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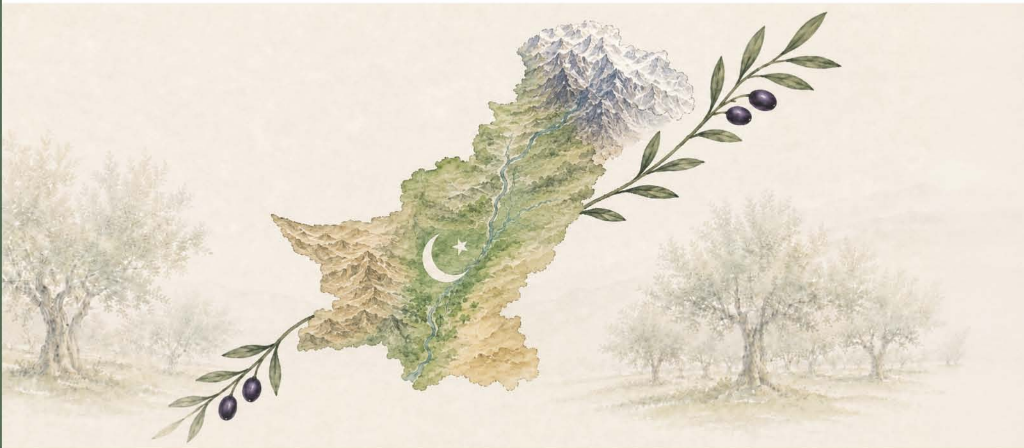

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Olive orchard management for sustainable production

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Abstract. The rapid development of olive cultivation in Pakistan has created an increasing need for scientifically grounded and locally adapted agronomic practices enabling sustainable productivity, efficient resource use, and high-quality olive production. Olive cultivation is strongly influenced by pedo-climatic conditions, orchard design, cultivar selection, irrigation management, pruning systems, soil fertility, and phytosanitary protection, all of which must be carefully integrated to support resilient production systems. Sustainable approaches based on Good Agricultural Practices, integrated management, and environmentally responsible farming are becoming essential for improving orchard performance while preserving soil health, biodiversity, and water resources. Moreover, balanced fertilization strategies, efficient irrigation methods, cover cropping, reduced tillage, and integrated pest and disease management are key components of modern olive cultivation. Similarly, proper harvesting and post-harvest handling practices play a decisive role in maintaining fruit integrity and optimizing olive oil quality. The adoption of these agronomic and sustainable management tools represents a crucial step toward strengthening the long-term effectiveness, productivity, and environmental sustainability of the olive sector in Pakistan.

Keywords. Good Agricultural Practices – Integrated Pest Management – Soil fertility – Irrigation management.

Gestion des vergers oléicoles pour une production durable

Résumé. *L'expansion rapide de l'oléiculture au Pakistan a mis en évidence la nécessité de pratiques agronomiques adaptées aux conditions locales afin d'assurer une production durable, une utilisation rationnelle des ressources et une huile d'olive de qualité. La culture de l'olivier dépend fortement des conditions pédo-climatiques, du choix variétal, de la conception des vergers, de la gestion de l'irrigation, des systèmes de taille, de la fertilité des sols et de la protection phytosanitaire. L'intégration cohérente de ces facteurs est essentielle pour développer des systèmes de production résilients et performants. Les approches fondées sur les Bonnes Pratiques Agricoles, la gestion intégrée et les méthodes de culture respectueuses de l'environnement contribuent à améliorer les performances des vergers tout en préservant les sols, les ressources en eau et la biodiversité. Une attention particulière est accordée à la fertilisation raisonnée, aux techniques d'irrigation efficientes, aux cultures de couverture, à la réduction du travail du sol ainsi qu'à la gestion intégrée des ravageurs et des maladies. De plus, les pratiques appropriées de récolte et de post-récolte jouent un rôle déterminant dans la préservation de l'intégrité des fruits et l'amélioration de la qualité de l'huile d'olive. L'adoption de ces stratégies agronomiques durables constitue ainsi une étape essentielle pour renforcer la productivité et la durabilité du secteur oléicole au Pakistan.***

Mots-clés. *Bonnes Pratiques Agricoles – Lutte intégrée – Fertilité des sols – Gestion de l'irrigation.*

I – Introduction

The rapid expansion of olive cultivation in Pakistan, with millions of trees established across diverse agro-ecological zones, has marked a significant step toward developing a national olive industry. However, this growth has not always been accompanied by equally robust, standardized knowledge on orchard management and agronomic practices. As a result, many olive plantations are managed under inconsistent or suboptimal conditions, limiting their productive potential and the quality of outputs.

Olive production is inherently a complex and knowledge-intensive system that requires careful adaptation to local pedo-climatic conditions. Factors such as cultivar selection, orchard design, pruning strategies, nutrient management, irrigation scheduling, and pests and diseases control must be harmonized to ensure sustainable productivity. In the absence of comprehensive, locally adapted guidelines, growers often rely on fragmented information or practices transferred from other regions, which may not be suitable for Pakistan’s unique environmental conditions.

