies greatly from year to year. The mean annual winter rainfall (October-May) for the period 1929-2003 was 209 mm, with lower and upper quartiles of 164 and 252 mm. The driest year in the record received only 52 mm (1972/73), whereas a total of 399 mm was recorded during the wettest year (1987/88). The small amounts of rain that occasionally fall during the hot summer months, which have generally limited benefit for agriculture, were ignored in this analysis.

Much of the rain falls between December and February (Fig. 6). In addition to inter-annual variability, rainfall distribution over the wet season is also far from homogenous. For instance, in the 2001/02 rainy season, the amount of rainfall recorded during the whole month of February was only 1.9 mm. This low and unevenly distributed rainfall is barely sufficient to produce any crop. Barley, which is one of the most drought-resistant annual crops, produces grain only once every three or four years. In most cases, crops are grazed by animals or supplemental irrigation is provided to achieve economically-viable grain yields.

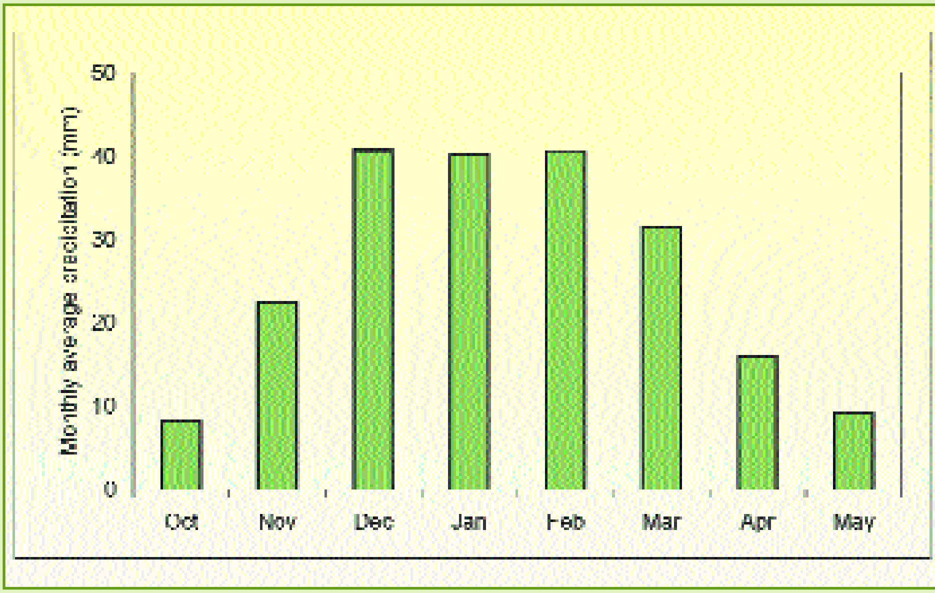


Fig. 6. Average monthly winter precipitation in the Khanasser Valley for the period 1929-2003.

An established approach for assessing irrigation needs is the computation of crop water requirements from meteorological data and crop coefficients. This procedure is explained in detail by the FAO (Allen *et al*., 1998). The method includes the use of climate data for computing reference evapotranspiration (ET_0) for a hypothetical crop (0.12 m high, surface resistance 70 s m^{-1}, albedo 0.23), closely resembling a well-watered uniform grass cover. Computation of the reference evapotranspiration requires minimum and maximum temperatures, relative humidity or dew point temperature, wind speed, and solar radiation or sun hours. Allen *et al*. (1998) provide procedures for estimating missing parameters, but maximum and minimum temperatures are the minimum data requirements. The climate parameters should be measured above an extensive well-watered short crop, such as grass.

Evaporation pans can also be used to estimate reference evapotranspiration. However, pans require frequent and careful management, and can serve as a water source for animals, thereby reducing accuracy. Allen *et al*. (1998) suggest the use of pan data only for periods of around 10 days. A pan coefficient is used to relate pan evaporation to reference evapotranspiration:

$$ET_0 = K_p E_{pan}$$

where K_p is the pan coefficient and E_{pan} the observed pan evaporation. Pan coefficients range from 0.4 (strong wind, low humidity, fallow environment) to 1.1 (light wind, high humidity, cropped area). Coefficients for different types of pans and environmental conditions are listed by Allen *et al*. (1998).

To estimate the water needs of a particular crop, the reference evapotranspiration is multiplied by a crop coefficient:

$$ET_c = K_c ET_0$$

where ET_c is the crop evapotranspiration and K_c the crop coefficient. The crop evapotranspiration represents the water use of a crop under optimal, uniform conditions, with crop coefficients varying as a function of crop growth stage.

Crop coefficients depend on tree characteristics, orchard management, and environmental conditions. Allen *et al*. (1998) list the following crop coefficients for olive orchards with 40 to 60% ground cover, and a tree spacing of 5 m x 10 m: 0.50 for December to February, 0.65 for March, and 0.70 during the remainder of the season. Fernández and Moreno (1999) summarized olive crop coefficients determined by various researchers for orchards in southern Spain: values ranged from 0.45 for June to July, to 0.70 for March and November.

Allen *et al*. (1998) provide procedures for adjusting the crop coefficient for a number of special conditions, such as not wetting the entire soil surface, incomplete soil cover, and control of stomatal conductance. Various researchers (e.g., Fernández *et al*., 1997; Girona *et al*., 2002; Palomo *et al*., 2002) use a ground-cover factor to account for the incomplete cover of the orchard:

$$ET_c = K_r K_c ET_0$$

where K_r is the ground-cover factor, computed as twice the percentage of the orchard soil surface that is shaded by the trees as observed from overhead.

To estimate irrigation requirements, a soil moisture balance is computed throughout the season by adding effective rainfall and subtracting crop water requirements. For the purpose of olive production, the effective rainfall can be defined as the observed rainfall minus losses due to surface runoff and deep percolation. These losses will be small for deep, flat soils with high infiltration rates. Small rainfall events are often considered ineffective, but this supposition may be incorrect because the rain drops will cover the soil surface and vegetation, thereby reducing soil moisture losses and transpiration (Dastane, 1978). Although the effectiveness of rainfall depends on the rainfall characteristics, often a fixed reduction factor is used. Smith (1992) suggests that the values of the reduction factor range between 0.7 and 0.9. The soil moisture balance is, thus, computed as follows:

$$\Delta SM = ET_c - cP$$

where ΔSM is the change in soil moisture storage, c is the fraction of the rainfall that is considered effective (reduction factor, ranging between 0 and 1), and P is the rainfall.

Whereas the net irrigation requirements are defined by the soil moisture balance, gross irrigation requirements (the amount of water to be delivered to the field) are computed by multiplying the net irrigation requirement with the application efficiency of the irrigation system. In modern, commercial orchards, irrigation is scheduled using climate data from the previous day or week, so-called real-time irrigation scheduling. But climatic data are not available for all areas and irrigation recommendations are often based on average conditions. If available, observed rainfall should be taken into consideration.

An example of the computation of net irrigation water requirements, under average climate conditions for the Khanasser Valley, is presented in Table 4.

Table 4. Computation of net irrigation requirements for mature orchards, using average climate data for the Khanasser Valley, Syria.

Month	K_r[1]	K_c[2]	ET_0[3] mm/mo	ET_c mm/mo	cP[4] mm/mo	ΔSM[5] mm/mo	NIR[6] mm/mo
September	0.29	0.60	225	39	0	-39	39
October	0.29	0.65	121	23	7	-16	16
November	0.29	0.70	60	12	20	8	0
December	0.29	0.55	40	6	37	31	0
January	0.29	0.55	37	6	36	30	0
February	0.29	0.55	53	8	37	29	0
March	0.29	0.70	102	21	29	8	0
April	0.29	0.65	144	27	14	-13	0
May	0.29	0.60	220	38	8	-30	0
June	0.29	0.55	300	48	0	-48	0
July	0.29	0.50	326	47	0	-47	32
August	0.29	0.50	307	44	0	-44	44
Total			1935	319	188	-131	131

1 K_r: ground-cover factor (see text). Calculations assumed a tree spacing of 7 m × 7 m and a ground cover area shaded by the tree of 7 m^2 (1.5-m radius).

2 K_c: crop coefficient (see text). Coefficients were determined for mature trees in southwest Spain with a 7 m × 5 m spacing where K_r = 0.70 (Fernández and Moreno, 1999).

3 FAO–Penman-Monteith reference evapotranspiration ET_0 (Allen *et al*., 1998) computed using climate data for 1981 to 1985 from the Khanasser Valley.

4 Effective winter rain, average of 1929 to 2003 rainfall data for Khanasser town and valley, assuming 90% effectiveness (c = 0.9).

5 Monthly change in soil moisture storage, positive values indicate a surplus, negative values indicate a shortage.

6 Net irrigation requirement, computed by adding the monthly soil moisture surpluses and shortages. The water surplus from the winter months is depleted in July; net irrigation requirement is computed by adding the ΔSM-values from November to July.

The results indicate that there is a rainfall surplus in winter. Although some of this water will evaporate from the soil surface, field measurements in the Khanasser Valley have indicated that part of the moisture will remain stored in the deeper layers for use during the beginning of the dry season (April-June). Approximately 130 mm of irrigation could be applied to satisfy the tree's water requirements during the summer months from July to September.

Improving Water-Use Efficiency in the Dry Areas

Since water is the main limiting factor in the dry areas, any potential for the improvement of agricultural production would come from the improvement of water-use efficiency. Even in areas characterized by very limited water resources, olive trees can still be grown successfully if proper management practices are implemented. This section discusses possible ways to improve water-use efficiency in olive groves.

Runoff-Water Harvesting

Runoff-water harvesting can substantially increase the amount of water available for trees. This technique involves the collection and concentration of surface runoff from a catchment area to a target area where crops are grown. The catchment area is generally larger than the target area (Oweis *et al*., 2001). Small soil bunds, approximately 15 to 30 cm high, are constructed to direct the water to, and collect it around, the tree, using a 'v'-shape or semi-circular design. These dikes can easily be made by farmers with a hoe (see Critchley and Siegert, 1991). To ensure the flow of runoff, the orchard needs to have a slope (3-20%). In dry environments, water harvesting is of major importance, as it can increase the amount of water stored in the soil during winter and decrease the amount of irrigation water required in summer. This technique is particularly useful for young trees, which have not yet developed a large root system. However, the success of this method requires, among other factors, high-intensity rainstorms, low infiltration rates, crusting and/or shallow soils in the catchment area, and soil that is able to store the harvested water in the target area.

Deep storage of water minimizes direct evaporation during the very hot summer. Two conditions are necessary to ensure deep storage in the target area:

1. The soil must be very permeable to a fairly good depth (i.e., 50 cm) to allow rapid water infiltration.
2. For deep soils, the water-holding capacity of the top layer should be low so that water can infiltrate to the lower layers, where it is not exposed to evaporation from the soil surface.

Another traditional water-saving practice is the use of stone mulch, where the soil around the tree trunk is covered with stones to reduce evaporation losses from the soil surface (Li, 2003). Adding olive-mill waste to the soil can also reduce evaporation losses (Mellouli *et al*., 1998). The use of olive cake increases the soil water-holding capacity (El-Asswad *et al*., 1993), but its phytotoxicity and high salinity restrict its use.

'V'-shaped water-harvesting structures around the tree direct runoff water to the tree basin. This olive orchard is located on the eastern hillsides of Harbakiyeh village, Khanasser Valley, where annual rainfall (220 mm) is not enough to sustain olive growth.

Water harvesting in the Khanasser Valley

Water-harvesting systems on the stony hillsides (8-15% slope) of Habs village indicated that the amount of water harvested is highly dependent on the very variable rainfall characteristics of the area. Approximately 200 L $tree^{-1}$ was harvested from 50- and 70-m^2 untilled catchments during the wet 2002/03 season (302 mm). With tree water use low during the rainy winter months, the root zone needs to be sufficiently deep to store the water for subsequent use during the hot summer. Thus, for shallow soils on the hillsides the use of larger catchment areas is not recommended. In the deeper soils at the foot of the hills, catchment areas of up to 100 m^2 may still be efficient.

A number of farmers in the Khanasser Valley who have groves on the hillsides have constructed non-permanent water-harvesting structures on their own initiative. The farmers use and modify plowing furrows to divert runoff water towards their trees. The disadvantage of this method is that the structures need maintenance after each tillage operation. These structures are also susceptible to destruction by heavy rainfall events and need more maintenance than the structures in the untilled stony fields.

Soils in the Khanasser Valley are moderately deep on the valley floor and shallow on the hillsides. The chalky limestone layer below the shallow soils on the hillsides may act as a moisture reservoir. However, it is useful to increase the depth of the planting holes to ensure the easy access of the root system to deep water-holding layers.

Tree Spacing and Density

The term “tree density” generally means the number of plants per unit area, without taking into account canopy size, cover density, age, or time necessary for completing tree development. Tree density is determined by tree spacing, which designates the distance between two adjacent rows. Pansiot and Rebour (1961) reported that olive trees are highly productive under rainfed conditions around Sfax in southern Tunisia, where the annual rainfall is less than 200 mm. This is possible because of the extremely low planting density, not exceeding 17-20 trees ha^{-1} (22-24 m between trees), in order to increase each tree’s share of water. Among other characteristics, these trees, planted in a sandy soil, have very extensive root systems that extract water from locations far from the trees, which enables them to withstand drought. We have been able to notice 1-inch diameter roots growing at least 10 m away from the closest olive tree.

Most olive trees in central and southern Tunisia are successfully grown under rainfed conditions with low rainfall because of the wide spacing adopted (24 m × 24 m).

Tree density affects the volume of soil from which the roots can extract water and nutrients. Thus, the lower the rainfall, and the poorer and shallower the soil, the greater should be the tree spacing. Pansiot and Rebour (1961) recommended a maximum density of 100 trees ha^{-1} (a spacing of 10 m × 10 m) for rainfed trees under abundant rainfall (800 mm $year^{-1}$). Irrigated olive trees are obviously more densely spaced than rainfed trees. Average tree density in Italy, including irrigated and non-irrigated groves, is around 160 trees ha^{-1}, while it is estimated to be 135 trees ha^{-1} in Syria, 105 trees ha^{-1} in Spain, and 40 trees ha^{-1} in Tunisia. If the tree density is too high, light becomes another limiting factor to olive growth and yield. Also, in densely spaced orchards, pest infestations are more common and more difficult to control.

Pastor and Humanes (1990) found that under an annual average rainfall of 500 mm in Cordoba, Spain, higher yields per hectare were obtained with a density of 312 single-trunk trees ha^{-1} (8 m × 4 m) than with 100 trees ha^{-1}, which were pruned to three trunks per tree. A density of 400 trees ha^{-1} did not produce significantly higher yields than the 312-tree ha^{-1} density, and at one site even resulted in lower yields after 12 years. Tous *et al*. (1999), testing different tree spacings under 500 mm annual rainfall in Catalonia, Spain, reported that 312 trees ha^{-1} provided the highest economic return. However, higher yields per tree were obtained for a spacing of 8 m × 7 m (234 kg) than for the 8 m × 4 m spacing (196 kg). Both studies reported that increased tree density had no significant effect on the oil content of the olives.

When trees are grown using water-harvesting techniques, tree spacing determines the catchment area from which surface runoff can flow to the tree. Thus, the optimal tree spacing should be computed based on crop water requirements and rainfall and runoff characteristics. In addition, the depth and water-holding characteristics of the root zone, which forms the reservoir for storing the harvested water, need to be taken into account.

Tree density in the Khanasser Valley groves

Tree density in the groves of the valley varies widely, from 75 to 333 trees ha^{-1}. Tree spacing ranges from as low as 5 m × 5 m to as high as 8 m × 10 m. However, the typical spacing was around 8 m × 8 m in most of the groves investigated. The choice of tree spacing was mainly related to water availability. Indeed, tree density was higher in groves where the farmers had their own water sources (mostly wells). The least dense groves were found on the marginal hillsides (e.g., Habs village) characterized by shallow and poor soils and where irrigation poses technical and financial problems.

Most of the olive groves in the Khanasser Valley, including this one in the village of Harbakiyeh, were established within the last six years. It is important to keep relatively large spaces between the trees to increase each tree's share of water and to avoid competition.

Regulated Deficit Irrigation

It has been documented that irrigating olive trees increases olive and oil yield by increasing the number and size of the fruits (Michelakis, 1990; D'Andria *et al*., 1999). Ozyilmaz and Ozkara (1990) also reported an increase in the pulp/pit ratio under summer irrigation. Full irrigation requirements are, however, difficult to meet, since olives are traditionally grown in water-limited areas, where irrigation water is often scarce. Therefore, various researchers have tested the effect of applying water at levels below the full crop water requirements, so-called "deficit" or "regulated deficit" irrigation (Kirda, 2002).

Michelakis (1990) tested the effect of different irrigation levels on 15-year-old 'Kalamon' and 'Amfissis' table-olive varieties, planted on deep clay soils with a spacing of 5 m × 5 m, under 732 mm rainfall, in northwest Crete. Fruit yield and fruit size increased significantly with a seasonal irrigation application of 264 mm, in comparison with that of rainfed trees. No significant differences were found between the 264-mm (0.3 E_{pan}) and 574-mm (0.6 E_{pan}) applications. Goldhamer *et al*. (1994) applied season-long deficit irrigation to mature 'Manzanilla de Sevilla' canning olives, grown with a tree spacing of 4.6 m × 9.1 m in San Joaquin Valley, California, under approximately 100 mm effective rainfall. Irrigation amounts were scheduled as a function of daily reference evapotranspiration, using different crop coefficients. Their results show a linear, nearly one-to-one relationship between olive yield and irrigation application between 230 mm (K_c 0.16) and 950 mm (K_c 0.75), suggesting that satisfying full crop requirements gives maximum yields.