Moreover, there is an increasing global emphasis on adopting agricultural systems that are environmentally sustainable, resource-efficient, and safe for both producers and consumers. This is particularly relevant for olive cultivation, which is often perceived as a low-input crop but still requires careful management to minimize environmental impact while maintaining economic viability. Approaches such as Good Agricultural Practices (GAP), integrated agriculture, and organic farming provide structured frameworks to achieve these objectives by promoting efficient input use, ecological balance, and long-term soil and plant health.

In this context, the development and dissemination of clear, science-based, and locally relevant guidelines for olive orchard management are essential. Such guidelines should not only address the technical aspects of cultivation but also integrate principles of sustainability, climate resilience, and environmental stewardship. This chapter aims to bridge the existing knowledge gap by outlining key agronomic practices and sustainable management strategies tailored to the needs of olive growers in Pakistan, thereby supporting the long-term productivity and competitiveness of the sector.

II – Olive cultivation: Main agronomic aspects

1. Pedo-climatic inclination

A thorough understanding of the environmental characteristics of a given territory is a fundamental prerequisite for effective olive orchard management. Such knowledge enables farmers to make informed decisions regarding key aspects of cultivation, including the selection of suitable cultivars based on local conditions, the establishment of natural protective systems that enhance biodiversity and support beneficial insect populations, and the optimization of agronomic practices such as soil preparation, fertilization, and plant protection.

The defining features of any agricultural environment are primarily determined by three interconnected factors: soil, climate, and vegetation. Soil (pedological characteristics) plays a central role in determining crop adaptability and guiding soil management practices. Maintaining optimal soil conditions enhances plant growth, resilience, and productivity, while also preserving soil health. Climatic conditions are equally critical, influencing the suitability of specific olive cultivars and enabling satisfactory yields with minimal external inputs. Vegetation, both natural and cultivated, contributes to the development of ecological balance by supporting biological control mechanisms and protecting soil from erosion and degradation.

Planning agricultural activities based on these factors allows for the optimization of production while reducing dependence on external inputs such as fertilizers and pesticides. In this context, the concept of inherent suitability refers to the natural capacity of a given area to sustain olive cultivation efficiently and sustainably with minimal intervention. Among all environmental variables, soil and climate remain the most decisive determinants of this suitability. Table 1 summarizes the key soil parameters to consider when assessing the suitability of a site for establishing a new olive orchard.

Table 1. Key soil parameters for evaluating planting site suitability.

Pedological parameters	Optimal Values
Soil weaving	Medium texture
Drainage	Good; there must be a quick draining of surface water
Useful depth	50-100 cm; The pitch must not exceed 100 cm from the surface
pH	6-8.5
Active limestone	8-15%
Salinity	Less than 6 mS/cm[1]

Olive trees require specific environmental conditions related to climate, exposure, and topography. Climatic factors, particularly minimum winter temperatures and the accumulation of chilling hours, represent the main limiting constraints for their cultivation. Temperatures below -6 to -7 °C can cause significant damage to leaves, branches, and trunks, while values below -10 °C may result in plant death. Additionally, even mild frost events (2-3°C below zero) during sensitive phenological stages, such as bud break in spring (April-May), can severely affect plant development. The extent of damage depends not only on temperature intensity but also on duration, plant physiological stage, humidity, and site exposure (Table 2).

Table 2. Temperatures relating to the main phenological phases, below which the development of the stages can be significantly slowed down or compromised.

Phenological phase	Average T (°C)	Optimal T (°C)
Beginning of budding	10.5-11	15
Beginning of blossoming	15	18
Beginning of the anthesis	18-19	20
Beginning of the fruit set	21-22	23
From blossoming to flowering	10	18-22
From the beginning of flowering to fruit set	15	23-25
From fruit set to veraison	20	21-22
From veraison to complete ripening	15	15-18
From complete ripening to the end of the harvest	5	7-8
From the end of the harvest to the blossoming	-5	0-5

The olive tree is a heliophilous species, requiring high light availability for optimal growth and productivity. Therefore, south and southwest exposures are generally preferred, along with orchard designs that maximize light interception. Traditionally, olive cultivation is recommended up to elevations of 600-700 meters above sea level, particularly in well-exposed areas. However, field experiences in Pakistan suggest that olive trees can adapt to diverse microclimatic conditions, including higher-altitude plateaus such as those found in Balochistan.

Environmental conditions also influence oil quality. Oils produced in lower-altitude areas tend to be richer in solid glycerides, whereas those from higher altitudes contain a higher proportion of liquid glycerides, making them generally more digestible and often more desirable from a nutritional and commercial perspective. Latitude, altitude, and exposure collectively affect temperature regimes, which in turn influence the biochemical composition of olive oil during fruit maturation.

In addition to temperature and radiation, other climatic factors such as wind, snow, and hail also affect olive productivity. Moderate wind during flowering can enhance pollination, particularly in self-incompatible cultivars, whereas strong and persistent winds may cause mechanical damage and increase evapotranspiration, especially in arid regions. In such environments, the establishment of windbreaks using locally adapted species is essential to reduce water loss, protect plants, and improve overall orchard performance.

2. Olive groves, orchard systems and varieties

A. Olive groves

a) Planting material

The establishment of new olive groves should rely exclusively on self-rooted plants grown in containers. This approach ensures the development of a well-structured root system, uniform plant growth, and earlier entry into production. All nursery material must be accompanied by proper genetic and phytosanitary certification, guaranteeing its authenticity, local adaptability, and high agronomic quality.

b) Planting operations

Planting is best carried out during spring or early autumn to favor optimal plant establishment. Rows should preferably be oriented along a north-south axis to maximize light interception and ensure uniform canopy illumination throughout the day.

c) Planting density

Plant spacing depends on the chosen training system. For the mono-cone system, a spacing of approximately 6 m between rows and 5-6 m between plants within rows is recommended. For vase systems, common configurations include 6×6 m or 5×6 m, allowing adequate canopy development and light distribution.

B. Orchard systems (Form of farming)

The choice of orchard system should promote rapid vegetative growth, early fruiting, optimal light distribution within the canopy, consistent productivity, and reduced labor costs for pruning and harvesting. Additionally, the system should respect the natural growth habit of the olive tree to minimize excessive pruning interventions.

For olive groves intended for manual harvesting, simple vase and polyconic vase training systems are recommended. In contrast, the mono-cone system is more suitable for mechanized harvesting. In particular, during the early growth stages, the mono-cone system enhances early production, supports balanced canopy development, reduces alternate bearing, and improves harvesting efficiency under mechanical shaking.

C. Variety selection

The selection of suitable olive cultivars is a critical step in orchard planning. Genetic characteristics determine the plant's adaptability to soil and climatic conditions, resistance to pests and diseases, precocity, yield potential, fruit quality, and susceptibility to alternate bearing. Cultivars should be selected based on their economic potential and their compatibility with local environmental conditions. In addition to widely cultivated commercial varieties, the inclusion of locally adapted or native cultivars can help preserve regional identity while enhancing product quality, whether for oil or table olive production.

In monovarietal orchards, it is advisable to include an appropriate proportion of compatible pollinizer cultivars (generally around 10%) where necessary. This ensures effective cross-pollination, improves fruit set, and enhances overall productivity, particularly in varieties with limited self-fertility.

D. Pruning

Pruning is a fundamental practice used to regulate the natural growth of the olive tree and adapt it to the selected training system. Its main objectives are to maintain canopy efficiency, regulate the distribution and renewal of fruiting branches, improve light penetration and air circulation, and reduce the risk of pest and disease development. Proper pruning also helps manage crop load and mitigate alternate bearing.

a) Training pruning

Training pruning is carried out during the juvenile phase to establish the structural framework of the tree. During the first years, pruning should be light, as excessive cutting can delay growth and postpone the onset of production.

- At planting: Seedlings should be cut at approximately 100 cm height, retaining lateral shoots to support early growth.
- Third year: If growth is weak, competing branches should be removed. In well-developed plants, branches below 50 cm and any suckers should be eliminated.
- Fourth year: As primary branches develop, competing shoots and poorly positioned branches should be removed.

Under proper management, the main branches will form favorable angles with the trunk, ensuring structural strength, resistance to environmental stresses, and efficient light interception.

b) Production pruning

Production (or maintenance) pruning is performed during the bearing phase to sustain productivity and maintain the balance between vegetative growth and fruiting. Excessive pruning should be avoided, as it disrupts the equilibrium between the canopy and root system and reduces yield potential.

Pruning intensity should be adjusted according to plant age and expected production. Light pruning is recommended following a heavy crop year, while more intensive pruning may be applied when a low-yield year is anticipated. The goal is to regulate vegetative growth, maintain optimal canopy volume relative to available resources, and limit alternate bearing. This practice is typically carried out annually or biennially, preferably from late winter to early spring, after the risk of severe frost has passed.

c) Management of pruning residues

Pruning residues can be removed, burned, or, preferably, recycled within the orchard. When shredded and incorporated into the soil, residues contribute to organic matter content, improve soil structure, and partially restore nutrients removed by plant growth. This practice is particularly suitable for young orchards, where pruning material consists mainly of small-diameter branches. Over time, it contributes to natural soil mulching.

d) Timing of pruning

Pruning is generally carried out during late winter or early spring, after the risk of severe frost. Low temperatures can damage exposed tissues and delay wound healing, increasing the risk of infection. In regions prone to late frosts, pruning should be delayed to protect plants and promote faster healing. Since pruning influences flower bud differentiation, its timing should also consider plant vigor; in vigorous trees, pruning can be delayed until floral structures are visible, whereas in weaker plants it should be carried out earlier (before February). Excessive delay should be avoided, as it can weaken plants and hinder new shoot development. Pruning after the onset of active growth may also remove developing buds and reduce productivity.

Summer pruning is generally limited to the removal of suckers and water sprouts, particularly in young or establishing orchards. In regions characterized by extreme heat and dry conditions, such as Punjab and Potohar, a two-stage pruning approach may be beneficial. Partial canopy retention before peak summer can protect trees from sunburn, while subsequent pruning at the onset of the monsoon season improves air circulation and reduces humidity-related risks.