Studies on the effects of deficit irrigation on young trees were conducted during the period 1997-1999 by D'Andria (2001) for five different olive-oil varieties in southern Italy and by Girona *et al.* (2002) for the variety 'Arbequina' in eastern Spain. Both studies scheduled irrigation based on reference evapotranspiration and a ground-cover factor (K_r) which changed with the growth of the trees. D'Andria (2001) irrigated 5- to 7-year-old trees, planted at a spacing of 6 m $\times$ 3 m, from early June to mid-October/mid-November, using a K_c of 0.6 for full irrigation. Treatments included full irrigation, 66% (K_c 0.4) and 33% (K_c 0.2) of full irrigation, and a rainfed control. The author concluded that adding 33% of crop water requirements did not significantly improve the yield when compared with rainfed trees, except in the case of the 'Kalamata' variety. The author also observed that satisfying all crop water requirements gave comparable results to those obtained when 66% of crop water requirements were satisfied, the latter being the most efficient treatment. Girona *et al.* (2002) tested seven irrigation treatments, with K_c values ranging from 0.25 to 0.85, on 4- to 6-year-old trees with a tree spacing of 6 m $\times$ 4 m. The authors reported maximum vegetative growth at K_c 0.74, maximum fruit yield at K_c 0.73, and maximum oil yield at K_c 0.68.

Whereas the above studies reduced water application throughout the irrigation season, higher water-use efficiency may be obtained when deficit irrigation is limited to selected non-sensitive crop stages. Alegre *et al.* (1999) tested the effect of deficit irrigation on 100-year-old trees, established in deep clay-loam soil, at a density of 100 trees ha^{-1}, in eastern Spain, with an average annual rainfall below 425 mm. The trees were irrigated from 5 July to 17 September. The authors reported small differences between the fully-irrigated control, which received a total of 108 mm (computed from ET_0 with K_r 0.4 and K_c 0.7), and the three deficit-irrigated treatments (85, 68, and 59 mm). The 59-mm treatment had smaller fruits and lower yields, but a higher oil percentage, than the other treatments. No significant differences were detected in the total oil yield of the four treatments. Goldhamer (1999) reduced irrigation water supply by 50%, in comparison with that given to the fully-irrigated control (K_c 0.65, 770 mm), for 42 days during mid-June till July (T1) and for 70 days during June till mid-August (T2), in an "on" year in a mature table-olive orchard in California. The two treatments did not reduce yield or fruit value and resulted in 16% (T1) and 25% (T2) water savings, compared with the control.

The effect of irrigation timing was also clearly proved by Ozyilmaz and Ozkara (1990) in western Turkey. Mature trees of the dual-purpose variety

'Memecik' were irrigated at different development stages by bringing the top 90 cm of the 9 m × 9 m basin to field capacity. The average annual rainfall during the experimental years (1980-1987) was 873 mm. The authors found that the largest increase in yield (54%), compared with a non-irrigated control, was obtained when the plants were irrigated after the end of bloom, in June, and at pit hardening, in July (216 mm in total). When irrigation was applied both at pit hardening and at fruit coloring, in September, (279 mm total) yield increased by 49%, whereas irrigation at pit hardening alone (149 mm) resulted in a yield increase of 44%. Irrigation reduced the oil content; but, when applied at pit hardening only, oil content (27.2%) was only slightly lower than that of the non-irrigated control (27.9%). The reduction in oil content due to irrigation was more pronounced in the other treatments (25.6% average oil content). It can be deduced from this work that irrigation during the pit-hardening stage was the most effective for oil production.

The above studies indicate that deficit irrigation can reduce water use, and thus cut irrigation costs, without affecting economic yields, if proper management practices are applied. To achieve good yields with a minimal amount of water, it is important to avoid water stress at critical growth and production stages indicated earlier (Table 3).

Importance of the End-Use of Olive Production

The end purpose of olive cultivation is very important in deciding whether to irrigate or not. For table olives, the size of the fruit is more important for marketing than oil content. Sufficient water supply is therefore required to achieve commercially acceptable fruits. The overwhelming majority of farmers in dry areas grow olives for oil or as a dual purpose fruit; so, fruit size is less important than oil content and oil yield. When table varieties are considered, the above studies show that irrigation should be about 65% of crop requirements. It is also pertinent to mention that excessive irrigation will not increase oil yield.

Irrigation practices in the Khanasser Valley

Most farmers in the Khanasser Valley irrigate their orchards in summer (May or June through October). Moreover, some farmers start watering their trees earlier (in March or April) while some others reported that they might irrigate in winter (January or February) if rainfall is not adequate to sustain tree growth in spring.

Water for most of the farmers comes from their own wells, which tap the upper, unconfined aquifer system, varying in depth from 35 to 65 m and operated using diesel pumps. Those whose wells are in or near the olive grove mostly use PVC pipes to convey water to the trees through surface irrigation. Others, who do not have an on-site well, either buy water or convey it from other wells using a tank pulled by a tractor and connected to a hose to irrigate the trees. These farmers usually drive uphill in order to evacuate water from the back of the tank.

For those who irrigate, the number of irrigations in summer varies from 3 or 4 to 12. Accordingly, irrigation frequency varies from one to two irrigations per month, depending on plant age, water availability, tree and soil water status, and weather conditions. Although almost all of the olive growers in the valley believe that the more they irrigate the better it is for the trees, the amount of water added to the tree basin varied greatly from one site to another, mainly according to water availability. The smallest amount reported was 150-200 L water tree^{-1} (3 or 4 applications of 50 L tree^{-1}) in the case of 3-year-old plants grown on the hillsides of Harbakiyeh. The greatest amount of water added in one growing season was 1600 L tree^{-1}, given in 4 applications, to 25-year-old trees in a grove southeast of Khanasser town. However, most of the farmers apply 500 to 1000 L tree^{-1}.

Use of Chemicals to Increase Drought Resistance

Chemical compounds such as paclobutrazol or triapenthenol, which are potent shoot-growth retardants, decrease the water use of olive trees (Frakulli and Voyiatzis, 1999). These growth regulators, tested on various tree species, reduce water loss from the leaves (Steffens and Wang, 1984) and fruits (Sankhla *et al.*, 1989) and can therefore control tree growth and size (Ogata *et al.*, 1989; Stan *et al.*, 1989). Paclobutrazol also increases fruit size and fruit yield per unit of canopy volume, although it decreases the total yield, relative to that of untreated plants (Ogata *et al.*, 1989). In addition, these compounds are able to protect plants from various environmental stresses (e.g., high temperatures and frost). They ensure satisfactory fruit set and yield under stressful (high temperature and drought) con-

In the drier areas, such as the Jabal al-Hoss plateau, Syria (200-250 mm annual rainfall), olive trees should be kept small, to reduce water losses through transpiration. The height of these 15-year-old trees is less than 2.5 m.

ditions (Porlingis and Voyiatzis, 1999). These compounds can be applied to the soil with water or as a foliar spray. However, the use of chemical growth regulators for olive production in the CWANA region seems to be limited to research studies.

Irrigation Water Quality

In arid and semi-arid regions, the water resources available for irrigation often have elevated salt contents. Excess salinity in the root zone affects plant growth. Surface water quality may be affected by the discharge of poor-quality drainage water, whereas groundwater quality may suffer when extraction exceeds the natural recharge rate. Although olive is listed as a moderately salt-tolerant crop (Maas and Hoffman, 1977), inappropriate irrigation with poor-quality water may cause short- and long-term problems that are very difficult to alleviate.

The salt content of irrigation water is usually expressed in terms of Electrical Conductivity (EC_w in dS m^{-1}) at a standard temperature of 25°C. EC_w can be easily measured with inexpensive, and sufficiently accurate, handheld EC-meters, both in the field and in the lab. Conversion factors are often used to express water quality in terms of salt content (Richards, 1954; Abrol *et al.*, 1988). The exact conversion depends, of course, on the ionic composition of the water.

Due to evaporation from the soil and water uptake by the trees, the salts added at each irrigation accumulate in the root zone. Thus, the salinity of the soil water (EC_{sw}) is higher than that of the irrigation water. The EC_{sw} is difficult to measure. Soil salinity is, therefore, usually measured from an extract of the saturated soil paste (EC_e). For many soils, the EC_{sw} at field capacity is approximately equal to two times the EC_e (Maas and Hoffman, 1977). In gypsiferous soils, the dissolution of gypsum in the saturation paste will raise the EC_e. Because gypsum is generally beneficial to most soils and crops, the salinity increase due to gypsum (approximately 2 dS m^{-1}) should be subtracted from the measured EC_e (Ayers and Westcot, 1985).

Threshold values for crop tolerance to salinity are generally reported as EC_e (e.g., Maas and Hoffman, 1977). According to these authors, the yield decline of olive due to salinity will start at an EC_e of approximately 3 to 6 dS m^{-1}. These thresholds are only indicative. The suitability of a water source for irrigation depends not only on the total amount of salt present, but also on the kind of salt. Olive trees are generally more susceptible to specific ion toxicities (sodium, chloride, boron) than annual crops (Ayers and Westcot, 1985; Maas and Hoffman, 1977). Salinity may also cause nutritional imbalances or deficiencies.

Water with a low concentration of salts (low EC) but with a high concentration of sodium relative to the concentration of calcium and magnesium (high SAR[1])

[1] $SAR = \frac{C_{Na}}{\sqrt{(C_{Ca} + C_{Mg})/2}}$, where C represents the concentration (me L^{-1}) of the subscript cations.

causes swelling and dispersion of clay minerals and breakdown (slaking) of aggregates. Irrigation with these waters results in soil crusting and reduced permeability. The process is enhanced by high soil pH. Soils affected by these processes are referred to as “sodic soils” (Rhoades *et al.*, 1993).

It is important to realize that the actual effect of salinity depends on a combination of various factors, such as water quality, climatic conditions, soil characteristics, agronomic management, irrigation management and methods, cultivar, growth stage, and rainfall (Rhoades *et al*., 1993). Research on these issues has been relatively limited, with most studies being conducted under controlled conditions in the greenhouse, on young plants, and for short periods of time (e.g., Therios and Misopolinos, 1988; Benlloch *et al*., 1991; Tattini *et al*., 1992; Benlloch *et al*., 1994; Heimler *et al*., 1995; Chartzoulakis *et al*., 2002). Results of field studies have been presented by Robinson (1987), Bouaziz (1990), and Klein *et al*. (1994).

Olive trees affected by salinity are usually smaller than unaffected trees, having less shoots, shorter internodes, fewer and smaller leaves, and a lower shoot/root ratio (e.g., Therios and Misopolinos, 1988; Tattini *et al.*, 1992; Gucci and Tattini, 1997). Salinity also affects germination, the number of healthy flowers per inflorescence, and fruit set. Typical symptoms of salt stress in olive plants are reduced growth, leaf-tip burn, leaf chlorosis, leaf rolling, wilting of flowers, root necrosis, shoot dieback, and defoliation (Gucci and Tattini, 1997).

Benlloch *et al*. (1991) and Tattini *et al.* (1992) found that the leaves of more salt-tolerant olive varieties had lower Na and Cl contents and higher K/Na ratios, whereas these varietal differences were almost non-existent in the roots. These authors conclude that salt exclusion from the shoots is one of the main mechanisms by which olives cope with salinity. Klein *et al*. (1994) reported that the concentration of Na and Cl in the roots, shoots, and leaves of 1-year-old cuttings of ‘Manzanilla de Sevilla’ increased with the salinity level of the irrigation water. The high Na influx was related to a reduced concentration of Ca in the roots, which impairs the selective permeability of the root to Na.

Bouaziz (1990) irrigated 13 different olive varieties with water containing 4 g L^{-1} total dissolved solids (approximately equal to an EC of 6 dS m^{-1}) on sandy, calcareous soils in central Tunisia. The trees, mostly planted with a spacing of 6 m × 6 m, were irrigated with 400 mm of water between February and October (0.4 E_{pan}) under 100 to 200 mm of annual rainfall. All varieties provided good yields, with the highest average yields for the nine-year study period being obtained by ‘Chemlali’ and ‘Manzanilla de Sevilla’ (4.7 tonne ha^{-1}) and the lowest by ‘Kalamata’ (1.9 tonne ha^{-1}). Most varieties showed a slight decline in yield over time. This could have been caused by different factors (e.g., irrigation system and pruning), as pointed out by the author, but may also have been caused by an accumulation of salts in the soil. The author did not report soil salinities.

Klein *et al*. (1994) tested the effect of irrigation with saline water on ‘Manzanilla de Sevilla’ and ‘Uovo de Piccione’ olives, after an 18-month establishment period during which good-quality water had been used. Irrigation with saline water (EC 5.5 to 6.5 dS m^{-1}) increased the percent dry weight and oil yield per unit fruit weight, as compared with that of the control (1.2 dS m^{-1}). However, after 18 months of irrigation with saline water, early rains (10 mm) leached the accumulated salts from the wetted front of the drip-irrigation zone into the main rooting area, causing leaf yellowing, leaf drop, and shoot dieback. Analysis of the leaves indicated that these symptoms were due to high Na concentrations.

Therios and Misopolinos (1988) reported a 50% reduction in water uptake in 3-year-old plants irrigated with water containing 80 meq L^{-1} NaCl (8.6 dS m^{-1}) grown in a sand-perlite culture in the greenhouse. At an EC of 6.6 dS m^{-1}, the reduction in leaf dry weight of the four tested varieties, compared with that of the distilled water irrigation (0 dS m^{-1}) treatment, varied between 11% and 63%, whereas the reduction in root dry weight varied between 22% and 51%. Freeman *et al.* (1994), cited by Gucci and Tattini (1997), reported a reduction in crop performance when water with an EC greater than 5.5 dS m^{-1} was used. The same authors stated that the SAR should not exceed 9 for maximum productivity.

In the dry areas, rainfall is often not sufficient to leach accumulated salts from the root zone. Thus, additional irrigation water needs to be applied; this requires the soils to have good drainage. Olive tree roots should not be exposed to high water tables. The fraction of the applied water that passes through the root zone and percolates below it is called the leaching fraction:

$$LF = D_{dw}/D_{iw}$$

$$D_{iw} = (K_c\ ET_0)/(1-LF)$$

where LF is the leaching fraction (less than 1), D_{dw} is the amount of water leached (mm), D_{iw} is the irrigation applied (mm) and ($K_c\ ET_0$) is the crop water requirement (mm).

Such a leaching fraction can be applied at each irrigation, or less frequently, as long as soil salinity levels are below the crop threshold value. For drip irrigation, it is generally not recommended that the leaching fraction be added to every application (Rhoades *et al*., 1993). When full irrigation is used, leaching requirements can be computed from the salinity of the irrigation water (EC_w) and the crop salinity-tolerance threshold (expressed as EC_e). Considering the salinity-tolerance range of olives (EC_e 3-6 dS m^{-1}), irrigation with an EC_w of 2 dS m^{-1}, in the case of the lower threshold, and 4 dS m^{-1}, in the case of the higher threshold, plus a 15-20% leaching fraction, will ensure that olive yields remain unaffected (Ayers and Westcot, 1985).

When rainfall fulfills an important part of the crop water requirements or when deficit irrigation is practiced, leaching requirements depend on rain, soil, tree age and variety, and irrigation characteristics. The supplemental irrigation of olive trees with saline water requires the regular monitoring of soil salinity levels and the development of a suitable leaching strategy.

Water quality in the Khanasser Valley

The quality of the groundwater in the side valley in which Habs and Harbakiyeh are located is good (EC < 2 dS m^{-1}, SAR < 4); but outputs are limited and some wells dry in summer. Salinity levels vary in the main valley. In general, salinity levels are around 2 dS m^{-1} along the sides of the valley and increase towards the middle, with the highest levels observed in the central part of the valley at its northern end (up to 30 dS m^{-1}). The groundwater in most of the central part of the valley is not suitable for the irrigation of olive trees.

Irrigation Techniques

Rainfall serves, traditionally, as the olive tree's main water supply. When water is only supplied during critical periods, two to four times per year, the installation of an irrigation system is generally not economically viable. Water can often easily be supplied by hose to small earth basins (e.g., 1.5 m diameter) around the young olive trees. For mature trees, the basins should be expanded to provide water to the full root system.

In Europe, where the availability of land may be as limited as that of water, numerous olive growers have intensified their operations. These intensive orchards have localized irrigation systems, also referred to as pressurized irrigation systems, because water is applied to the plants under pressure, provided by a pump or elevated water tank. Well-designed and properly operated localized systems provide much higher irrigation efficiencies than traditional surface-irrigation methods, because the water is distributed more efficiently. The emitters that discharge the water from the irrigation pipes include a variety of sprinklers, sprayers, bubblers, and drippers. An overview of the different systems and their performance characteristics has been provided by Phocaides (2000). Mini-sprinklers and bubblers are suitable for irrigating fruit trees, because of their high flow rates (up to 250 L hr^{-1}), and consequently the large diameter of the area they wet. Drippers require less pressure for their operation; but, the wetted soil volume of drip systems is limited and roots will restrict their growth to the wetted area. Thus, the roots will not be able to fully exploit subsequent rain falling on a larger surface area. Drip-irrigated orchards are often densely spaced and water is added frequently.

Fernández *et al*. (1992) examined the root dynamics of 20-year-old rainfed trees under different irrigation methods in Sevilla, Spain (550 mm average annual rainfall). They found that the root growth of trees that were irrigated with 4-L hr^{-1}

Surface irrigation is the traditional way of irrigating olive trees in the Khanasser Valley, using small dikes connecting the trees in rows. Water-use efficiency is low for this method and the trees located upstream receive much more water than the trees located downstream. However, this method favors the growth of a widely proliferated root system.

drippers (50 cm from the trunk, on four sides of the tree) was concentrated within the wetted soil volume. Root growth of trees that were surface-irrigated using 3-m radius basins, on the other hand, extended into a large zone around the trees. For rainfed trees the most intensive root dynamics were found far from the trunk, and also at a depth of 70-80 cm near the trunk.

Under Californian conditions, Henderson and Fereres (1981; cited in Fereres and Goldhamer, 1990) reported that wetting of 20-30% of the potential root zone of mature deciduous trees appears sufficient for maximum production, provided enough water is applied to meet ET demand.