3. Nutritional requirements of the olive tree

A. Soil analysis and foliar diagnostics

The adoption of a rational fertilization strategy is essential to maintain adequate soil fertility, prevent nutritional imbalances in plants and fruits, and minimize environmental impact. Determining the appropriate quantity and type of nutrients to be supplied requires an integrated approach based on soil analysis, foliar diagnostics, and estimation of nutrient removal (restitution criterion).

Soil physical, mechanical, and chemical analyses should be conducted prior to orchard establishment to guide basal fertilization and evaluate the initial fertility status of the site. These analyses provide critical information on nutrient availability and soil properties, allowing for tailored nutrient management. It is recommended to repeat soil analysis every 4-5 years to monitor changes and adjust fertilization practices accordingly. Tables 3-5 present the reference ranges for key soil physical, chemical and nutritional parameters used to assess soil fertility status and guide fertilization management in olive orchards.

Table 3. Reference values for the interpretation of soil analyses.

Assessment	pH in H_2O 1:2.5	Total limestone (CaCO3)	Total limestone (CaCO3) %	Organic matter (g / Kg =% 0)			Total Nitrogen (% 0)		
				Sand 60%	Medium	Clay 35%	Sand 60%	Medium	Clay 35%
Low	6.0-6.7	1-4	1.0-2.5	<12	<14	<17	<0.8	<1,0	<1.2
Normal	6.8-7.2	5-15	2.6-5.0	12-15	14-21	17-26	0.8–1.2	1.0–1.6	1.2–1,6
High	7.3-8.1	16-25	5.1-10	>15	>21	>26	>1.2	>1.6	>1.6

Table 4. Reference values for physiochemical soil analysis.

Assessment	Carbon Nitrogen Ratio (C/N)	Assimilable P		Exchangeable K			Exchangeable Ca mg/kg	Exchangeable Mg mg/kg
		Olsen mg/Kg	Bray 1 mg/Kg	Sand 60% mg/kg	Medium mg/kg	Clay 35%		
Low	6.0-6.7	1-4	1.0-2.5	0.6-1.0	1.0-1.5	1.25 - 2.0	<1000	60-100
Normal	9.1-11.0	10-15	16-30	81-150	101-250	151 - 300	1000-2000	100-150
High	11.1-20.0	16-25	31-50	151-250	251-350	301-450	>2000	>150

Table 5. Reference values for soil micronutrient status and related parameters.

Assessment	Soluble B mg/kg	Absorbable Cu mg/kg	Absorbable Fe mg/kg	S mg/kg	Mo Index pH +10 mg/kgMo	Total soluble salts %	Cation exchange capacity CSC meq/100g
Low	0,20-0,40	<1,0	<5,0	5-10	<6,3	/	6,0-12,0
Normal	0,41-1,00	1,1-6,0	5,1-130	11-15	6,3-8,2	<1,5	12,1-20,0
High	1,01-1,50	>6,0	>130	16-25	8,2	1,50-3,50	20,1-25,0

In addition to soil testing, foliar diagnostics offer a reliable method to assess the nutritional status of the olive grove during cultivation. This approach combines visual evaluation of vegetative growth and deficiency symptoms with laboratory analysis of leaf tissues. Leaf samples, collected at appropriate times and following standardized procedures, are analyzed to determine the concentration of essential nutrients. Table 6 shows the optimal percentage values by weight of the elements referring to the dry matter of the olive leaves. Leaf and fruit analyses together provide a comprehensive assessment of plant nutrition, enabling the identification of deficiencies, excesses, and nutrient imbalances that may affect productivity and fruit quality.

Table 6. Reference values for soil macronutrient status.

Nitrogen (N)	2.10 %
Phosphorus (P)	0,35 %
Potassium (K)	1.05 %
Total	3,50 %

B. *Fertilization plan*

a) Basic (Pre-planting fertilization)

Basic fertilization should be carried out before planting to improve the soil's physical, chemical, and biological properties. This typically involves the incorporation of well-decomposed organic matter, such as manure or other stabilized organic amendments, which enhance soil structure, microbial activity, and nutrient availability.

Application rates should ideally be based on soil analysis results. In the absence of analytical data, a general recommendation is to apply 30-50 t/ha of mature manure or equivalent organic material. Phosphorus and potassium requirements should be determined according to soil nutrient status.

b) Fertilization during plant establishment

During the early growth phase, nitrogen plays a key role in supporting vegetative development. In the first year, nitrogen should be applied in three split applications: the first at the onset of vegetative growth, followed by two additional applications at 15–20-day intervals. From the second to the fourth year, nitrogen should be applied in two doses during the main growth period (typically from March to July), ensuring continuous nutrient availability.

c) Production fertilization

Fertilization during the production phase aims to maintain a balanced nutrient supply in relation to the tree's vegetative growth and yield potential. Fertilization strategies must be adapted to local soil conditions, as determined by periodic soil analyses (recommended every 4-5 years), and complemented by field observations such as shoot growth, leaf color, canopy density, and the presence of suckers.