Bubblers and microjets, which allow high discharge rates, are more favorable for root growth; but, these systems are also more expensive. Palese *et al*. (2000) examined the root length density of the fine roots of rainfed trees and irrigated trees in a semi-arid Mediterranean environment in southern Italy. Trees were irrigated using microjets discharging 80 L hr^{-1} over a 1-m radius. The root length density of the trees was measured in February, May, and July, within a radius of 1.2 m at three distances from the trunk, and at 4 depths between 0 and 1 m. The results indicated that microjet irrigation allowed the roots to explore a greater volume of soil, even going beyond the wetted area. The differences were greatest at 0.8 to 1.2 m from the trunk. Root densities were always higher for the irrigated trees than they were for the rainfed trees, except in July, when rainfall increased the root density of the rainfed trees for the 0 to 0.5 m depth within 0.8 m from the trunk.

Underground irrigation systems, using porous pipelines (Phocaides, 2000) or clay pitchers (Bainbridge, 2000), save a large amount of water which would otherwise evaporate due to high temperatures in the surface layer and direct exposure to the sun. However, the establishment of an underground pipeline system is

Subsurface insert irrigation is a simple way of improving water-use efficiency. Water is supplied by hose (left) or pipe network (right) to 4- or 5-inch-diameter plastic tubes placed vertically in the soil. To ensure good water distribution in the root zone, a gravel pocket is placed at a depth of 40 to 70 cm, at the lower end of the tubes, in a circle or crescent around the tree, either at establishment or later on. This method conveys water to where it is needed, and therefore avoids losses through evaporation from the soil surface.

costly and the pipeline openings often become clogged. Clay pitchers may be less costly and easier to establish; but, the regular filling of the pitchers is rather labor intensive. Two farmers in Harbakiyeh village (Khanasser Valley, Syria) are applying subsurface irrigation to their olive trees using 3-inch-diameter plastic tubes inserted vertically into the soil to convey the water to the root zone. They use a gravel layer placed around the root zone at the outlet of the pipe to allow rapid water distribution within this zone. A similar technique has been applied in southern Tunisia (Sghaier *et al.*, 2001). Subsurface irrigation ensures better growth than surface irrigation methods (Abd El-Rahman and El-Sharkawi, 1974).

Irrigation recommendations for the Khanasser Valley

Supplemental irrigation could improve olive yields in the Khanasser Valley, as ET_0 is very high in the summer. Furthermore, young trees will still need to be irrigated, until their roots can reach the deep layers where additional moisture is stored. With the limited availability of good-quality water in the valley, intensive drip-irrigated orchards are not feasible. Tree growth and olive yield could be improved by providing irrigation during the dry season with a PVC hose or tanker. Watering should be sufficient to wet a volume of soil slightly larger than the root zone, so that the roots will be encouraged to spread in search of water. Therefore, larger amounts of water should be applied to older trees and deep soils. Soils should be filled up to field capacity, which is approximately 30% of the soil volume in the clay loam soils on the hillsides. Soil moisture measurements in Habs village indicated that the average soil moisture content in the root zone during the dry summer months decreased to approximately 20%. Thus, 10% could be added to the soil reservoir.

- In the case of young trees, shallow soils (e.g., 0.7 m) and a tree basin of 1.5 m^2 (0.7-m radius): $0.1 \times 1.5 \times 0.7 = 0.108\ m^3 \approx 100$ L could be applied to each tree per irrigation. Two to four irrigations should be given during the hot months.

- With relatively high rainfall and low evapotranspiration in winter, soil moisture storage is generally sufficient for the trees in spring (Table 4). Only in very dry years, an irrigation should be applied in April, before flowering. Irrigation during flowering is not necessary.

- The first summer irrigation should be given in July or early August after pit formation and hardening to increase fruit size while avoiding enlargement of the pit (i.e., this irrigation increases the flesh/pit ratio). Lavee (1986; cited in Fernández and Moreno, 1999) reported that the occurrence of water stress two or three weeks after fruit set, before pit hardening, reduces pit size.

- The second summer irrigation, in late August, is very important to compensate for water losses during the hot summer and to ensure good yield.

- In the case of extreme drought and high temperatures, a third irrigation could be considered in early September in order to increase fruit size. It should be kept in mind that irrigation decreases oil content, so one should not expect a great increase in oil production as a result of summer irrigation.

- For mature trees, adding approximately 130 mm of irrigation water during the summer would satisfy full crop water requirements. For a tree spacing of

7 m × 7 m, this equals 6370 L tree^{-1}. This amount is not applicable in the Khanasser Valley, where irrigation water is limited. A more sustainable alternative would be to supply water only to basins around the tree. It would be recommended to heighten the area around the trunk with soil such that the water will infiltrate beyond a distance of 1 m from the trunk, where the active root-hairs are growing.

Assuming a root depth of 1.3 m, and a 10% soil-water reservoir, 130 mm water fills the full depth of the root zone. Supplying the suggested 130 mm irrigation in a single application reduces evaporative losses from the surface. If the water is applied to a 1.7-m radius basin, without irrigating a 1-m radius inner circle around the trunk, 5.94 m^2 × 0.13 m = 0.772 m^3 = 772 L would be needed. Thus, one irrigation of 770 L could be applied in late July or early August.

Chapter IV

Impact of Temperature on Olive Production

Temperature Requirements of Olive

The olive tree is a sclerophyllous and glycophytic species adapted to the hot dry summers characterizing the Mediterranean climate. Some authors even consider it to be a desert shrub (Schwabe and Lionakis, 1996). Olive is being successfully grown under rainfed conditions in areas of very low rainfall such as Sfax, Tunisia, where average annual rainfall does not exceed 200 mm. Olive trees might therefore represent a good, high-value alternative for use in harsh climates where other species barely survive.

It is noteworthy that varieties vary in chilling requirements and tolerance to high or low temperatures (Bongi *et al*., 1987). In general, Italian varieties are the most cold tolerant while North African (Moroccan and Tunisian) varieties are the most tolerant of high temperatures. The olive tree's physiological winter-chilling requirement is estimated to be around 150 to 300 hours at temperatures below 9°C, occurring between November and February. However, Hartmann (1953) indicated that some varieties may need more than 1000 hours below 7°C to produce flowers.

Effect of High Temperatures

Olive trees can withstand high temperatures. Nevertheless, if these occur in April or May, at the time of flowering and new shoot growth, they may be harmful. Hartmann *et al*. (1980) reported that the occurrence of high temperatures before and during bloom caused a substantial decrease in olive productivity in California. The exposure of olive trees (variety 'Chalikidikis') to a maximum temperature of 35°C during the flowering period and 37°C before fruit-set reduced fruit-set rate to 1.4% (Porlingis and

High temperatures in April and early May can desiccate inflorescences and cause severe losses or even prevent fruit production, as in this example from the Khanasser Valley. Planting heat-tolerant varieties is therefore essential in the areas susceptible to high spring temperatures.

Voyiatzis, 1999). High temperatures (above 33°C) can burn flower parts and endanger production. Porlingis and Voyiatzis (1999) remarked that fruit set was also reduced when trees were subjected to high temperatures (36-41°C) in a greenhouse for 5 days after the end of the flowering period. The most favorable temperatures for flowering, pollination, and fertilization are between 18 and 22°C.

The effects of high temperatures could be alleviated by the application of paclobutrazol as explained in the previous chapter.

Effect of Low Temperatures

The olive tree is sensitive to low temperatures although it is probably the most cold tolerant of the subtropical fruit trees (Denney and McEachern, 1985). On unharvested trees, there is a risk of fruit freezing when temperatures drop below -3°C. The low temperature tolerance limit is near -7 to -8°C. During the spring, young vegetation and inflorescences are sensitive to temperatures below zero while, during flowering, temperatures lower than 10°C hinder fertilization. In 1985, frost in southern France killed more than 25% of the 4 million olive trees that existed then.

Sudden below-zero temperatures in April killed these young shoot tips. Trees grown in valleys or in areas susceptible to the accumulation or passage of cold air were the most damaged, while those present a few meters upslope were not affected.

Temperature in the Khanasser Valley

The climate in the Khanasser Valley is characterized by long, very hot summers and cold winters. The long-term data (1957-1985) presented in Fig. 7 were recorded in Khanasser town; temperatures in the main valley observed during

1980-1985 and 1998-2003 indicate that the daily minimum temperatures in the valley are generally 1 to 3° lower than in the town, whereas the daily maximum temperatures in the valley are slightly higher in summer and sometimes lower in winter.

July and August are the hottest months, with average shade temperatures of 37°C. The four hottest summer months in the 1957-1985 record had an average daily maximum temperature of 39°C and a minimum temperature of 22°C. In July 1981 maximum temperatures in the valley exceeded 45°C for four consecutive days. Monthly average daily maximum temperatures during flowering and fruit-set in April and May are 23 and 29°C, respectively. Temperatures rarely exceed 35°C in April, or 40°C in May. The occurrence of high temperature (July-August) is fortunately not harmful to olive trees, as it does not coincide with sensitive stages (i.e., flowering and the fruit-set periods in April and May), especially when the trees belong to appropriate varieties that tolerate high temperatures. Nevertheless, trees may require more irrigation to compensate for water losses induced by heat waves.

Cold winter nights are frequent in the Khanasser Valley. For the 28-year monitoring period, 17% of the nights in December, January, and February had temperatures below zero. The coldest month in the 28-year record (January 1964) had an average daily minimum temperature of -3.3°C. There was only one day in the record (18 January, 1973) where the temperature remained below zero: -0.6 and -9.0°C for the daily maximum and minimum temperature, respectively. Because these low temperatures do not occur during sensitive stages, the risk of olive trees grown in the Khanasser Valley suffering cold-related damage is low.

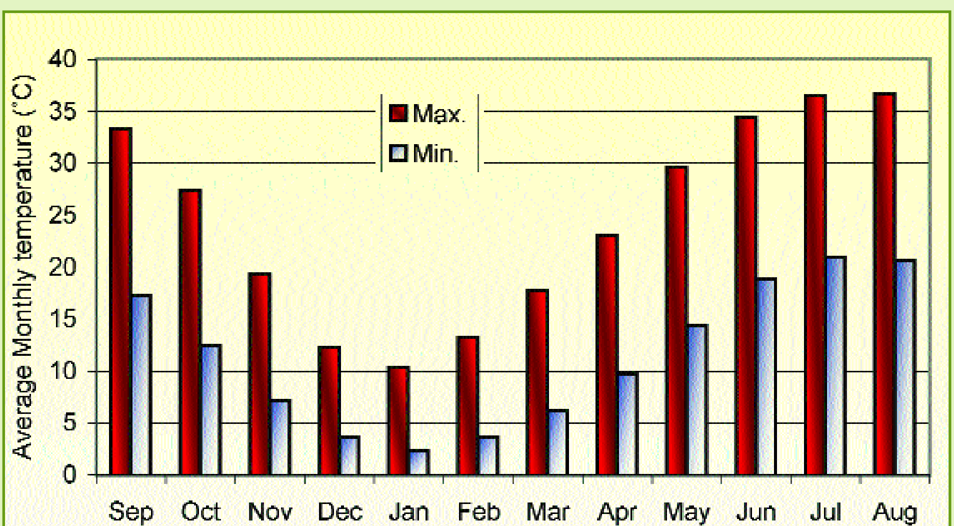


Fig. 7. Monthly average daily maximum and minimum temperatures in Khanasser town for the period 1957-1985.

CHAPTER V

Soil Fertility Management in Olive Groves

Soil Requirements of Olive

When their water supply is adequate, olive trees are not exacting with regard to the nature of the soil. They grow in a variety of soil types, from sandy to clayey. However, they prefer light, moderately fine-textured, and well-drained soils. The tree is susceptible to waterlogging in the root zone; thus, water-retaining clay soils (clay soils containing more than 20% clay) are not particularly suitable. The tree usually does well on very poor soils, even without fertilization, except for marshlands or saline soils, where it cannot survive. It also thrives in rocky or shallow soils, or soils with high lime contents, although the best yields are obtained on relatively deep and fertile soils (Pansiot and Rebour, 1961).

In marginal dry areas, soil conditions may, however, be the main limiting factor affecting olive growth. Ben Rouina *et al*. (2002) showed that, under arid conditions in Southern Tunisia, deep sandy soils ensure better yields than shallow clay soils. This is mainly due to the roots' better exploration of deep soil profiles; Ben Rouina *et al*. (1999) noticed that olive roots extended to a depth of more than 3 m in the sandy soil of coastal parts of Tunisia.

The optimum soil pH for olive trees is between 7.0 and 8.0, which is typical for calcareous soils. A very low pH will stunt a young olive tree's growth. In the case of acid soils, one simple way to raise soil pH entails incorporating agricultural lime into the root zone (the top 60 cm at least) during ground preparation work prior to planting (Pansiot and Rebour, 1961).

Soil characteristics in the Khanasser Valley

The soils in the Aleppo region are characterized by an aridic soil moisture regime and a thermic soil temperature regime. These soils are typical of a Mediterranean climate that is transitional to a temperate-continental climate. The soils in the Khanasser Valley can be divided into two main categories, as follows:

Soils of the hillsides: The soils on the valley's hillsides are dark-brown to brown, strongly calcareous, and classified as Eutric Leptosol (FAO/UNESCO, 1994) or Lithic Xerorthent (USDA Soil Taxonomy, 1975). These soils have a strongly developed, sub-angular, blocky structure in their surface layer, due to self-mulching. They are fine textured, shallow, well drained, and extremely stony. The surface layer is approximately 5-10 cm thick, while the subsoil is about 40-60 cm thick.

Soils of the valley floor: Two main soil classes are found within this area: Luvic Calcisols and Calcic Gypsisols (FAO/UNESCO, 1994) or Typic Calciorthid (USDA Soil Taxonomy, 1999). The soils of the valley floor are fine to medium textured with some clay enrichment in deep layers. These yellowish-brown to brown soils vary in depth, from less than 1 m to 16 m. They are well drained with a high water infiltration capacity. They have high lime and gypsum contents.

Both hillside and valley floor soils are poor in both organic matter (1-1.5%) and the main mineral elements. Total nitrogen content of the valley soils ranges generally between 650 and 800 ppm while total phosphorus content is between 550 and 800 ppm. This low soil fertility is due to the interaction of several factors, such as the originally poor parent material, climatic conditions (drought and high temperatures), physical land degradation, overgrazing and lack of vegetation, and improper management practices.

The soils in the Khanasser Valley fulfill the pH requirement for olive trees as their pH is around 8, with the exception of some saline soils in the northern part of the valley floor close to Jabboul salt lake.

Olive Nutrition and Chemical Fertilizer

It is generally believed that the olive tree is adapted to poor soils and has low nutrient requirements. However, fertilization has been found to result in a significant increment in growth and productivity, especially in poor soils (Ferreira Llamas, 1984). Furthermore, there is evidence that fertilizer dressing will promote the growth of young trees and bring them into early fruit bearing (Garcí a *et al*., 1999). When intensive conditions are considered, N uptake from the soil can be very high; therefore the trees need nitrogen application on a regular basis, especially after the first four years of growth. Xiloyannis *et al*. (2002) showed that under irrigated, intensive growing conditions (555 trees ha^{-1}) in Southern Italy, annual nitrogen uptake from the soil by olive trees (cv. 'Coratina') increased from 9.2 kg ha^{-1} in the case of 2-year-old trees to 186 kg ha^{-1} in 6-year-old trees. The greater demand for nitrogen occurs between the onset of annual growth (March) and fruit set (May).

Current fertilization practices in the Khanasser Valley

Although the soils in the Khanasser Valley are poor, the use of fertilizer in olive groves is limited, mainly due to economic risks. However, olive growers in the Khanasser Valley also think that fertilizer (and manure) can further increase soil temperature in this hot area, which can harm plant roots. Of the eleven olive growers we interviewed, only two farmers stated that they add fertilizer to their trees on a regular basis (usually 0.5 kg urea tree^{-1} in late March or April). However, fertilizer application at planting is more commonly practiced than post-planting fertilization. In fact, five farmers informed us that they added fertilizer when planting their olive trees. The amount of fertilizer (usually urea) added to the trees at this stage varied from 1.5 to 3 kg tree^{-1}.

Recommended Fertilizer Rates

There is no consensus on a fertilization scheme applicable to all olive groves. Indeed, the required fertilizer rates and application pattern, for a given olive grove, depend on many factors, such as soil conditions (moisture, texture, and fertility); orchard density; and tree conditions (variety, productivity, size, and age). This could explain the results of Fernández-Escobar and Marin (1999), who showed that increasing the amount of N applied from 0 to 1 kg N tree^{-1} did not lead to an increase in yield or in other production parameters in rainfed olive groves in Andalusia, Spain. Loupassaki (1998) and Anonymous (1984), among others, provide further information on olive fertilization.

Nevertheless, Fernández-Escobar and Marin (1999) suggest that N should be added only if leaf N content is lower than a threshold value of 1.5%. General recommendations for the use of fertilizer with olive are given by Geus (1973) who suggested, for every tree, an annual application of 500-1000 g N, 300-600 g P_2O_5, and 500-1000 g K_2O. However, these rates should be doubled for very-high-yielding trees or when trees are under irrigation. In general, the recommended fertilizer amendments for regions receiving more than 400 mm of rain are as follows:

- For young trees growing in normal conditions, each tree must be given, annually, 100 g of nitrogen per year of age up to the fruiting stage (e.g., for a 5-year-old tree, the amount of nitrogen to be added is $100 \times 5 = 500$ g N tree^{-1}).
- For trees of average productivity (30 kg of olives per tree), the approximate dose, calculated with 20% ammonium nitrate, would be 1.5 kg N tree^{-1} year^{-1}.

For other elements, 2.5-3.0 kg of superphosphate and 0.5-0.8 kg of potassium sulfate per tree should be added to the holes at planting (Pansiot and Rebour, 1961). Annual applications of these two fertilizers should not exceed 1 kg tree^{-1} of each fertilizer.

Since the average amount of rainfall in the Khanasser Valley does not exceed 223 mm, the recommended amounts of fertilizer should not surpass 65% of the aforementioned values. There is evidence that the application of 750 g N and 500 g K_2O tree^{-1} was optimal for achieving higher growth and yield in 14-year-old olive trees (cv. 'Frantoio') in semi-arid parts of India (Jasrotia *et al*., 1999).