Nitrogen management is particularly critical. To ensure efficient uptake and minimize losses, nitrogen applications should be split into two or more doses aligned with key phenological stages. Typically, half of the nitrogen is applied at vegetative restart and the remainder during advanced fruit set. Nitrogen applications during flowering should be avoided, as they may increase flower drop and negatively affect fruit set.

Excessive nitrogen fertilization should be carefully avoided, as it can lead to excessive vegetative growth, increased susceptibility to pests and cold stress, delayed fruit ripening, and reduced oil quality and yield. As a general guideline, nitrogen application rates should not exceed approximately 3 kg per quintal of olives produced (or expected) per year.

In rainfed conditions, particularly in dry environments, nitrogen applications should be concentrated in the rainy season (late winter to early spring), and late applications should be avoided. Fast-acting nitrogen sources (*e.g.,* nitrates) are recommended at the beginning of the vegetative cycle, while other forms such as ammonium-based fertilizers or urea may be used later. When nitrogen application exceeds 60 kg/ha, it should always be applied in split doses.

Phosphorus and potassium fertilization should also be guided by soil analysis. Where needed, these nutrients can be applied annually at rates up to 30 kg/ha (P) and 40 kg/ha (K), or alternatively every 4-5 years if soil levels are below optimal thresholds. Their application is preferably carried out in autumn after harvest, in conjunction with soil tillage, or at the end of winter.

Organic fertilization remains an important component of sustainable nutrient management. Application of approximately 20 t/ha of mature manure every 3-4 years is recommended, with a corresponding reduction (about 30%) in mineral nitrogen inputs during the year of application. In the absence of manure, green manure practices using leguminous crops (*e.g.,* broad beans or lupines) can be adopted. These can be sown in alternate rows and incorporated into the soil at the beginning of flowering to improve soil fertility and structure.

In irrigated orchards, particularly under drip irrigation systems where the inter-row is kept free of weeds, fertilizers should be applied locally along the tree row. This targeted application allows for a reduction of approximately 20% in fertilizer input while maintaining efficiency.

Finally, attention should also be given to secondary nutrients and micronutrients. Olive trees are sensitive to deficiencies in calcium, magnesium, and trace elements such as iron, manganese, and boron. Maintaining appropriate nutrient balance is essential, with optimal Ca/Mg ratios around 2 and Ca/K ratios generally ranging between 2 and 3.5, although higher values may occur under specific environmental conditions.

4. Parasitic diseases and pests

Although the olive tree is a species well adapted to Mediterranean environments and traditionally considered resilient, modern cultivation systems require more precise and sustainable plant protection strategies to ensure consistent yields and high-quality production.

The intensive and indiscriminate use of broad-spectrum pesticides has led to several critical issues, including the development of pest resistance, disruption of natural predator-prey relationships, and a decline in beneficial organisms. Moreover, excessive reliance on chemical control increases the risk of toxic residues in olive fruits and oil, posing potential threats to human health and the environment. In this context, there is a growing need to shift toward more sustainable approaches to plant protection. Integrated Pest Management (IPM) represents a key strategy in modern olive cultivation, aiming to balance effective pest control with environmental and economic sustainability. Table 7 presents the main olive diseases and insect pests with a brief description of their symptoms, epidemiology, biology and control measures.

Table 7. Major olive diseases and pests: Symptoms, epidemiology, and management.

Category	Disease/Pest	Symptoms and damage	Epidemiology/Biology	Management
Fungi	**Peacock eye (*Spilocea oleagina*)**	Brown circular leaf spots (10-12 mm), velvety appearance, often with concentric rings; affects leaves, twigs, fruits; causes defoliation, fruit drop, and plant weakening	Develops slowly; favored by high humidity and free water; optimal temperature 13–16°C; confined to leaf cuticle; severe in spring and autumn	Resistant cultivars; pruning to improve aeration; avoid excessive nitrogen; copper-based fungicides in autumn and late winter; reduce canopy humidity
Fungi	**Anthracnose (*Colletotrichum acutatum*)**	Leaf spots, necrosis, fruit rot with sunken lesions and orange spores; fruit drop, mummification; reduced oil quality and yield	Favored by high humidity and rainfall, especially in autumn; linked to susceptible cultivars and high inoculum presence	Resistant cultivars; pruning and sanitation; removal of infected material; copper-based fungicides; early harvesting to avoid wet conditions
Bacteria	**Olive knot (*Pseudomonas savastanoi*)**	Tumor-like swellings on twigs, branches, leaves, and fruits; cracking surface; branch dieback and plant weakening	Enters through wounds (pruning, hail, insects); spreads via rain; survives in plant tumors	Use certified plant material; avoid injuries; prune properly; remove infected tissues; protect against frost and pests
Insects	**Olive psyllid (*Euphyllura olivina*)**	White waxy secretions and honeydew; affects buds, flowers, shoots; causes flower drop and reduced fruit set; promotes sooty mold; yield losses up to 60%	Three generations/year; active in spring and autumn; optimal temperature 20-25 °C; high mortality above 32 °C	Monitoring (traps, inspection); early control of first generation; pruning to improve airflow; use of neem oil, horticultural oils, insecticidal soaps
Insects	**Olive fly (*Bactrocera oleae*)**	Larval feeding in fruit pulp; fruit drop; reduced yield; poor oil quality (high acidity, bad odor); facilitates secondary infections	Overwinters as pupae or larvae; multiple generations (3-4/year); oviposition in summer; development favored by moderate temperatures (<30 °C)	Monitoring and trapping; timely harvesting; removal of infested fruits; biological and chemical control when thresholds exceeded