Application Time and Methods

Olive trees require usable nitrogen (both nitrate-nitrogen and ammonium-nitrogen), mainly before and after flowering (March to July), in order to nourish the flowers and ensure the formation of young fruit during the following months. A shortage of nitrogen at this critical stage is responsible for an increased percentage of imperfect flowers and poor fruit set. In non-irrigated areas, fertilizer can only be added in fall (urea) and early spring (ammonium nitrate). When irrigation is available, it is better to spread applications out over the season, in order to avoid leaching (especially in the case of ammonium nitrate), the heaviest application being given in February. Excessively strong concentrations should be avoided by dividing and spacing out the applications (two or three over the year depending on rainfall). Other fertilizers (superphosphate and potassium sulfate) can be added in fall, except in regions where cold weather could destroy young shoots (Poli, 1986).

One of the best application methods is to broadcast the fertilizer under the canopy and then incorporate it into the soil through light tillage (Loupassaki, 1998). Application of nitrogen must be avoided on hot, dry days especially in areas with calcium-rich soils. In drip-irrigated orchards, fertilizers can be applied through the irrigation system ("Fertigation"), which has the advantage of saving resources and safeguarding the environment (Xiloyannis *et al*., 2002). Fertigation time must, however, be carefully selected in order to avoid probable negative effects, especially in the case of late application.

The combination of foliar and soil applications increases nitrogen-use efficiency and reduces the total amount of N needed to fertilize the orchard (Fernández-Escobar and Marí n, 1999). Foliar analysis is a simple and effective method for determining the nutrient status of the tree.

Manuring

Organic manures result mainly from animal wastes. The main benefit derived from the use of organic matter is the supply of nitrogen and other nutrients in readily available forms. Furthermore, organic matter contributes to the improvement of the physical properties of the mineral-poor soils prevailing in the dry areas. By increasing the soil water-holding capacity, winter organic amendments in the dry areas can alleviate the negative effects of drought on plants.

Current manuring practices in the Khanasser Valley

Recourse to manure in the Khanasser Valley olive groves is more frequent than the application of chemical fertilizers. Indeed, five olive growers indicated that they add 4-8 kg of sheep manure to each tree every year in winter (from

December to March). This amount varies from one farmer to another and it tends to increase with tree age. Similarly, four olive growers reported that they added manure to their trees at planting. The amount of manure added per tree ranged in general between 1 and 2 kg, although in one extreme case 50 kg were applied. Interestingly, some farmers indicated that they do not add manure because they fear that this might increase soil temperatures in this region, which is characterized by very hot summers.

When considering the establishment of an olive grove, it is best to incorporate farmyard manure well before planting: possibly at the time of the first plowing or when preparing the planting holes. The best time for organic amendment is in late November, in order to avoid high temperatures and to ensure better decomposition, which releases nutritive mineral elements in synchrony with tree growth, which starts in spring. The application of slurries to the soil surface on sunny days may result in high NH_3 losses through volatilization (Amberger *et al.*, 1982). Manure can instead be placed in the bottom of planting holes and covered with a smooth 10-15 cm soil layer, so that elements are readily accessible to the roots. Contact between the roots and the manure should be carefully avoided, as decomposition products can damage the fragile new roots or tissues about to callus over.

Maximum benefits are obtained from manure when it is added on a continuous basis. Yearly amendments of 20-30 kg of manure per tree are important, to compensate for the loss of minerals in the soil and to improve soil structure in olive groves in dry areas. Manure can also be beneficial if applied less frequently: every 2 to 3 years. For example, Loussert and Brousse (1978) recommended a rate of 50 kg of manure per tree every three years, especially in irrigated groves.

Tillage Recommendations for the Dry Areas

No-Till

No-till farming (or conservation tillage) is recommended to prevent soil degradation and erosion. No-till is generally combined with the application of herbicides to control weeds. This technique was reported to increase olive production in rainfed groves in Andalusia, Spain, where the average annual rainfall range is 400-700 mm. In fact, in their review of no-till trials using different olive varieties, Pastor and Guerrero (1990) observed that no-till practices increased olive yield in 81 of the trials and decreased it only in four trials. The authors did not provide an explanation; but, the use of herbicides in the no-till trials may have been more effective than tillage in controlling water use by weeds. On average, the trees in the no-till orchards produced 39.6 kg olives tree^{-1} versus 34.2 kg olives tree^{-1} in the tilled orchards. The average amount of oil produced was 9.76 and 8.50 kg tree^{-1} for non-tilled and tilled trees, respectively. No-till can also have favorable effects with regard to water harvesting, since it facilitates water runoff.

Deep Tillage

Deep tillage (soil ripping) prior to planting improves moisture storage in the soil and soil exploration by olive roots. In a study conducted under rainfed conditions in Southern Syria (average annual rainfall around 300 mm), Nseir *et al*. (1985) found that ripping the whole field to a depth of 90 cm increased cumulative olive production over 8 years by 3-5 times, in comparison with that of conventionally tilled soil (plowed at 30-35 cm depth).

Other Tillage Operations

Superficial tillage in spring, that aims to destroy capillaries, reduces water losses during the dry season and keeps water in the bottom layers of the soil. This measure should, however, be carried out carefully, in order to ensure that the surface roots growing in the vicinity of the tree are not destroyed. Nseir *et al*. (1985) observed that covering the soil around the trunk with black plastic mulch during the summer reduces water evaporation, and hence improves tree growth and yield.

Tillage practiced in the Khanasser Valley olive groves

Most of the farmers interviewed practiced cross-superficial (up to 20 cm deep) cultivator plowing, mainly during the period April-June and in the fall. Some farmers also plow their land in winter, to increase water infiltration into the soil and destroy early-growing weeds. The number of plowing operations ranges between 2 and 4 per year, depending on tractor availability. The farmers' main purpose when spring plowing is to control weeds; summer plowing is aimed at reducing water evaporation from the soil through the destruction of soil capillaries. Fall plowing is performed to prepare the land for the cropping season and to increase water infiltration into the soil.

Chapter VI

Various Agronomic Management Issues in Olive Groves

Pruning

More than any other cultural technique, pruning is a way of directly affecting tree biology. In the case of "formation pruning", the goal is a tree shape suitable to local management aims. Fruit-production pruning is essential, in order to redistribute nutrients effectively and allow light to reach the fruit-bearing twigs. As a side effect, pruning also influences microclimatic conditions in the tree canopy, thus affecting the proliferation of pests and diseases. Pruning can interrupt the alternate-bearing cycle and cause balanced production from one year to another by preventing overcropping.

When growing olives in semi-arid rainfed regions, the tree should be kept small, to reduce water losses through transpiration. Under such dry conditions, excessive pruning every 3 or 4 years is even recommended in dry years, to keep transpiration under control.

When winter frost is common, it is recommended that the trees be pruned in mid- to late February, before the onset of vegetative growth. Winter pruning in November is not recommended, as it may expose tissues (or the entire tree) to frost damage.

Pruning is essential in controlling tree shape and size. It is also important for fruit bearing, since it regulates vegetative growth and facilitates the growth of new branches that will bear fruit in the following season. This shrub-like 4-year-old olive tree needs formation pruning, as suckers and branches are growing without any control.

Severe pruning of olive trees every second year is a common tradition in north-western Syria. This practice results in completely alternate production and accelerates soil erosion processes in these already-degraded hilly areas.

Olive pruning in the Khanasser Valley

Although they are aware of the need to prune their trees, olive growers in the Khanasser Valley do not have pruning skills. Therefore, in most cases, they hire the services of skilled pruning workers, especially those from the region of Afrin in Aleppo governorate, which has a long tradition of olive growing. The poorer farmers either take the risk of pruning their trees themselves, thus unnecessarily damaging their trees, or do not prune at the proper time. This operation is usually practiced in early winter (November-December) or preferably towards early spring (February or March). Trees in six of the olive groves studied were pruned during early spring. However, in the other orchards the trees were still too young to be pruned.

Intercropping in Olive Groves

The fairly slow growth of olive trees results in a lot of unused space within olive groves during the first years of plantation establishment, especially when wide spacing is used. It is thus logical to plant some annual crops (e.g., legumes) in between the trees when rainfall is adequate or access to irrigation water is cheap. Such crops, however, should never be allowed to encroach on the soil needed by the trees for their normal development. Furthermore, vegetables should be avoided, as they may represent a source of contamination with *Verticillium* wilt.

Vegetable intercropping between olive trees in the Khanasser Valley. Vegetable intercropping is not recommended, since it might favor the spread of Verticillium wilt. Furthermore, in this case, the intercropped plants are grown too close to the trees, which might cause some competition.

During its first year of growth, an olive tree needs an area with a radius of 1.5 to 2 m. Intercropping can therefore be practiced between the trees, in the center of every four trees. However, intercropping should stop after 12 to 15 years in dry zones; great care must be taken because of the small amount of water available. It is recommended that sowing be performed only in alternate inter-rows, in a manner which will allow a biennial rotation of fallow and barley or leguminous crops, which demand low inputs of water, nutrients, and labor (Pansiot and Rebour, 1961).

Intercropping in the Khanasser Valley olive groves

Some olive growers in the Khanasser Valley practice intercropping, especially in winter. This practice allows them to exploit the space available between their olive trees (particularly the young ones) and to make use of winter rainfall. The main crops grown in olive groves are barley and cumin in winter, and vegetables in summer.

Some of the farmers in the valley plant grape vines between their olive trees. However, since water is not abundant in the valley, these crops may compete with the olive trees for available moisture and deplete the amount of water stored in the soil that can be extracted by olive during the dry summer. Furthermore, summer intercropping, mainly vegetables and watermelon, may increase soil and air humidity, therefore providing favorable conditions for the spread of *Verticillium* wilt disease, as some olive growers reported.

Olive Harvest

The marginal dry areas are most often characterized by abundant, low-cost labor and by limited grove sizes. Moreover, the manner in which the trees are established does not favor mechanical harvesting. Therefore, manual picking, using ladders and sticks, is still the most common way of harvesting olive in these areas.

Table olives may be picked green or black, depending on the end-product and the variety. In the case of oil varieties, olives are generally picked from October through December, when most of the fruits change from green to black or dark-purple. Ripening time depends on the variety, the climatic conditions, the water status of the tree, and the presence of other stressful factors. Oil content peaks when fruits have completely changed color. Our on-going experiments in different climatic zones show that olives ripen earlier in areas characterized by high temperatures and low water availability.

Manual harvest of olive in Syria.

Olive productivity in the Khanasser Valley

Only a few of the olive groves studied were already producing when the study began; however, even these were not producing at an economically viable level, except in three cases in the Khanasser Valley and a grove outside the valley. In the case of the trees in the productive stage in the valley, the maximum average yield obtained in the two groves aged 12-15-years was around 20 kg per tree. This yield was lower than 30 kg $tree^{-1}$ recorded for 12-year-old trees at Mazra'et ar-Rawabi outside the Khanasser Valley. The difference in yield between these two cases can be attributed primarily to the amount of water applied, in addition to the farmers' experience and the better management practices applied, such as the application of manure and pruning.

Chapter VII

Pests and Diseases of Olive

In this chapter, we provide brief information on the main pests and diseases that can be found in Syria, which are more or less the same as those in the other Mediterranean countries. The diseases discussed below were selected because they occur in some of the main growing regions of the country. Some of the diseases described below (e.g., peacock spot) do not represent a real threat to olive groves in dry areas, although they can be present for short periods when weather conditions are favorable (e.g., in late spring). Other important diseases around the Mediterranean were disregarded in this chapter, since their development requires very high humidity and mild temperatures, which are generally uncommon in the dry areas that this document focuses on. Further details of these diseases and information on other diseases can be obtained from the FAO publication on olive diseases in the Near East (Katsoyannos, 1992) or the comprehensive technical manual on "Olive pest and disease management" published by the International Olive Oil Council (López-Villalta, 1999).

Insects

The main insect pests that attack olive are the olive fly (*Bactrocera oleae* Gmelin), the olive moth (*Prays oleae* Bernard), the olive scale (*Parlatoria oleae* Colvée), and the leopard moth (*Zeuzera pyrina* L.).

Olive Fly (*Bactrocera oleae* Gmelin, Diptera, Trephritidae)

Olive fly is the primary threat to olive groves in the Mediterranean basin, central Asia and South Africa. However, it is not common in areas far from the olive's natural habitat (Australia, California, China, and South America).

The adult olive fruit fly is approximately 4-5 mm long, with clear wings containing dark veins and a small dark spot at the wing tip. The head, thorax, and abdomen are brown with darker markings; the thorax has several white or yellow patches on each side. The larvae are yellowish-white maggots with a pointed head.

Olive varieties differ considerably in their susceptibility to the fly. The fly generally prefers varieties which produce fruits characterized by a large spherical shape (Katsoyannos, 1992), a green color (Gümusay *et al*., 1990), a high water content, and a low oil content (Donia *et al*., 1971). This explains why table varieties, and large fruits in general, are usually attacked before smaller ones. Such trees with large fruits serve as gathering sites for the females.

Infection and damage

Olive flies only cause damage in their larval stage, since the larvae feed exclusively on olive fruits. The life cycle of the fly starts when mature larvae pupate inside the fruit in summer and stay there until fall, when they leave the fruit and pupate in the soil under the tree. Over-wintered adult flies lay eggs in mature, unharvested olive fruits in late winter and spring. These infested fruits drop from the tree and produce new adults. Female flies from this generation then attack the new crop of olives, laying their eggs in July and August.

Damage by the olive fruit fly includes oviposition openings on the fruit surface, fruit drop, and direct pulp destruction. Paraskakis (1990) observed a drop of 15-25% of 'Tsounati' olive fruits in the 1987/88 season. The infection renders the fruits useless for table purposes. In the case of oil olives, in addition to the reduction in oil yield (which can be severe in some cases), infection of more than 20% of the fruits leads to an increase in oil acidity and peroxide value, which substantially reduces oil quality and value (Parlati *et al.*, 1990).

Control

During the summer, high temperatures (above 33°C) kill the eggs, larvae, and pupae of the olive fly, especially when relative humidity is low. Thanks to its natural enemies (e.g., the parasitoid *Opius concolor* Szepligeti), efficient biological control of this pest is possible, and is being implemented in many countries. However, it is not recommended that olives be grown in infested areas, because control costs and crop losses will render olive production uneconomical.

Olive Moth (*Prays oleae* Bernard, Lepidoptera, Hypanomeutidae)

Also called olive kernel borer, the olive moth is common in the Mediterranean olive-growing countries, including most parts of Syria, and ranks second after the olive fly in the harmful effects it has upon the olives. *Prays oleae* Bernard affects all olive varieties, including wild species of the genus Olea.

Infection and damage

This insect lives exclusively on the olive tree, although its larvae can develop on other genera (*Jasminum*, *Ligustrum*, and *Phillyrea*). It has three generations that develop on different organs of the tree. The first generation of caterpillars lives and develops on floral buds. The second generation lives in the stone of the fruits, while the third develops on the leaves during over-wintering.

The over-wintering adults from the third generation appear in spring. Females of the moth prefer to lay their eggs in the flower calyx. The larvae hatch after 9-12 days and penetrate the floral buds, where they feed first on anthers and then move to attack the flower (stigmata, style, and ovary). Later larval stages live on the entire floral cluster, which is connected by a silky tissue. The pupae later develop between two leaves and the adults emerge.

The newly formed fruits are attacked near the stalk by larvae of the second generation, which eat the content of the stone. After staying for 80-135 days inside the fruit, the developed larva exits from the fruit via the same opening it made to enter. This process usually results in fruit drop. The adults emerge after 8-14 days.

The third generation begins when the inseminated females lay their eggs on the upper leaf surface. After an incubation period of 7-14 days, the larvae enter the leaf and live on leaf contents, forming tunnels inside the leaves. After the end of winter, the adults emerge and females again lay their eggs on floral buds, starting a new annual cycle.

The damage caused by this insect may therefore affect the flowers, the fruits, and the leaves. A drop of 5-8% of 'Kalamon' fruits was reported in Crete in 1988-1989 (Paraskakis, 1990). The damage caused can be substantial, especially if tree flowering and fertility are not high or when the insect population is considerable. Unfavorable climatic factors can greatly limit the development of this insect. Larvae wither and die when relative humidity drops below 50%. Similarly, a combination of high relative humidity (>70%) and high temperature (>30°C) leads to a high egg mortality rate (López-Villalta, 1999). This explains why this insect is uncommon in marginal dry areas.

Control

This caterpillar has many natural enemies, such as *Chrysoperla carnea* Stephens, which predate the insect's eggs, larvae, and chrysalides. It can be chemically controlled (using dimethoate or formothion) throughout all its active stages and with a high level of efficiency; the time of application depends on the type of insecticide used. Biological control measures recently achieved considerable progress in controlling this insect. Spraying foliage with the insecticidal bacterium *Bacillus thuringiensis* Berliner subspecies Kurstaki effectively reduces larvae populations (López-Villalta, 1999).

Olive Scale (*Parlatoria oleae* Colvée, Homoptera, Diaspididae)

The olive scale insect exists all over the Mediterranean basin as well as in other olive-growing regions as far away as California, China, and South America. This insect is found mainly when humid conditions (or microclimates) persist. The adult female scale is about 2 mm long, with a grayish, oval, waxy covering. The male scale is longer than the female, with a black spot at one end. It is a polyphagous scale insect feeding on more than 200 plant species including olives.

Damage

Olive scale affects twigs, leaves, and fruits. The young fruits are attacked, fed on, and deformed by the first brood of olive scale in late May and June. The attack of the second brood, in July and August, causes semi-circular, dark purple to black scales on the green fruits, decreasing fruit weight and altering the fruit quality of oil varieties. Furthermore, depigmentation of the entire fruit may occur in severe cases. The damage is more serious in the case of table olives, which become worthless, since fruit shape is the most important aspect in this case. Heavy olive scale infestations will also occur on branches, twigs, and leaves, resulting in a substantial reduction in the tree's productivity.

Control

Olive scale can be well controlled by two parasites: *Aphytis maculicornis* Masi *and Coccophagoides utilis* Doutt. If these parasites are not present, or are eliminated due to the use of other pesticide treatments, chemical treatments could be considered in late May-June for the first brood and July-August for the second brood, when the insects start to crawl towards the fruits.

Leopard Moth (*Zeuzera pyrina* L., Lepidoptera, Cossidae)

The leopard moth is a widely distributed multi-host insect. In addition to olive, this moth can affect species belonging to more than 30 botanical families, including apple and cherry. The serious damage caused by *Zeuzera pyrina* L. was exclusively limited to olive trees in the Eastern Mediterranean region, including Syria, until the early 1990s, when the pest was detected throughout a large part of southern Italy (Guario *et al*., 2002). No olive varieties are known to be resistant to this insect, although some varieties (e.g., 'Sorani') are less sensitive than others. However, healthy trees (fertilized, properly pruned, and irrigated) resist attack better than less healthy ones.

Infection and damage

The life cycle of the leopard moth on the olive tree takes one year to complete. Adults mate during the summer and lay their eggs a few days later. After eggs hatch, the larvae can stay in a silk-covered nest for a long period if the temperature is not favorable. Thereafter, the larvae attack lateral buds and form upward sub-cortical tunnels. The larvae then make an opening to get out of the branch and attack a new branch. Such movement continues until they are more than one month old, when they can attack main branches by boring a tunnel into the cambium. Their presence is revealed by the release of large amounts of sawdust and excreta from the opening. Larvae become fully developed in late winter, when they return to the entrance of their tunnel and overwinter as chrysalides. Adults emerge in June or, in some cases, in May.

This pest causes serious damage, especially when it attacks young (1-2 year old) trees, as one larva can kill the tree. The infection of secondary branches can result in their death and therefore in a decrease in plant vigor.

Control

When infestation is severe, a piece of cotton wool immersed in a material that generates toxic vapors (e.g., carbon sulfate, paradichlorobenzene) can be placed at each opening of the leopard moth tunnels. Spraying with insecticide (formothion or trichlorfon) is only recommended in the case of young larvae. Research is currently focusing on the use of a synthetic sex pheromone to attract the male to traps and then follow their flight and estimate the optimal time for treatments.

Olive Beetle (*Phloeotribus scarabeoides* Bernard, Coleoptera, Scolytidae)

The olive beetle is a pest specific to the olive tree. It is present in all the Mediterranean countries and represents a serious threat in the dry areas, due to the slow and weak tree growth if no irrigation is available. The adult is 2-2.5 mm long and 1.5-2 mm wide.

Infection and damage

In the arid areas, the insect overwinters in young shoot galleries as a larva, nymph, or adult; it leaves its shelter in February or March to attack a new host, whereupon the female digs breeding galleries in the trunk and branches. Inside these galleries the male joins the female for mating and the female lays eggs, which hatch after one to two weeks. The larvae dig small tunnels under the bark, taking three to four weeks to leave the branch as an adult in order to attack new olive branches. This beetle has three or four generations as follows:

- First generation: Adults emerge in March-April after a period of overwintering.
- Second generation: Adults emerge from April to July.
- Third generation: Adults emerge from June to August/September and the insects overwinter as adults and, for some lately-laid eggs, as larvae or nymphs.
- Fourth generation: When fall temperatures are relatively mild, adults may emerge during the period August-November.

In addition to the damage it causes by feeding on plant tissues, this beetle may cause infected branches to fall, either directly or as a result of wind damage. Infested trees are small and demonstrate slow vegetative growth and a low leaf-to-wood ratio, resulting in low productivity. Furthermore, infected trees become more susceptible to other pests and diseases (e.g., olive thrips and olive knot).

Control

In addition to pruned or broken branches left on the ground, trees which are weak (due to poor care, diseases, or drought) represent the best host for this insect to lay its eggs on. Therefore, the best method to avoid or minimize infection is to keep the trees healthy (fertilized, properly pruned, and irrigated), so that they can resist attack, and to burn or bury all pruning residues. Growing resistant varieties (e.g., 'Sorani') can also reduce the incidence of infection.

Chemical control is needed when no protective measures are taken and when more than 10% of the trees are infested. The application of organophosphorous insecticides is recommended when most of the adults have exited the branches (in July).

Diseases

The diseases that affect olive are mainly caused by fungi, with the exception of olive knot, which is a bacterial disease. According to local extension services, the most important olive diseases in Syria are *Verticillium* wilt and peacock spot.

Verticillium Wilt (*Verticillium dahliae* Klebahn)

Verticillium wilt is one of the main olive diseases common in Syria and the northern Mediterranean countries. It is caused by the fungus *Verticillium dahliae* Klebahn, which can survive in the soil or in the roots of infected trees for as long as 15 years. The fungus is mainly spread through infected soil by tillage operations and irrigation water.

The fungus affects mainly irrigated groves or those trees grown (currently or in the past) with other host crops (e.g., cotton, eggplant, pepper, and sunflower). The optimal daytime temperatures for its development range between 20 and 25°C in spring and 30 and 35°C in summer.

Infection and damage

The pathogen enters the plant through the roots and causes apoplexy, or a rapid decline, and slow decay. Apoplexy takes place in late winter and early spring, causing desiccation of the shoots or branches. The bark becomes purple while the leaves and twigs suddenly wilt, turn brown, and curl. This process intensifies as the season progresses and the whole branch dies back. Slow decay, which occurs in spring and early summer, involves necrosis on budding inflorescences. The death of mature trees infected with *Verticillium* is possible.

Control

This disease is very difficult to control; the most efficient way to avoid it is by growing relatively resistant varieties (e.g., 'Arbequina', 'Chemlali', 'Coratina', 'Empeltre', 'Frantoio', 'Kalamata', and 'Oblonga') and by ensuring the use of inoculum-free rootstock. When planting olives in an orchard which previously contained other susceptible crops, it is strongly recommended that the roots and debris of these crops be removed and burned and the soil sterilized, either by solarization or fumigation (using chloropicrin).

Affected branches, and trees in severe cases, should be cut at a distance from the infected area and burnt outside the grove. Weed control and the elimination of susceptible plants also contribute to limiting the spread of the disease.

Peacock Spot (*Spilocaea oleagina* Castagne)

Caused by the fungus *Spilocaea oleagina* Castagne, peacock spot (also called peacock eye and leaf spot) is a serious disease of olive that is widespread in the coastal humid areas of Syria and in other inland irrigated orchards. It is also associated with high tree densities, which favor humid microclimates. This disease is of minor importance in hot, arid regions, since spore germination and growth are limited by temperatures higher than 30°C and lower than 5°C. However, irrigated olive groves can still be infected if a favorable microclimate exists.

Infection and damage

The fungus survives on trees in old leaf lesions that have a white, crusty appearance. The margins of these lesions enlarge in fall and a new crop of spores develops. The peak infection periods are October-November and March-April; dissemination occurs mostly through rainfall when enough water is present at the penetration point. Sooty blotches on the leaves develop into green-black circular spots 2 to 10 mm in diameter, sometimes with a faint yellow halo around the spot. Leaves fall prematurely and twig death may occur due to defoliation, which results in a subsequent decrease in productivity.

Control

Some varieties (e.g., 'Arbequina', 'Frantoio', 'Manzanilla de Sevilla', 'Moroccan Picholine', 'Nabali baladi', and 'Picual') are more susceptible to this disease than others. Infected leaves (either on the tree or on the ground) represent a source of infection to the other leaves.

Careful pruning can help in controlling this disease by reducing relative humidity within the tree canopy. Chemical control of the disease is possible (using Bordeaux mixture or copper pesticides). Once this disease occurs on trees, it is important to treat it annually, in late October before the winter rains begin.

Olive knot (*Pseudomonas savastanoi* Smith)

The only olive disease caused by bacteria, the olive knot or tuberculosis, is specific to *Olea europaea* L. and *Nerium oleander* L. It is present in all the regions in which these two species are grown.

Pseudomonas savastanoi Smith is a mobile gram-negative bacterium that is very sensitive to sunlight and drought. The optimal temperature for its development is 22-25°C and it can multiply easily in the range 18-28°C. Infection can even take place at temperatures as low as 5°C.

Infection and damage

Although it develops mainly on young branches and buds, this disease affects all plant organs (twigs, branches, trunks, roots, and leaves). Small shoots may be defoliated and killed. Rough galls or swellings ('knots') of variable size can be formed on branches and trunks.

Bacteria survive in the knots and are readily washed off at all times of the year. Infection occurs at low temperatures, usually in fall or spring. Openings are necessary for penetration by the bacteria; these are provided by leaf scars, pruning wounds, or bark cracks due to frost.

Control

Chemical treatment (with copper compounds or Bordeaux mixture) can reduce the number of bacteria, but it will not eliminate them completely. As a result, the bacterial population will multiply soon after the application of the insecticide if the treatment is not continuous. Two applications each year are needed to control the bacteria during the post-harvest period through to early spring. Because leaf scars are susceptible when fresh, treatment should be timed to protect as many leaf scars as possible. The best way to control the disease, and to limit its proliferation, is the cutting and burning of the infected parts of the tree using sterilized tools. It is better to avoid this disease by growing resistant varieties (e.g., 'Arbequina', 'Picual', 'Qaisi', and 'Sorani') and avoiding injuries to the tree during management operations (mainly pruning and harvesting). Pruning trees in July to August helps to avoid infection through pruning wounds.

Olive pests and diseases in the Khanasser Valley

A few isolated cases of olive scale and *Verticillium* wilt were encountered during this study in different groves in the valley. The first is due to bad pruning (or even absence of pruning) and intensive irrigation, which provide favorable conditions for the development of the insect. The main reason for the presence of *Verticillium* wilt is the cropping of the adjacent land with vegetables: a common practice in the valley, although it remains at a small scale when undertaken. With these exceptions, olive diseases are still rare in the Khanasser Valley area, for the following reasons:

- The valley is not a traditional olive-growing area, so the presence of pathogens is discouraged by the small acreage of the host.
- The environmental conditions in the valley do not favor most olive pests, which require mild and humid conditions. Dry air and extreme temperatures (both in summer and winter) make it difficult for most olive pests to survive and develop.

Chapter VIII

Other Tree Species Adapted to Dry Environments

This chapter describes some trees that may be suitable for the edapho-climatic conditions that prevail in the dry areas around the Mediterranean. Pistachio, almond, cactus pear, fig, pomegranate, jojoba, grape, and mulberry are among the candidates. With the exception of jojoba, all these species are already well established in different parts of CWANA. However, given the harsh climate in this area, further studies are still needed to assess the adaptability of these species to the specific local environments, and special care must be taken to improve growing conditions for these species. Furthermore, marketing studies should complement the agro-ecological information provided in this document, especially for new industrial crops such as jojoba. The main characteristics of some of these species are summarized in this chapter for quick comparison (Table 5).

Pistachio (*Pistacia vera* L.)

Origin and Production

The pistachio (*Pistacia vera* L., Anacardiaceae) probably originated in Central Asia, though it has often been referred to in early histories of Western Asia and the Mediterranean countries (Tous and Ferguson, 1996). The fruits are classified as drupes with edible seeds. World pistachio production is currently increasing, and the commercial crop in 2002 exceeded 570,000 tonnes (FAOSTAT, 2003). The main producers are Iran (53%); the United States (24%, mainly in California); Syria (9%); and Turkey (7%). Smaller quantities are produced in China, Greece, Afghanistan, Italy, Uzbekistan, Tunisia, and Australia.

Botanical Description

The pistachio is a moderately sized deciduous and dioecious tree (3 to 8 m). In commercial orchards the ratio of staminate trees to pistillate trees is 1 to 8. Pistachios have an extended juvenile period and require 5 years of training to establish a modified central leader canopy and 8 to 12 years to reach full bearing capacity under good, irrigated conditions. It is also a strongly biennial-bearing species, as fruit embryo growth induces the abscission of already induced floral buds. For example, in Turkey the ratio of "on" to "off" trees is 1:1 (Kaska, 1994). Cultivars differ among countries and are bud-grafted on the seedlings of different pistachio rootstocks (*P. atlantica*, *P. chinensis*, *P. terebinthus*, *P. integerrima*, and the hybrid *P. atlantica* × *P. integerrima*). The main commercial cultivars are 'Ashouri Red' and 'Batouri' in Syria; 'Momtaz', 'Owhadi', and 'Kalehghouchi' in Iran; 'Uzun' and 'Kirmizi' in Turkey; 'Aegina' in Greece; 'Bianca' in Italy; 'Mateur' in Tunisia; 'Larnaka' in Cyprus; and 'Sirora' in Australia. California's industry consists of 'Kerman' (a pistillate cultivar imported from Iran) and 'Peters' (a staminate cultivar).

Pistachio nuts are borne in clusters that can be harvested by hand, by knocking with a pole, or by shaking. The crop matures in late summer through to early fall (August-October).

Environmental Requirements

The environmental and soil conditions preferred by pistachio are very similar to those of olive. Although pistachio will grow in rocky, shallow soils, productivity is enhanced in deep, well-drained soils coupled with proper cultural practices. Pistachio is salt tolerant and can be grown in alkaline soils and those with a high lime content (Tous and Ferguson, 1996).

Pistachio is quite drought tolerant; its native range is characterized by long, hot, dry summers. Germana (1997) showed that the water potential, transpiration, and photosynthesis of pistachio trees were little affected by water stress. However, the tree responds well if more water is applied. Caruso (1990) recommended a summer supplemental irrigation of 500-600 m^3 ha^{-1} $year^{-1}$ to maintain good tree performance and nut production under southern-Italian conditions.

The tree is grown in areas characterized by moderately cool or cold winters, where winter temperatures fall below 7°C for a total of at least 1000 hours, and which therefore provide the conditions required to break the tree's rest period, and enable normal growth and fruiting of pistachio.

Diseases

No serious diseases of pistachio have been reported in Syria, Turkey, or Iran. In California, however, many orchards have been seriously threatened by *Verticillium* wilt (*Verticillium dahliae* Klebahn). Recent orchard surveys in this state have revealed that other diseases, such as *Botrytis* blossom and shoot blight (*Botrytis cinerea* Persoon), and *Botryosphaeria* panicle- and shoot blight, caused by *Botryosphaeria dothidea* Mougeot, are increasing (Michailides *et al*., 1988). Processing pistachios within 24 hours of harvest can avoid aflatoxin contamination, which is caused by the fungus *Aspergillus* (Ferguson and Arpaia, 1990).

Uses

Besides their use in sweets, cakes, and ice creams, pistachio nuts are eaten roasted or even fresh (in season) in eastern Mediterranean countries. Pistachio nut oils are also used in the cosmetic and pharmaceutical industries (Caruso, 1990).

Fig (*Ficus carica* L.)

Origin and Production

The fig (*Ficus carica* L., Moraceae) probably originated in Western Asia and spread to the Mediterranean. The fig is a moderately important world crop, with an estimated annual production of one million tonnes of fruit in 2001 (FAOSTAT, 2003). The leading producers are Turkey (255,000 tonnes) and Egypt (188,000 tonnes). Greece, Iran, Morocco, and Spain are also important producing countries, while Syria comes eighth, with 4% of the world's production. The economic importance of fig production is likely to continue despite the short commercial life of the fresh fruits. In the world market, there is an increasing demand for fresh figs and a stable demand for dried figs. Fig production in some European countries is slowly decreasing while Turkey, Syria, and Mexico are expanding their fig production. Recent evaluation of new cultivars in Europe, and 'Calimyrna' improvement in the United States, combined with improved cultural practices and better fresh-fruit post-harvest practices are opening up new opportunities for this crop (Tous and Ferguson, 1996).

Botanical Description

The fig is a small to medium-sized tree which is usually around 5-6 m in height. The aerial organs of the tree contain copious amounts of milky sap or latex. The root system is horizontally extensive, sometimes with a radius of 15 m, and typically shallow, although in permeable soil some of the roots may go as deep as 8 m (Rehm and Espig, 1991). Its deciduous leaves are palmate, being deeply divided into 3 to 7 main lobes and more shallowly lobed and irregularly toothed on the margins. The blade is up to 25 cm in length and width, fairly thick, rough on the upper surface, with soft hairs on the underside. The fruit (2.5-10 cm long) is technically a synconium: a fleshy, hollow receptacle with a small opening at the apex which is partly closed by small scales. It may be obovoid, turbinate, or pear-shaped, and varies in color from yellowish-green to coppery, bronze, or dark-purple. Tiny flowers are massed on the inside wall. In the case of the common fig discussed here, the flowers are all female and need no pollination. There are three other types, the caprifig which has male and female flowers requiring pollination through a tiny wasp, *Blastophaga grossorum*; the Smyrna fig, needing crosspollination by caprifigs in order to develop normal fruits; and the San Pedro fig which is intermediate, its first crop being independent like the common fig, while its second crop is dependent on pollination. The skin of the fig is thin and tender, the fleshy wall can be amber, whitish, pale-yellow, pink, rose, red, or purple; it is juicy and sweet when ripe and gummy with latex when unripe. Fig seeds may be large, medium, small, or minute, and range in number from 30 to 1600 per fruit (Morton, 1987).

The common fig and the Smyrna fig are the two main commercial types of figs. Cultivars of both types bear one or two crops per year. The most famous are, in California, 'White Adriatic' (syn. 'Verdone'), 'Black Mission', 'Kadota' (syn. 'Dottato' in Italy), and 'Conadria' (Storey, 1975; Ferguson *et al*., 1990); in Spain, 'Cuello de Dama Blanco' and 'Napolitana Negra' (Llacer *et al.*, 1994); in Greece, 'Kalamon' (Lionakis, 1994); in Egypt and Tunisia, 'Sultani' (Mansour, 1994; Mars, 1994); and in Morocco, 'Rhouddane' (Wallali,1994). The Smyrna types include the popular Turkish cultivar known as 'Sarilop' in Turkey and 'Calimyrna' in the United States and other cultivars from Algeria ('Taranimt' and 'Tameriout') which produce high-quality dried fruit (Rebour, 1955; Aksoy, 1994).

Environmental Requirements and Management

The typical fig-producing regions (mainly Mediterranean countries) have mild winters and hot, dry summers. The fig tree is tolerant of a wide range of environmental conditions, including drought, although it grows most vigorously when abundant water is available. However, very hot, dry spells will cause fruit-drop even if the trees are irrigated (Morton, 1987).

The tree has a low chilling requirement and will withstand some frost. However, a frost of -5 to -10°C may kill the plant down to ground level (Tous and Ferguson, 1996). Figs can be grown on a wide range of soils, including heavy clays, loams, and light sands; but, ideally the soil should be well drained. The plant is moderately tolerant of high salinity (IBPGR, 1986).