5. Water requirements, irrigation methods, and water management

Water availability is a critical factor influencing olive tree productivity. Soil water deficit during the vegetative season, particularly in summer, represents one of the main constraints to yield and is a major contributor to alternate bearing. Adequate water supply promotes vegetative growth, advances flowering, reduces production alternation, and improves fruit development. Furthermore, irrigation increases the pulp-to-stone ratio, enhances lipid synthesis, and improves oil quality by influencing its chemical composition. It also shortens the unproductive period during the early stages of orchard establishment.

A. Irrigation methods

Irrigation can be applied using various techniques, however, localized (drip) irrigation is considered the most efficient and suitable method for olive cultivation. Drip irrigation ensures high water-use efficiency (up to 90%), providing uniform and controlled water distribution with short irrigation intervals (typically every 2-4 days) and relatively low volumes per application (approximately 120-150 L per plant per irrigation event). This system is adaptable to different soil types and topographical conditions and operates at relatively low pressure (1-2 atmospheres), resulting in reduced management costs. Compared to traditional irrigation methods, drip systems limit weed development, enable precise nutrient delivery through fertigation, and allow the use of moderately saline water without significant adverse effects.

B. Critical water demand periods

The olive tree requires the greatest water supply from March to September, corresponding to the period of active vegetative growth. Within this period, certain phenological stages are particularly sensitive to water stress: i) flower development, ii) fruit set, and iii) fruit growth. Water deficits during these stages can significantly reduce yield and fruit quality.

C. Irrigation volumes and scheduling

In traditional olive orchards, where planting density and spacing are variable and irrigation systems are not fixed, it is difficult to define irrigation volumes on a per-hectare basis. In such cases, supplemental irrigation is recommended during critical phenological stages, with approximate applications of 300 L per plant per irrigation event. In specialized or high-density orchards equipped with micro-irrigation systems, irrigation scheduling should be adjusted based on plant water requirements, soil characteristics, and climatic conditions. Reference irrigation schedules (shifts) are typically based on fully productive orchards with moderate vigor and planting density.

Rainfall should be considered when planning irrigation, however, only effective rainfall contributes significantly to soil moisture. Precipitation below certain thresholds can be considered negligible, as it does not sufficiently replenish soil water reserves. Conversely, rainfall exceeding the following thresholds should be considered effective: 30 mm for sandy soils, 40 mm for medium-textured soils, and 50 mm for clay soils.

Proper irrigation management requires integrating these factors to optimize water use efficiency while maintaining plant productivity and fruit quality.

Table 8. Watering volumes (water return) and irrigation shifts for micro-irrigation systems.

Month	Watering (mm/day)*	Interval (days)		Rain (mm)**
		Drip	Microjet	
April	1.0	3	5	2.0
May	2.0	2	3-4	2.0
June	2.5	2	2-3	2.5
July	2.0	1-2	3-4	2
August	2.0	1-2	3-4	2

*The quantity of water to be returned to the crop based on its water needs.
** It is important to evaluate rainfall to irrigate only when necessary; the tool to use is the rain gauge.

6. Methods of harvesting and storing olives

Olive harvesting is one of the most labor-intensive operations in the production chain, accounting for up to 50% of total production costs in many European countries. For this reason, mechanization, either partial or full, has been widely adopted in these regions to reduce labor requirements and improve efficiency. In contrast, in Pakistan, where labor costs are comparatively lower, mechanized harvesting is still limited and not yet widely adopted. Nevertheless, regardless of the harvesting method employed, it is essential to handle olives carefully to avoid mechanical damage. Practices such as stepping on olives collected on nets must be strictly avoided, as they initiate fermentation processes that lead to significant organoleptic defects in the oil.

A. Structure and maturation of the olive

The olive fruit (drupe) undergoes a progressive color change during maturation. Initially green, it becomes yellowish with reddish patches and eventually turns purplish or black at full maturity, depending on the variety.

Olives typically weigh between 1 and 8 grams and are composed of approximately: 40-50% water, 15-32% oil (fatty substances), and 25-35% dry matter. The composition of the fruit is influenced by several factors, including cultivar, climatic conditions, agronomic practices, and orchard location.

Oil accumulation begins at the onset of veraison (color change), when the fruit loses its intense green color and gradually develops darker pigmentation. This process continues until full maturation. However, harvesting should not be delayed excessively, as overripe fruits are associated with quality deterioration.