The tree is propagated by rooting 20-cm cuttings of one- to three-year-old wood taken during the dormant season. Fruit bearing begins after three years. Regular fertilization will increase yields without reducing fruit quality. Figs carry two crops in a year, the main crop normally being the second crop in late summer and autumn. The first (or "breba") crop is produced from flowers initiated in the preceding late summer and maturing from May to June. The second crop is produced from flowers on the current season's growth. Pruning may be required to maintain a balance between new and old wood, as well as to remove suckers and to keep the tree's canopy at a reasonable size for easy harvesting (Tous and Ferguson, 1996).

Fresh figs are picked when they begin to soften and a color change indicates maturity. When picking, gloves should be worn to prevent damaging the fresh fruit and to prevent the skin irritation caused by the milky latex, which contains ficin and which exudes from the broken stem. Since fresh figs ripen irregularly, picking should be undertaken daily or weekly during the long harvest period (4-6 weeks). After harvest, the dried figs are washed and can be stored for a few days at 0-1°C. The fruit is dried in the sun or by using an electric dryer at 60-70°C before it is processed into dried figs (Tous and Ferguson, 1996).

Pests and Diseases

Figs are not usually seriously affected by pests, except in high-rainfall areas. In these areas, and during the rainy season, fruit cracking usually occurs and fungicidal sprays may be necessary to control surface rot (*Alternaria alternata* Fries), smut (*Aspergillus niger* van Tieghem), and mold affecting the fig (*Botrytis* spp., *Penicillium* spp.). Aphids, birds, fruit flies, and scale insects are occasionally a problem. Figs are highly susceptible to nematodes and should not be planted in infested soils (Tous and Ferguson, 1996).

Almond (*Prunus dulcis* [Miller] Webb)

Origin

The almond (*Prunus dulcis* [Miller] Webb, Rosaceae) originated in the hot, dry climate of the Middle East (probably Arabia or Iran), and was spread along the shores of the Mediterranean in northern Africa and southern Europe by the Egyptians, Greeks, and Romans. The almond was taken to California in the 1700s by the Spanish Padres who set up the Mission at Santa Barbara.

Botanical Description

The almond is most closely related to the peach, falling into the Prunoideae subfamily of the Rosaceae. The name for the almond was changed in the 1980s to

Prunus dulcis [Miller] D.A. Webb; formerly it was known as *P. amygdalus* Batsch.

Almond is a tree of medium height (usually less than 10 m). Its leaves are minutely serrate with an alternate lanceolate to oblong lanceolate shape. Its white to pink flowers are solitary, actinomorphic, 2-5 cm broad; they appear with or before the foliage. Its fruits are oblong drupes 3-6 cm long, and the tough flesh splits at maturity to expose the pitted stone. The endocarp may be thin or thick; the seed is flattened, long-ovoid, and has a brown seed coat. Fruits occur mainly on the shoot spurs, which remain productive for up to five years (Duke, 1983).

Most varieties of almond are self-sterile, but newly-developed commercial cultivars (e.g. All-in-one) are self-fertilizing. Therefore, it is recommended that different varieties be grown on the same site, to ensure reciprocal pollination (Rehm and Espig, 1991).

Main commercial varieites in California are: Cavaliera (very early), Non-Pareil (early), Texas (very late), Marcona (late), Thompson, and All-in-one.

Environmental and Management Requirements

The almond is a Mediterranean fruit crop, requiring mild winters and long, rainless, hot summers with a low humidity. Almond does well in the hot, dry interior valleys of the Mediterranean countries, where the nuts mature satisfactorily. It survives single digit temperatures and has a low winter-chilling requirement (300-500 chill units for proper bud break). Because of this low chilling requirement (or short rest period), and the relatively low amounts of heat required to bring the trees into bloom, the almond is generally the earliest deciduous fruit or nut tree to flower; it is, therefore, extremely susceptible to frost injury when late spring frosts prevail (Saure, 1985).

Almond trees have been planted in certain areas with water supplies which are inadequate for other fruit or nut crops. Almond is reported to tolerate annual precipitation levels as low as 200 mm, although the yield of nuts will be low (Duke, 1983). Almonds need ample rainfall or irrigation water to produce the maximum number of well-filled almond nuts, as is the case in California.

In general, conditions favoring peach production will also favor almond production. The almond tree has been successfully grown on a wide range of soils, with pHs ranging from 5.3 to 8.3. It is successfully grown in hilly and rocky areas although it is deep-rooted and draws heavily on the soil. For best results, soil should be deep, fertile, and well drained. Sandy loams are best, but since they are often deficient in minerals, careful attention must be paid to the proper fertilization of the trees, especially for commercial production. Almond trees have high N and P requirements although stone fruit trees are rarely fertilized in the Mediterranean countries. Sandy soils are easy to cultivate and it is comparatively easy to grow cover crops on them, provided they are properly fertilized (Duke, 1983).

Fruit-bearing trees may be pruned of surplus branches to about 20% of the old-bearing wood. Trees exhibiting a decline in production may be severely cut back at the top.

Seedling trees and field-budded trees are still cultivated in non-intensive plantings in the Mediterranean area. Seedlings are planted, and trees producing bitter kernels are grafted to superior individuals. Such trees are said to be more tolerant of drought and high soil pH than those obtained by vegetative propagation. For special types, scions are budded or grafted on to bitter or sweet almond, apricot, myrobalan, peach, or plum seedlings. Such trees are planted 6-8 m apart and can be irrigated, in spite of their drought tolerance for maximum yields.

Uses

Almond varieties are classified as either "sweet" or "bitter". Sweet almonds contain a large quantity of a bland, fixed oil and emulsion, gum, and mucilage sugar; they have an agreeable taste and are nutritious. Bitter almonds contain the same substances in addition to a crystalline glucoside called amygdalin.

Almonds are cultivated for their nuts, used in sweets, baked products and confectioneries, and for the oils obtained from the kernels. The oil produced is used as a flavoring agent in baking, perfumery, and pharmaceutical industry. Benzaldehyde may be used as almond flavoring, being much cheaper than almond oil. As for essential (vaporizing) oils, the only type is bitter almond oil. Sweet almond oil is used for cosmetic creams and lotions. The gum exuded from the tree has been used as substitute for tragacanth, which is a gum procured from a spiny leguminous shrub (*Astragalus gummifer* Labillardiere) of western Asia and used in pharmacy, adhesives, and textile printing.

Problems, Pests, and Diseases

Rainfall often creates problems: during bloom, it decreases bee activity and therefore fruit set; during fruit development it causes fungal and bacterial diseases; and prior to harvest it can cause brown rot or *Rhizopus* rot of fruits, as shucks split. Almond trees are susceptible to bacterial canker caused by *Pseudomonas syringae* van Hall, brown rot, *Rhizopus* rot, *Verticillium* wilt, and other diseases that affect peach.

Table 5. Characteristics of some drought-tolerant tree species.

Characteristics	Olive	Pistachio	Fig	Almond
Water requirement	Low	Low	Low	Low
Management requirement	Medium	High	Low	Medium
Adaptability to high temperature	High	High	High	High
Resistance to frost and low temperatures	Frosts in April-May are harmful	Spring frost is harmful	Withstands short and light frosts	Susceptible to spring frost
Low temperature limit	-7 to -10°C may kill shoot parts	-7 to -10°C may kill shoot parts	-5 to -10°C may kill shoot parts	-5 to -10°C may kill shoot parts
Tolerance to salinity	High	Medium-high	Medium-high	Medium
Production age (yr)	4-6	10-11	3	4-5
Adaptability to calcareous soils	High	High	High	High
Adaptability to shallow poor soils	High	High	High	High
Vulnerability to pests	Low	High	Very low	Medium
Longevity	Centuries	200-300 years	Decades	20-30 years

Pomegranate (*Punica granatum* L.)

Origin and Production

The pomegranate[1] (*Punica granatum* L., Punicaceae) is one of the oldest known edible fruits. The tree is native to the Near East (probably Persia or Arabia) and has been cultivated extensively in the Mediterranean countries (Tunisia, Turkey, Egypt, Spain, and Morocco); Iran; Afghanistan; India; and, to some extent, in the United States (California), China, Japan, and Russia. Crop production is stable and the fruits are normally sold in the local markets of these countries, except Spain and Turkey, which also export. The future of this crop depends on the selection of high-quality cultivars with soft seeds, higher total soluble solids, a richer color (Kumar, 1990), and berries resistant to cracking and borers.

[1] This section is mainly adapted from Tous and Ferguson (1996).

Botanical Description and Varieties

The pomegranate fruit is a false berry and is subglobose in shape. It is shiny red, yellowish green or whitish, and is crowned with a persistent calyx; it has a hard rind. Internally, the fruit's locules vary in number (from few to many) and contain many seeds. The testa of the seed is filled with a whitish pulp (aril) and an acid juice. The seeds vary in size and hardness. Fruits with hard seeds are of poor eating quality; therefore, those cultivars producing soft-seeded fruits are preferred. Hard-seeded fruits with a higher juice content and an intense red color are utilized for processing (Kumar, 1990).

The pomegranate is both self-pollinated and cross-pollinated by insects. The fruit is consumed fresh or processed into juice, syrup (grenadine), jams, or wine. The juice content of pomegranate fruit accounts for about 45% to 65% of the whole fruit, or 76% to 85% of the arils. Pomegranates are also valued for their therapeutic properties (Kumar, 1990).

Several cultivars are grown commercially in the world. The names of most of these cultivars reflect the color or the shape of the fruit and one cultivar might have different names in different countries. The most important cultivars are:

- 'Ahmar', 'Aswad', and 'Halwa' in Iraq;
- 'Nab el-Jamal', 'Laffan', 'Sultani', and 'Wardi' in Syria;
- 'Red Laffani', 'Malissi', and 'Ras el-Baghel' in Palestine;
- 'Mangulati' in Saudi Arabia;
- 'Wonderful' in California;
- 'Mollar' and 'Tendral' in Spain;
- 'Schahvar' and 'Robab' in Iran;
- 'Hicaz' in Turkey;
- 'Zehri' and 'Gabsi' in Tunisia;
- 'Alandi' and 'Ganesh' in India.

Environmental and Management Requirements

The plant favors a semi-arid climate and is extremely drought-tolerant. However, for good fruit production, the plant must be irrigated when grown in the dry areas. Pomegranate requires a long hot summer for its fruits to mature, yet can withstand low temperatures (of -9 to -12°C) in the winter. Fruits produced in humid areas are of a lower quality (Morton, 1987).

Pomegranates grow naturally as a bushy shrub or a small tree with spiny branches. The pomegranate bears heavily and regularly every year, and requires very little care. It thrives on calcareous, alkaline soil and on deep, acidic loam, as well as upon a wide range of soils in between these extremes.

The tree requires minimal pruning, except for the removal of suckers at the base of the plant and some shaping of the canopy. It is propagated mainly by hardwood or softwood cuttings. The tree comes into bearing three to four years after planting. The fruit is harvested by hand from mid-September to early November. The most important problem is the cracking of berries, which affects pomegranate quality in storage and reduces its marketing value. In India and Egypt the fruit borer (*Virachola isocrates* Fabricius) is a serious pest (IBPGR, 1986; Patil and Karale, 1990). Different post-harvest diseases caused by fungi such as *Aspergillus niger* van Tieghem, *Botrytis cinerea* Persoon, and *Alternaria* spp. cause the berry to split before ripening. The practice of picking early in the season, to avoid fruit cracking, is known to affect the fruit taste (Kumar, 1990).

Cactus pear (*Opuntia ficus-indica* L.)

Origin and Current Distribution

The cactus pear (*Opuntia ficus-indica* L., Cactaceae) is native to the desert zones of northwestern Mexico and the southwestern United States (Knight, 1980). The plant was brought to Europe in the 15th century by the first Spanish colonialists from Mexico; it had spread throughout the whole Mediterranean Basin by the late 17th century (Retamal *et al*., 1987). This fruit is also known as "barbary fig", "tuna", and "Indian fig". The total world crop in the early 1990s was estimated at 300,000 tonnes of fruit. Mexico's production reached 200,000 tonnes of fruit on an area of 50,000 ha (Flores and Gallegos, 1994). The other important production region is the Mediterranean basin (Italy, Spain, Egypt, and Morocco) and, to a lesser extent, South America, South Africa, southwestern Asia, the USA, and Australia. The fruits are normally sold in the local markets of the producing countries, except in the case of Mexico, Italy, and Chile, which are also exporters. This plant has a tremendous potential for expansion if the proper conditions are put in place.

Botanical Description

The *Opuntia* is a cactus belonging to the Cactaceae family. It is a fleshy bush or a small tree in which the branches or stems ("cladodes" or "nopalitos") have the appearance and function of a leaf. The plant may reach a height of 5 m and the fruit is generally pear-shaped, with a number of small spines and a soft juicy pulp containing numerous small black seeds. The fruits ripen and are harvested by hand from July to December.

Environmental and Management Requirements

Opuntia spp. can tolerate temperatures as high as 50°C (or even higher in the case of some varieties). However, it is less tolerant to cold; cell injury can occur at temperatures of -5 to -10°C (Nobel, 2001). Cactus is one of the most efficient plants in converting water to dry matter. Successful rainfed plantations can be established in deep sandy soils with only 100-150 mm of mean annual rainfall (Le Houérou, 1994; cited by Guevara and Estevez, 2001; Nefzaoui and Ben Salem, 2001). *Opuntia* performs well on deep, light-textured soils, including coarse sands; it prefers calcareous soils.

The plant requires minimal management and is propagated mainly by vegetative means (cladodes or shoots). Fruiting begins at 2 or 3 years and reaches full production at around 7 or 8 years. A mature plant can yield 100 to 200 fruits (Knight, 1980). Many local cultivars have been developed and are, generally, named according to their fruit color at maturity. Future demand for this fruit depends upon the development of high-quality spineless cultivars with few seeds. Due to its xerophytic habitat, the cactus pear does not have serious problems with pests and diseases. However, in some areas, the fruit fly (*Ceratitis capitata* Wiedemann) damages the fruits, particularly during years with mild weather during fall (Barbera *et al*., 1992; Lionakis, 1994).

Uses

The fruits of the cactus pear can be consumed fresh, but are also used to produce paste, jam, salads, and refreshing drinks. The cactus pear is not cultivated as a regular commercial crop; rather, it is planted as defensive hedges and windbreaks, and in gardens. The vegetable stems represent a source of forage or feed for livestock and wildlife. These organs can also be used for medicinal (it contains an anti-diabetic agent) and industrial (producing alcohol, soap, pigments, pectins, and oils) purposes (Lakshminarayana, 1980; Borrego *et al.*, 1990; Hegwood, 1990). Cactus pear can also play a key role in erosion control and land rehabilitation, particularly in arid and semi-arid zones (Inglese and Gugliuzza, 2002). Millions of hectares of marginal land in arid parts of the world, where irrigation cannot be practiced, could come into their own as food and feed producers once improved cultivars of cactus pear are available (Knight, 1980).

Jojoba (*Simmondsia chinensis* [Link] Schneider)

Origin

Jojoba or goatnut (*Simmondsia chinensis* [Link] Schneider, Simmondsiaceae), is an evergreen woody shrub native to the Sonoran Desert in southern Arizona, California, and Baja California in Mexico (Yermanos, 1974). Thanks to its high-quality oil, this species is one of the first new arid-land crops to be produced on an industrial scale (Naqvi and Ting, 1990).

Botanical Description

Jojoba (pronounced "hohoba") is the only species within the genus *Simmondsia*, and has a dioecious flowering habit (male and female flowers are borne on separate plants). The staminate and pistillate flower buds usually develop in the spring and late summer on new growth and remain dormant until warm weather occurs in late winter or early spring. Flowering occurs in March through May in response to winter rains while fruits ripen in July and August. Its seeds are small (650 to 5500 seeds kg^{-1}). There is also much plant-to-plant variability in natural populations for a wide array of other morphological characters. In the wild, the jojoba tree is usually less than 5 m high, producing several branches at the base of the plant. Its leaves are opposite, oval or lanceolate, and gray-green, having a waxy cuticle that reduces transpiration. The plant develops a few long taproots (up to 12 m in length) which can supply the plant with water and minerals from far below the soil surface (Hogan and Bemis, 1983). It has been estimated that some older plants may be between 150 and 200 years old (Duke, 1983).

Environmetal and Management Requirements

Throughout its natural range (between latitudes 23°N and 34°N and between longitudes 110°W and 118°W), jojoba grows from sea level to 1500 m asl. Temperature is one of the most critical factors to be considered when selecting sites for commercial production. The plant can tolerate extremely high summer temperatures, and plants that are three or more years old can usually survive winter temperatures as low as -10°C; but, developing flower buds can be damaged by negative temperatures of -4°C and killed if temperatures reach -6 to -7°C, which results in no or little seed yields (Duke, 1983; Naqvi and Ting, 1990; Nelson and Watson, 2001). Commercial plantings are effectively limited to those areas where minimum temperatures are expected to be above -5°C. According to Nelson and Palzkill (1993) and Nelson *et al.* (1993), frost-induced loss can be reduced if the trees are subjected to water stress in early fall and winter. However, these authors did not provide an explanation of this result, though it might be associated with the decrease in metabolic activity and water content in the tissues.

Jojoba plants are extremely tolerant of drought (Al-Ani *et al.*, 1972). Although some native stands have been found in areas receiving annual rainfall of only about 125 mm (Duke, 1983; Naqvi and Ting, 1990), Nelson and Palzkill (1993) showed, under Arizona's arid conditions, that a fairly good level of production (727 g seeds per 8-year-old tree on average) requires 550-700 mm of water (provided by rainfall and supplemental irrigation). This can be compared with the low level of production (224 g seeds tree^{-1}) exhibited when less than 400 mm of water is available. Jojoba water needs are highest during late winter and early spring. For optimum production, the crop needs irrigation and care, and should consist of a good cultivar (Naqvi and Ting, 1990). Good levels of growth and development are being attained with one third or less of the amount of water required for citrus, cotton, or other row crops under comparable conditions (Duke, 1983).

Jojoba grows on coarse, light, or medium-textured soils; but, the soil must have good drainage and good water infiltration (Hogan and Bemis, 1983). Young jojoba plants are very sensitive to flooding. Salt in the soil or irrigation water adversely affects seed germination and the growth of young jojoba seedlings. Individual seedlings vary in their tolerance to salt, which raises the possibility of selection and breeding for increased tolerance (Duke, 1983). Older, established plants are more salt tolerant.

Some attempts have been made to grow this crop in India and Palestine, as well as in other countries in the Mediterranean basin. However, the success of such introductions depends on proper management protocols and agreements with industrial partners, to ensure the marketing of the fruits.

Industrial Use

Forty to sixty percent of the content of jojoba seeds consist of a chemically unique oil, which is more accurately characterized as a fatty acid ester of a long straight-chain alcohol. Its chemical and rheological structure is very similar to, and can substitute readily for sperm whale oil, which is becoming less available due to the decrease in whaling.

Hydrogenation converts jojoba oil into a white crystalline wax, which is difficult to synthesize in commercial quantities. The wax is useful for a wide array of industrial products, including creams, ointments, specialized high-pressure lubricants, antifoaming agents, detergents, disinfectants, driers, emulsifiers, fibers, plasticizers, protective coatings, resins, and surfactants (Tous and Ferguson, 1996).

The purity, absence of odor, and resistance to rancidity that characterize this oil have stimulated its use in the cosmetic industry. All aspects of jojoba's natural history, culture, production, utilization, as well as research needs were reviewed by Hogan and Bemis (1983).

Grape (*Vitis vinifera* L.)

Origin and Production

Grapes (*Vitis vinifera* L., Vitaceae) are native to Turkey, where wild grapes still grow. This is an important fruit crop in Syria, where production amounted to 369,000 tonnes in 2002 (FAOSTAT, 2003). The multiple uses of the fruits and leaves of this crop make it a profitable investment, especially when the fruits mature early (in warm climates).

Environmental and Management Requirements

Grape production is mainly limited to the Northern Hemisphere: it requires long, warm to hot, dry summers and mild winters. Plant damage occurs at -18°C; frost kills young shoots. The daily mean temperature should be at least 18°C. This species will not endure the high temperatures coupled with high humidity, which promote disease. Grape culture is best in areas where there is no rain between blooming and harvesting. Rain is desirable in winter but not in spring or fall. Irrigation is desirable, and often essential, in the dry areas. Several irrigations may be necessary, beginning in spring when available soil water is being depleted, and continuing until harvest, or even later in very hot regions (Duke, 1979).

Grapes do well in poor soils; they can grow in soils having pHs which range from 4.5 to 8.7. They prefer sandy or gravelly clay loams, which provide good drainage.

Occurring in life zones that range from cool-temperate (from moist to wet) to tropical (from very dry to moist), *Vitis vinifera* L. is reported to tolerate annual precipitation rates and temperatures that are extremely variable (Duke, 1979).

Mulberry (*Morus* spp. L.)

Origin, Classification, and Botanical Description

Mulberry (*Morus* spp., Moraceae) is a small to medium-sized monoecious or dioecious shrub or tree (up to 15 m high). The trunk is wide-spreading and may attain 60 cm in diameter. Mulberry leaves are thin, light green, alternate, stipulate, and variable in shape. In fact, they may be lobed or unlobed, cordate, dentate, acuminate, or long-petiolate. The leaf dimensions are 12 cm × 8 cm on fruiting branches and up to 25 cm × 20 cm on vigorous non-fruiting branches. Mulberry flowers are small and greenish-yellow; staminate spikes turn into deciduous organs while pistillate spikes mature into an aggregate fruit (syncarp) of drupelets. The syncarp is ovoid to oblong-cylindrical and 1-5 cm long. It is white, pink, purple, or nearly black according to species. It is sweet but insipid and edible long before ripe. Seeds are brown and very small (1-1.2 mm long). Flowering takes place in spring (March-May) and fruits are formed and harvested in summer (Duke, 1983).

Three species of mulberry exist:

- Black mulberry (*M. nigra* L.): native to western Asia, this species has been grown for its fruits in Europe since before Roman times. This is the predominant species in the Mediterranean region.
- White mulberry (*Morus alba* L.): this species originated in eastern and central China; it became naturalized in Europe centuries ago. The tree was introduced into the USA for silkworm culture in early colonial times and naturalized and hybridized with the native red mulberry.
- American mulberry, red mulberry (*M. rubra* L.): native to the eastern USA from Massachusetts to Kansas and down to the Gulf coast.

Hybrid forms exist between *Morus alba* and *M. rubra*.

Environmental and Management Requirements

In general, mulberries are drought and cold tolerant, although they may need to be watered during dry seasons, especially in the case of young trees. If the roots become too dry during drought periods, the fruit is likely to drop before it has fully ripened. The black mulberry is more fastidious, faring less well in cold climates or in areas with humid summers. Among the three species, the white mulberry has the highest cold tolerance, although some clones can be damaged at temperatures of -4°C or lower. Red mulberry is also hardy to sub-zero temperatures, while black mulberry is the least cold-hardy. It is important to stress the fact that cold tolerance varies considerably from one variety to another.

Mulberries need full sun and adequate space. The distance between trees should be 5 m at least. The trees are quite wind-resistant with some cultivars being used as windbreaks. Mulberries like a warm, well-drained soil, preferably a deep loam. Shallow soils, such as those frequently found on chalk or gravel, are not recommended.

Mulberries generally tolerate poor soils and thrive with minimal fertilization. In most Mediterranean countries, mulberries are never fertilized. However, some nitrogen fertilizer may still be needed to improve tree growth and yield, especially in the poor soils that characterize the marginal dry areas. Annual application of a balanced fertilizer, such as 10:10:10 NPK, will maintain satisfactory growth.
No special pruning techniques are needed after the branches have been trained to a sturdy framework, except to remove dead or overcrowded wood. A mulberry tree can be kept to a tidy form by developing a set of main branches and then pruning laterals to 6 leaves in July, in order to develop spurs near the main branches. It is not advisable to prune the trees heavily, since the plant is inclined to bleed at the cuts. Cuts of more than two inches in diameter generally do not heal and should be avoided. Bleeding will be less severe if the tree is pruned while it is dormant.

Diseases and Pests

Mulberries are generally free of pests and diseases, although cankers and dieback can occur. In some areas "popcorn disease" is an occasional problem, in which fruits swell to resemble popped corn. *M. alba* × *M. rubra* hybrids are particularly prone to this condition. The disease carries over from one season to the next, so the collection and burning of infected fruits helps to control it. The ripe fruit is very attractive to birds, but there is usually enough fruit left over for harvesting.

Other Species

Some other tree species less well known in the region might also be considered for use in dry environments. For instance, carob (*Ceratonia siliqua* L.), Indian jujube or "ber" (*Ziziphus mauritiana* Lamarck), common jujube (*Ziziphus jujuba* Miller), and guayule (*Parthenium argentatum* Gray) are drought- and heat-tolerant trees which are more or less adapted to the extreme climate in the marginal dry areas of the CWANA region. However, further studies on the ecological and socioeconomic suitability of these species are still needed before any recommendations can be forwarded.

Chapter IX

Summary and Conclusions

During the last decade, olive research in the traditional olive-growing zone around the Mediterranean Sea has progressed considerably. However, the information we have today has been mainly obtained from work conducted on a small number of dominant European varieties under classical Spanish, Italian, or Greek conditions. ICARDA's research in the dry environments of the Khanasser Valley, Syria, (220 mm annual rainfall) indicates that there exists potential for the expansion of olive production in areas that have long been neglected. Limited information is available on the performance and management of olive trees both under the harsh climatic conditions prevailing in the countries located to the south and east of the Mediterranean and in other recently-established olive areas around the world. Studies conducted in Tunisia indicate that the 'Chemlali' groves in central and southern Tunisia are doing well, achieving economically-viable yields in areas receiving less than 200 mm of annual rainfall. Various Syrian olive varieties also have promise for such environments and merit more attention.

The end-use of olives (i.e., oil versus table) and the availability of water should be the main criteria used when selecting olive varieties for the establishment of an orchard. Olive trees grown for oil production require less irrigation water than table olives, because summer irrigation leads to an increase in fruit size rather than oil content. Most farmers in Syria prefer to grow olives for oil or as a dual-purpose fruit. In this case, the 'Qaisi' variety performs best in the dry and hot conditions of Syria's inlands. The 'Sorani' variety is also promising, especially considering its high oil content, although this might drop under dry conditions. When irrigation water is available, 'Sorani' would be one of the most rewarding oil varieties in marginal dry areas. In the case of table olive production, 'Jlot' seems to be the best variety under the rainfed conditions which prevail in the dry areas of southern Syria (300 mm rainfall). ICARDA is currently conducting cooperative research with the Syrian Olive Bureau in two traditional and two new olive-growing zones in Syria, to assess the fruit ripening pattern, oil content, and oil-quality parameters of popular Syrian varieties under different climatic conditions. Varieties showing good levels of performance in other arid regions of the Mediterranean basin (e.g., 'Chemlali' and 'K20' in Tunisia and 'Nabali Muhassan' in Jordan and Palestine) need to be tested to assess their performance under other dry-environment conditions.

In spite of its drought tolerance, the olive tree responds positively to supplemental irrigation when grown in arid conditions. According to the literature, rainfed olive production can be successful in areas with 350 to 400 mm of rainfall. Extreme drought conditions may be harmful to trees if no water is applied to compensate for evaporation losses during the hot summer period. For good yields, the amount and frequency of water application are less important than the timing. Summer irrigation should start in late July or early August, when the pit has hardened. Research is needed to determine supplemental-irrigation requirements and strategies in the new olive expansion areas.

Because of the scarcity of water resources in the dry areas, it is recommended that regulated deficit irrigation be practiced whenever possible. This technique can save considerable amounts of water, especially in summer. Precision-irrigation techniques can also play an important role in decreasing water application, and thus increasing water-use efficiency. Localized irrigation methods keep most of the exposed soil surface dry and therefore reduce soil moisture evaporation. However, the cost of installing and managing such systems in order to supply only a few irrigations in summer may be too high to be economically viable. Another disadvantage of these methods is that they limit root growth to the wetted zone, reducing the trees' ability to extract soil moisture from a larger area during the rainy season. Alternative precision-irrigation techniques should be considered and evaluated in the dry areas. Some farmers in the Khanasser Valley are using a low-cost, albeit labor- and time-consuming, subsurface irrigation technique, using plastic tubes that are inserted vertically into the soil to convey water to buried stone pockets in the root zone. A pipe network can be coupled with this technique to reduce labor needed.

Groundwater often serves as a valuable source of irrigation water in marginal dry environments. With natural groundwater recharge inherently low, uncontrolled pumping is resulting in falling water tables, and is sometimes also increasing salinity levels. It is essential that farmers adopt water-saving techniques and grow drought-adapted crops, in order to ensure the sustainable development of their farms and avoid the fate that other groundwater-dependent regions have faced as a result of severe over-pumping of their available water resources. To avoid chronic water-shortage problems, water-management recommendations and regulations should be based on scientific assessments and established in cooperation with farmers, stakeholders, and policymakers.

Although salinity is one of the common features of marginal dry areas, little information is available on the response of different olive varieties to saline conditions. Most of the research on salinity has been done under controlled conditions using young trees. Furthermore, only some major varieties have been tested for their tolerance to salinity. Preliminary studies in Tunisia and Greece indicate that many other less-well-known varieties could show promise under saline conditions. It is necessary to perform screening tests using the maximum number of varieties. Syrian and Tunisian varieties may be among the most promising, since some of them already grow in inherently saline soils. In addition, experiments on the irrigation of olives with saline water should be conducted to establish guidelines for proper saline-irrigation management.

Olive groves established in marginal dry areas should be spaced widely (at least 8 m × 8 m), to avoid competition for water. If the olives are planted on a sloping area, small dikes could be established just downhill from the trees, to harvest surface runoff. The highest water-harvesting efficiencies are obtained on crusting and stony soils. Because the water use of olive is low during the cool, rainy season, the root zone should be sufficiently deep to store the harvested water. When the trees are still young, winter crops, such as legumes and barley, can be grown in between the trees. To improve the adoption and efficiency of water-harvesting methods, ICARDA is undertaking both participatory and controlled research with olive growers in the Khanasser Valley, aimed at developing those water-harvesting techniques that are most suitable for local conditions and management practices.

The application of water-harvesting techniques in hilly areas could result in the adoption of a reduced or no-till soil-management strategy, which is less labor intensive than conventional tillage systems. A review study in Spain (400-700 mm rainfall) indicated that no-till improved olive productivity, in comparison with conventional tillage (Pastor and Guerrero, 1990). However, herbicides are generally used to control weeds in no-till systems. The use of herbicides conflicts with the increasing international interest in organic farming, and is therefore discouraged. In most of the olive groves in Syria, especially in those located in inland governorates, recourse to herbicides and pesticides is minimal.

The addition of organic matter, mainly compost, is essential to improve the inherently poor soil fertility and water-holding capacities of most soils in the dry areas. Manure should be applied at the beginning of the rainy season. The amount and timing of organic fertilizer application should be selected carefully, given the low rainfall in the dry areas. To allow the provision of sound recommendations to farmers, the nutrient contents of manure should be tested.

The fact that the marginal dry areas cannot compete with the traditional olive-growing areas in terms of production should encourage farmers to consider producing products with high added value. Organic olive farming is one possible way to ensure a good level of profitability for resource-poor farmers in the marginal dry areas. Organic farming is believed to be more feasible in these areas given that disease incidence there is comparatively lower than it is in the traditional production areas. In addition, in comparison with the traditional areas, the dry areas have the advantage of lower-cost land, cheaper labor, as well as less expenses being incurred for pesticides. Managing irrigation costs would therefore be the main economic challenge for olive growers in these areas.

Considering the fact that farmers in the recently established olive-growing areas do not have a long tradition of olive production, good extension services are critical for well-adapted and productive olive orchards. Closer cooperation between research institutions and extension services is also needed, to ensure that the actual problems faced by farmers are addressed and that all vital information is provided to them.

Sustainable development of marginal dry lands should not only focus on olive production. For both economic and agro-ecological reasons, other drought-tolerant crops should be introduced as well. Promising drought-tolerant species include pistachio, fig, and almond. Diversification of income sources reduces the vulnerability of the farmers to sudden shocks and events such as disease infestations and marketing problems. Rehabilitation of degraded rangelands and improved range and livestock management is another important issue in the traditional crop-livestock systems in marginal dry areas. The availability of sufficient high-quality fodder may have the additional advantage of reducing the damaging effects of free-roaming animals, especially goats.

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Appendices

Appendix 1. Main olive varieties used for oil production

Variety	Origin	Growth habit	Fertility[1]	Fruit size, weight (g)	Fruit shape	Drought tolerance	Cold tolerance	Salinity tolerance	Tolerance to pests[2]		Alternate-bearing	Yield[3]	Pulp/pit ratio[4]	Oil content (%)[5]
									High	Low				
'Arbequina'	Lleida Spain	Drooping	SF	Small 1-1.5	Rounded top, spherical, symmetrical	Moderate	High	High	OK, VW	BS, OF, PS	Slight	High	3.5-4.5	23-26
'Ayvalik'	Ayvalik Turkey	Erect	PSF	Medium-big	Ovoid, symmetrical	Moderate -high			OF	PS, VW	Moderate	High	5.5-6	23-25
'Bayadi' ('Grande Ayrouni')	Lebanon	Spreading	PSF	Small-medium	Ovoid, asymmetrical	Moderate	Moderate	Moderate		OK, PS, VW	Significant	Medium-high		26-28
'Biancolilla'	Sicily Italy	Spreading	PSF	Medium 2.5-3	Ovoid, symmetrical	Low	High		PS	OF, OK	Significant	High		15-18
'Bosana'	Sardinia Italy	Drooping	PSF	Small 2-2.5	Elliptical, asymmetrical, round top		High				Moderate	High		17-20
'Carboncella'	Latium Italy	Erect	SS	Small 1.5-2	Ellipsoidal, symmetrical	Moderate	Moderate-high		OF, OK, OM	PS	Moderate	High		21-25
'Carolea'	Calabria Italy	Erect	SS	Medium-big 4-5	Ovoid asymmetrical	Moderate	Moderate-high		OK	OF, OM, PS, VW	Significant	High	3.5-4.5	20-25
'Casaliva'	Benaco Italy	Erect	SF	Medium 2.5-3	Ovoid, symmetrical	Low	Low-moderate			OF, OK, OM, PS	Slight	High		22-25
'Chemlal'	Kabylia Algeria	Spreading	SS	Medium	Ovoid, asymmetrical	High	High		PS	OK, VW	Significant	High		15-17

1 Fertility abbreviations: PSF: Partially self-fertilizing, SF: Self-fertilizing, SS: Self-sterile.
2 Pest abbreviations: BS: Black scale, OB: Olive beetle, OF: Olive fly, OK: Olive knot, OM: Olive moth, OS: Olive scale, PS: Peacock spot, VW: *Verticillium* wilt.
3 Yield classification is based on 'on' years only.
4 This ratio varies greatly according to growing conditions.
5 Oil content under rainfed conditions in the natural habitat of the variety.
Note: Blank cells indicate characteristics for which no data could be found.