B. Early and late harvesting

The timing of harvest significantly influences both yield and oil quality. The decision to harvest early or late depends on the desired characteristics of the final product:

- Early harvest: Produces oils that are more intensely fruity, with higher aromatic complexity and better overall quality.
- Late harvest: Results in oils that are milder, less fruity, and often higher in apparent oil yield due to fruit dehydration.

In some situations, early harvesting may also be necessary to avoid damage from late-season pest infestations, particularly the olive fly *Bactrocera oleae*.

It is important to note that the perceived increase in oil yield at later stages of ripening is often misleading, as it results mainly from water loss rather than increased oil synthesis. For optimal quality, harvesting should begin when approximately 10% of the fruits have undergone color change and be completed before this exceeds 50%. Early harvesting generally ensures better preservation of organoleptic properties, including aroma and flavor.

C. Main harvesting methods

Only harvesting methods that preserve fruit integrity and ensure high oil quality should be adopted. The principal methods include: i) Manual harvesting (hand picking), ii) facilitated harvesting (assisted tools), and iii) mechanical harvesting.

The collection of olives fallen naturally on the ground is strongly discouraged, as these fruits are often overripe or deteriorated, leading to poor oil quality. Similarly, traditional beating of branches with sticks should be avoided, as it damages both fruits and tree structure and increases susceptibility to diseases.

a) Manual harvesting

Manual harvesting consists of picking olives directly from the tree by hand. Although labor-intensive and costly, it remains the most selective and least damaging method. Manual or hand harvesting has several advantages including:

- Minimal damage to fruits and trees;
- Reduced risk of pest-related damage;
- Lower need for cleaning and processing;
- Production of high-quality oil with superior organoleptic characteristics.

b) Facilitated harvesting

Facilitated harvesting involves the use of tools such as manual or pneumatic combs, rakes, or hook shakers, combined with nets or sheets placed under the canopy to collect the falling fruits. Combs are typically mounted on telescopic rods, allowing access to upper canopy areas, while hook shakers use mechanical vibration to detach fruits. These tools improve harvesting efficiency while maintaining relatively low levels of fruit damage. This method represents a compromise between manual and mechanical harvesting, increasing productivity while preserving acceptable quality standards.

c) Mechanical harvesting

Mechanical harvesting is mainly adopted in large-scale orchards to reduce labor costs and improve operational efficiency. It involves the use of trunk or branch shakers equipped with vibrating arms, often combined with fruit interception systems such as nets, conveyor systems, or inverted umbrellas.

The successful adoption of mechanical harvesting requires appropriate orchard design and pruning systems. Trees should be trained to facilitate machine operation, typically with a vertical structure and a trunk height of at least 70 cm to allow proper grip of the shaking mechanism. Harvested fruits are collected using interceptor systems and transported via trailers or wagons equipped with automated loading systems. Although still limited in Pakistan due to economic and logistical constraints, mechanical harvesting represents a promising option for future intensification of olive production systems.

7. Regulation on Good Agricultural Practices

A. Management of soil fertility

Effective soil fertility management under Good Agricultural Practices (GAP) requires optimizing nitrogen dynamics within the soil-plant system, considering inputs, outputs, and internal transformations. This is particularly important in systems with successive crops, where maintaining both economic viability and environmental sustainability is essential. The primary objective is to ensure adequate crop nutrition while minimizing nitrogen losses through runoff, volatilization, and leaching into surface and groundwater.

A comprehensive understanding of the agronomic context is crucial to establishing a balanced relationship between fertilizer use, crop requirements, and environmental protection. The behavior and environmental impact of nitrogen depend on multiple interacting factors, including soil characteristics, climatic conditions, crop demand, and management practices. Therefore, nitrogen fertilization should be based on a balance approach, whereby the quantity applied compensates for the difference between crop requirements and the soil’s natural nitrogen supply. Analytical data can be used to estimate both the crop’s nitrogen uptake and the soil’s capacity to supply nitrogen over time. The availability of nitrogen is influenced by seasonal variations in temperature, moisture, and soil aeration, as well as soil texture and structure.

To reduce nitrate losses through percolation, appropriate land management strategies must be adopted. These include maintaining soil cover, incorporating crop residues, and minimizing periods when the soil remains bare. Although less common in perennial systems, crop rotation in olive orchards, particularly through the use of cover crops, can provide substantial benefits. By alternating olive trees with cover crops such as legumes, soil fertility can be improved through nitrogen fixation. Cover crops also suppress weed growth, reducing the need for herbicides, and help manage pests and diseases by breaking their cycles. Additionally, these crops improve soil structure and prevent erosion. Implementing this practice involves introducing cover crops like clover or vetch during the off-season, planting annual or biennial crops between young olive trees until they reach full canopy coverage, and growing green manure crops to be incorporated into the soil. An example rotation plan might involve planting legumes for the first two years, incorporating them as green manure in the third year, rotating with cereals or other non-legume cover crops in the fourth and fifth years, and allowing a fallow period or reintroducing legumes in the sixth year. Timing rotations around the olive tree growth cycle and harvest period, choosing compatible crops that do not compete heavily with the olive trees for resources, and managing cover crops properly are crucial considerations. While traditional olive orchards may not typically use crop rotation, integrating cover crops and practicing strategic fallowing can provide significant benefits to soil health, pest management, and overall orchard productivity.

a) **Grassing (Cover cropping)**

The establishment of vegetative ground cover (grassing) is a key practice for improving soil health and reducing environmental risks. Ground cover absorbs excess nitrates, thereby limiting their leaching into groundwater, and contributes to improving soil structure, biodiversity, and organic matter content. Grassing systems may be classified as:

- Spontaneous grassing, which relies on natural vegetation and is particularly useful in reducing nitrate leaching and protecting soil during vulnerable periods;
- Controlled (sown) grassing, commonly used in organic systems, involving selected species to ensure effective soil coverage and nutrient management.