Variety	Origin	Growth habit	Fertility	Fruit size, weight (g)	Fruit shape	Drought tolerance	Cold tolerance	Salinity tolerance	Tolerance to pests		Alternate-bearing	Yield	Pulp/pit ratio	Oil content (%)
									High	Low				
'Chemlali Sfax'	Sfax Tunisia	Erect	SF	Small 1-1.5	Ovoid, symmetrical	Very high		High		OK	Significant	High	5-6	22-24
'Chetoui'	Tunis Tunisia	Erect	SF	Medium 2.5-3	Ovoid, asymmetrical	Moderate	High	Low	VW	OK, PS	Slight	Medium	6-7	18-22
'Coratina'	Puglia Italy	Erect	SS	Medium 3-3.5	Ovoid, slightly asymmetrical	High	High	Moderate	OM	OF, PS	Slight	High		21-26
'Cornicabra'	Toledo Spain	Erect	PSF	Medium 3-3.5	Elongated, curved, asymmetrical	High	High			OF, OK, PS, VW	Significant	High		22-27
'Dan'	Damascus Syria	Erect	SF	Medium	Elongated, symmetrical	Moderate-high	Moderate-high		VW	OB	Significant			20-22
'Dolce Agogia'	Perugia Italy	Erect	SS	Medium 3.5-4	Ovoid	Moderate	High		OK, PS	OF, OM	Moderate	High		18-20
'Dritta'	Abruzzo Italy	Spreading	SS	Medium 2.5-3	Ovoid, slightly asymmetrical		Moderate-high		OK	OF, OM, PS	Slight	High		16-20
'Empeltre'	Catalonia Spain	Erect	PSF	Medium 2.5-3	Rounded top, ovoid, slightly asymmetrical	High	Moderate		VW	OF, OK, PS,	Significant	High	4.5-5.5	21-23
'Frantoio'	Tuscany Italy	Slightly erect	SF	Medium 2.5-3	Oblong, slightly asymmetrical	Moderate	Moderate	High	OM, VW	OF, OK, PS	Moderate	High	3-3.5	23-26
'Galega Vulgar'	Portugal	Erect	SF	Medium	Ovoid, slightly asymmetrical	High	Medium-high	Low	OK, VW	OF, OM	Significant	High		16-20
'Hojiblanca'	Cordoba Spain	Spreading	SF	Medium-big 3.5-4.5	Elliptical, slightly asymmetrical	High	Moderate	Moderate		OF, OK, PS, VW	Moderate	Medium-high		20-25
'Itrana'	Lazio Italy	Erect	SS	Medium 3-4	Round, asymmetrical	Moderate	High		OK, PS	OF	Slight	High		18-20
'Koroneiki'	Greece	Spreading	PSF	Small 1.5-2	Ovoid, slightly asymmetrical	High	Low	Moderate	PS, VW	OF, OK	Slight	High		24-28

Variety	Origin	Growth habit	Fertility	Fruit size, weight (g)	Fruit shape	Drought tolerance	Cold tolerance	Salinity toleranc	Tolerance to pests		Alternate-bearing	Yield	Pulp/pit ratio	Oil content (%)
									High	Low				
'Leccino'	Tuscany Italy	Slightly drooping	SS	Medium 2.5-3.5	Ovoid, slightly asymmetrical	Moderate	High	Low	OK, OM, PS	BS, OF, OS, VW	Slight	Medium	3-3.5	19-24
'Lechin de Sevilla'	Seville Spain	Spreading	SF	Medium	Ovoid, asymmetrical	High	Moderate	High	OF, PS	OK	Significant	High	7-8.5	20-22
'Mastoidis' ('Tsounati')	Greece	Erect		Small 1.5-2	Ovoid, asymmetrical	Moderate	High	Low	OK	OF, PS	Significant	Medium		24-26
'Memecik'	Turkey	Spreading	PSF	Medium 3-4	Ovoid, asymmetrical	High	High			OF	Moderate	High	5.5-6	25-28
'Mission'	California USA	Erect	SF	Medium 3-4	Oval, slightly asymmetrical		High		OK	PS, VW	Significant	Medium -high	6-7	20-23
'Moraiolo'	Tuscany Italy	Spreading erect	SS	Small 2-2.5	Round, spherical	Moderate	Low	Moderate	OM	BS, OF, OK, PS, VW	Slight	Medium-high	3.5-4	17-22
'Moresca'	Sicily Italy		SS	Medium 2.5-3	Ovoid, asymmetrical	High	Moderate			OK, PS, VW	Significant	High		Low
'Moroccan Picholine'	Marrakech Morocco	Erect	PSF	Medium	Ovoid, asymmetrical	High	High			OK, PS, VW	Significant	Medium-high		18-24
'Nabali baladi'	Nablus Palestine	Spreading	PSF	Small-medium 2-3	Ovoid, slightly asymmetrical	High	Moderate-high	Low	OB	OF, PS	Significant	High		30-33
'Nabali Muhassan' ('Rase'i')	Jordan and Palestine	Spreading	SF	Medium -big 4-6	Ovoid, asymmetrical, with end curvature	Very high	High	High		OB, PS	Moderate	High	5	16-24
'Pendolino'	Tuscany Italy	Drooping	SS	Small 1.5-2	Ellipsoidal, asymmetrical	Moderate	Moderate		OF	OK, PS	Slight	High		20-25
'Picholine'	Langueduc France	Spreading	PSF	Medium 3.5-4	Elongated, ellipsoidal	Moderate	High		OF, PS	OK	Slight	High		17-22
'Picual'	Jaén Spain	Spreading	PSF	Medium-big 3-4	Elliptical, pointed tip, symmetrical	Low-moderate	Moderate-high	High	OK	OF, OM, PS, VW	Significant	High	4-5	20-25

Variety	Origin	Growth habit	Fertility	Fruit size, weight (g)	Fruit shape	Drought tolerance	Cold tolerance	Salinity tolerance	Tolerance to pests		Alternate-bearing	Yield	Pulp/pit ratio	Oil content (%)
									High	Low				
'Qaisi' ('Kaissy')	Aleppo Syria	Erect	SF	Medium-big 4-6	Spherical, slightly asymmetrical	Very high	High		OK, PS	OB, OF	Moderate	Medium-high	5-6	18-22
'Rosciola'	Latium Italy	Erect	SS	Medium 2-3	Ellipsoidal, round top		High			OF, OK, PS	Slight	Medium		20
'Sorani'	Idleb Syria	Spreading	SF	Medium 3-4	Elongated, pointed top	High	High		OB, OK	VW	Moderate	Medium	3.5-4	28-30
'Taggiasca'	Liguria Italy	Spreading drooping	PSF	Medium 3-3.5	Cylindrical, elongated	Low	Low			OF, OK, PS	Slight	High		23-26
'Trilye'	Izmir Turkey	Erect	PSF	Small 1.5-2	Ovoid, slightly asymmetrical	Low	Moderate			OB, PS	Significant	High	5.5-6	26-29
'Verdial'	Andalusia Spain	Erect	PSF	Medium-big 4-4.5	Spherical, almost symmetrical	High	High		OF, OK	PS	Slight	High		22-30
'Zeiti'	Aleppo Syria	Drooping	SS	Small 1.5-2.5	Spherical, slightly asymmetrical	Low	Low-moderate	Moderate		OB, OK	Significant	High	2.5-3	30-32

Appendix 2. Main olive varieties used for table

Variety	Origin	Growth habit	Fertility[1]	Fruit size, weight (g)	Fruit shape	Drought tolerance	Cold tolerance	Salinity tolerance	Tolerance to pests[2] High	Tolerance to pests[2] Low	Alternate-bearing	Yield [3]	Pulp/pit ratio[4]	Oil content (%)[5]
'Ascolana Tenera'	Marches Italy	Slightly drooping	SS	Very big 7-10	Ellipsoidal, slightly asymmetrical	Moderate	High		OK, PS	OF, OM, VW	Slight	High	7-8	13-19
'Azeiteira' ('Cacereña')	Portugal and Spain	Spreading	SF	Big 4-5	Spherical, slightly asymmetrical		High		OF, OK	VW	Slight	Medium	7-7.5	10-14
'Barouni'	Ariana Tunisia	Spreading	SF	Big 6-7	Ovoid, asymmetrical	High	Low			OK, PS, VW	Significant	Medium	6.5-7.5	16-17
'Beidh-el-hamam'	Bizerte Tunisia	Erect	PSF	Big 6-8	Ellipsoidal, almost symmetrical	Low	High	Moderate	OK, PS, VW		Moderate	Medium	5.5-6	10-12
'Chalkidikis'	Chalkidiki Greece	Spreading	PSF	Big	Elongated, asymmetrical	High	High	Low			Significant	Medium		Medium
'Gordal' ('Sevillano')	Andalusia Spain	Slightly drooping	SF	Very big 10-12	Ovoid, slightly asymmetrical rounded-top	Low	High	Moderate	OF, PS	LM, OK, VW	Significant	High	7-7.5	14-15
'Hamed'	Siwa Egypt	Erect	SF	Big 6-7	Ovoid, asymmetrical	High	Low	High			Moderate	High	8	11-13
'Jlot'	Damascus Syria	Erect	PSF	Big 6	Elongated, slightly asymmetrical	High	Low	Moderate		OB	Moderate	High	5.5-6	10-15

[1] Fertility abbreviations: PSF: Partially self-fertilizing, SF: Self-fertilizing, SS: Self-sterile.
[2] Pest abbreviations: LM: Leopard moth, OB: Olive beetle, OF: Olive fly, OK: Olive knot, OM: Olive moth, OS: Olive scale, PS: Peacock spot, VW: Verticillium wilt.
[3] Yield classification is based on 'on' years only.
[4] This ratio varies greatly according to growing conditions and increases under irrigation.
[5] Oil content under rainfed conditions in the natural habitat of the variety.
Note: Blank cells indicate characteristics for which no data could be found.

Variety	Origin	Growth habit	Fertility	Fruit size, weight (g)	Fruit shape	Drought tolerance	Cold tolerance	Salinity tolerance	Tolerance to pests		Alternate-bearing	Yield	Pulp/pit ratio	Oil content (%)
									High	Low				
‘Kalamata’	Kalamata Greece	Erect	SF	Medium-big 4-6	Elongated, almond-shape	Low	Moderate	Moderate-high	OK	OF, OM, OS, PS, VW	Slight	High	8	14-17
‘Lucques’	Languedoc France	Erect	SS	Medium-big 4-5	Elongated asymmetrical	Moderate	High		PS, VW	OF, OS	Significant	Medium		16-18
‘Maiatica’	Basilicata Italy	Drooping	SS	Medium	Ovoid, asymmetrical	Low	Moderate			OF, OK, PS, VW	Significant	High	5.5	22-24
‘Manzanilla de Sevilla’	Seville Spain	Erect	SS	Big 4-5	Apple-shape, slightly asymmetrical	Moderate	Moderate	Moderate		OF, OK, OM, PS, VW	Moderate	High	7.5-8.5	15-20
‘Meski’	Ariana Tunisia	Erect	SS	Big 6-7	Ovoid, asymmetrical	Low		High	OK, VW	PS	Slight-Moderate	Medium	9-10	18-20
‘Nocellara del Belice’	Sicily Italy	Drooping	SS	Big 5-7	Spherical, slightly asymmetrical	Low	Moderate	Low	OF, PS	OK, OM, VW	Slight	Medium	5.5-6	13-15
‘Sigoise’	Tlemcen Algeria	Spreading	PSF	Medium-big 4.5-5	Ovoid, asymmetrical	Moderate	Moderate	High	OK, PS, VW		Significant	High	4.5-5	19-20

Appendix 3. Production information and climatic data of some main olive-growing regions

Spain:

- Jaén: Center of Spanish olive oil production; the olive groves around Jaén represent the backbone of Spain's 2,300,000-ha olive area. The main variety in the region is the widely-adapted 'Picual'. This Andalusian region produces 75% of the country's oil. Jaén is one of the coldest areas of Andalusia (see table below).
- Córdoba: Both the World Collection of Olive Varieties and the most important olive research institution, "Centro de Investigación y Formación Agraria", are based near Córdoba at "Alameda del Obispo". Main varieties of this province are 'Hojiblanca' and 'Picual' and, to a lesser extent, 'Manzanilla de Sevilla' and 'Arbequina'. The region to the south of Córdoba is considered to have an ideal climate for olive growing.
- Seville: Planted mainly with 'Manzanilla de Sevilla' (50%), 'Gordal' (10-15%) and 'Lechin de Sevilla' and 'Hojiblanca'. This region produces an average of 23,000 tonnes of oil and 117,000 tonnes of table olives per year. The total Spanish production of table olives is estimated at 250,000 tonnes year^{-1} (24.5% of world table-olive production).
- Toledo: One of Spain's coldest olive-growing regions. The area produces an average of 17,000 tonnes oil year^{-1}. The main varieties are 'Cornicabra' and 'Castellana'.
- Catalonia: The olive groves in this province represent 6% of the total Spanish olive area, and are mainly concentrated in Lérida and Tarragona. 'Arbequina' is the main variety grown in the province, representing around 40% of the trees, followed by 'Empeltre'. Oil production in this region amounts to 14,000-18,000 tonnes year^{-1}.

Italy:

- Milan: Considered the northern most extent of the Italian olive industry, due to the cold. 'Frantoio', 'Leccino', 'Moraiolo', 'Pendolino', and 'Casaliva' are the main varieties grown in the region.
- Sicily: Accounting for about 15% of Italy's olive acreage, the island is a major player in the country's table-olive market, as it ensures more than 50% of national production. The main table varieties in Sicily are 'Giarraffa', 'Nocellara del Belice', and 'Nocellara Etnea'. The major oil varieties are 'Biancolilla', 'Cerasuola', and 'Santagatese'.
- Lazio and Abruzzo: These two areas are important olive production sites (Lazio 72,000 tonnes and Abruzzo 40,000 tonnes oil year^{-1}). The main oil varieties grown are 'Carboncella', 'Frantoio', and 'Leccino', with 'Cucco' being grown for its dual-purpose fruit.

Greece:

- Crete: Crete accounts for 30% of olive production in Greece The Cretan climate is considered excellent for olive production. Cretans are known for their extremely high consumption of olive oil (70 g $person^{-1}$ day^{-1}) and also their extremely low incidence of heart problems. Crete produces 90,000 tonnes oil $year^{-1}$. 'Koroneiki' accounts for 85% of the olive trees on the island and tends to produce better on the warmer coastal plains and hillsides. However, its small fruit size makes mechanical harvesting difficult with traditional machinery. The most popular dual-purpose olive is 'Throumba'. The average rainfall is 520 mm.

Tunisia:

- Sfax: Although annual rainfall does not exceed 200 mm in this area, it is considered to be the main olive-producing region in the country. The main variety grown in the region is 'Chemlali Sfax', which constitutes 60% of the total number of olive trees in Tunisia.

The following table presents altitude, average annual precipitation, and monthly average temperature (maximum and minimum) data for some main olive-producing countries.

Climatic data of some main olive-growing regions

Country/Area		Monthly average temperature (°C)											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Spain													
Jaén													
Altitude: 600 m asl	Max.	12	14	17	20	24	30	34	34	29	22	16	12
Precipitation: 600 mm	Min.	5	6	8	10	13	17	21	21	18	13	9	5
Córdoba													
Altitude: 100 m asl	Max.	14	16	19	23	26	32	36	35	31	24	19	14
Precipitation: 600 mm	Min.	4	5	8	10	13	17	20	20	17	13	9	5
Toledo													
Altitude: 700 m asl	Max.	13	14	18	22	26	32	37	36	31	24	16	12
Precipitation: 350 mm	Min.	1	1	2	4	9	13	17	16	13	9	3	-1
Seville													
Altitude: 20 m asl	Max.	15	17	20	24	27	32	36	36	32	26	20	16
Precipitation: 560 mm	Min.	6	7	9	11	13	17	20	20	18	14	10	7
Morocco													
Marrakech													
Altitude: 460 m asl	Max.	18	20	23	26	29	33	38	38	33	28	23	19
Precipitation: 240 mm	Min.	4	6	9	11	14	17	19	20	17	14	9	6
Tunisia													
Tunis													
Altitude: 70 m asl	Max.	14	16	18	21	24	29	32	33	31	25	20	16
Precipitation: 420 mm	Min.	6	7	8	11	13	17	20	21	19	15	11	7
Turkey													
Izmir													
Altitude: 30 m asl	Max.	13	14	17	21	26	31	33	33	29	24	19	14
Precipitation: 650 mm	Min.	4	4	6	9	13	17	21	21	17	13	9	6

Appendix 4. International institutions involved in olive research

Institution	Address	Country
Institute of Subtropical Plants and Olive Tree	73100 Chania, Crete http://www.nagref-cha.gr/indexen.html	Greece
Lab. of Plant Physiology, University of Patras	Patras	Greece
Institute for the Propagation of Woody Plants	via Ponte di Formicola, 76 - 50018 Scandicci (FI)	Italy
Inst. Di Coltivazioni arboree, Univ. di Sassari De Nicola 1	07100 Sassari	Italy
Dipartimento di Produzione Vegetale, Universita della Basilicata	Via Nazario Sauro, 85-85100 Potenza	Italy
Dipartimento di Ortoflorofrutticoltura, Univ. Instituto Propagazione Specie Legnose, CNR	Firenze	Italy
C.N.R. Irrigation Institute	Via Patacca, 85, 80056 Ercolano, Napoli	Italy
Instituto di Coltivazioni arboree, Univ. of Perugia	Perugia	Italy
Institut National de la Recherche Agronomique, Centre Régional de Marrakech	BP. 533, Marrakech	Morocco
Centre UdL-IRTA, Area de Tecnologia Fruticola	Avda. Rovira I Roure, 177, 25198 Lleida	Spain
Departamento d'Arboricultura Mediterrania, IRTA Centre de Mas Bove	Apartat 415, 43280 Reus	Spain
Instituto de Recursos Naturales y Agrobiologí a de Sevilla	Avenida de Reina Mercedes 10, Apartado 1052, 41080 Sevilla	Spain

Institution	**Address**	**Country**
International Olive Oil Council	Principe de Vergara, 154, Madrid	Spain
Departamento de Agronomia, Universidad de Córdoba	Apartado 3048, 14080 Córdoba	Spain
Arab Center for Studies of the Arid Zones and Dry Lands (ACSAD)	P.O. Box 2440, Damascus http://www.acsad.org/acsad/	Syria
Institut de l'Olivier	BP 1087, 3000 Sfax	Tunisia
CRGR	BP 10, 2080 Ariana	Tunisia
Olive Research Institute	35100 Bornova, Izmir http://www.zae.gov.tr	Turkey
Department of Pomology, UC Davis	Kearney Agricultural Center 9240 South Riverbend Ave., Parlier, CA 93648 http://pom.ucdavis.edu/	USA
Department of Land, Air, and Water Resources, University of California, Davis	Kearney Agricultural Center 9240 South Riverbend Ave., Parlier, CA 93648 http://lawr.ucdavis.edu/	USA