The species to be considered suitable for this function should satisfy the following conditions:

- Establish easily with low input requirements
- Compete minimally with olive trees
- Avoid creating phytosanitary issues
- Contribute to soil protection and nutrient cycling

Grassing also reduces soil erosion, enhances water infiltration, and contributes to carbon sequestration. Periodic mowing or shredding creates a natural mulching effect, further improving soil conditions.

b) **Tillage and soil structure**

Tillage practices significantly influence soil structure, organic matter dynamics, and water movement. Deep ploughing redistributes organic substances throughout the soil profile, potentially increasing mineralization and nitrate nitrogen production, which is beneficial for plant nutrition but can also lead to leaching. However, in arable olive orchards, excessive ploughing may decrease organic matter levels over time, affecting soil fertility and structure negatively.

Primary and secondary tillage operations mainly affect soil macro-porosity, influencing water infiltration and runoff. Excessive tillage increases the risk of erosion and nutrient loss. For olive cultivation, minimizing tillage intensity can help maintain soil organic matter content and preserve soil structure, especially on sloping terrain where erosion control is crucial. Nonetheless, the choice of tillage intensity should be adapted to soil type and local conditions. In some soils with poor structure, occasional intervention may be necessary to maintain adequate porosity for root development.

c) Land management and water control

Land management practices in hydraulic-agricultural systems play a critical role in optimizing olive crop cultivation, particularly concerning water management and erosion control. In sloping olive orchards, the primary goal is to mitigate surface runoff, which can be achieved through strategically placed ditches that slow down water flow. This helps prevent soil erosion and retains water on-site for olive tree uptake, essential in maintaining soil moisture levels and preventing nutrient leaching. Conversely, in flat olive orchards, effective drainage systems such as underground drains or open ditches facilitate excess water removal, reducing the risk of waterlogging and enhancing root health.

In plain lands, hydraulic-agricultural management provides significant environmental and agronomic benefits by swiftly evacuating water, along with dissolved nitrates, to surface hydrological networks. This rapid water disposal minimizes the time nitrate-laden water spends percolating towards aquifers, thereby protecting groundwater quality. Properly designed drainage infrastructure, tailored to soil texture, structure, and rainfall characteristics, optimizes water movement while safeguarding against erosion and nutrient loss. Techniques like field ballasting enhance surface water evacuation to ditches, further supporting erosion control and nutrient retention.

Regarding olive crop management, these practices ensure optimal soil moisture levels and nutrient availability, crucial for healthy olive tree growth and productivity. By integrating hydraulic-agricultural strategies tailored to local conditions, olive growers can sustainably manage water resources, prevent soil erosion, and enhance overall orchard resilience against environmental challenges. This approach not only supports agricultural productivity but also promotes environmental stewardship in olive cultivation.

d) Types of nitrogen fertilizers and their application

Using fertilizers and soil improvers to supply nitrogen to olive crops requires careful consideration of the chemical forms of nitrogen present in these products. The selection and expected responses must be calibrated based on how each form of nitrogen behaves in soil and contributes to plant nutrition. Nitrogen can exist in various forms such as nitrate, ammonium, and organic nitrogen compounds, each influencing soil fertility and nutrient uptake differently. For olive cultivation, understanding these nitrogen forms' dynamics helps optimize fertilizer application strategies to enhance both production outcomes and environmental sustainability.

Different nitrogen forms vary in availability, mobility, and environmental impact:

- **Nitric nitrogen (NO_3^-)**: Immediately available to plants but highly susceptible to leaching. Best applied during peak crop demand and preferably in split applications. The main fertilizers containing only nitrogen in the nitric form are calcium nitrate (N=16%) and potassium nitrate (N=15%; K2O=45%).
- **Ammoniacal nitrogen (NH_4^+)**: Less mobile and retained in soil; requires microbial conversion before plant uptake, resulting in slower release. The main fertilizers containing only ammoniacal nitrogen are anhydrous ammonia (N=82%), ammonium sulphate (N=20-21%), ammonia solutions (minimum content: 10% N), ammonium phosphates (diammonium phosphate 18 /46 and monoammonium phosphate: 12/51).

- **Nitric + ammoniacal fertilizers**: Provide both immediate and sustained nitrogen availability. Depending on the ratio of nitric to ammoniacal nitrogen, these fertilizers provide flexible solutions for various stages of crop growth and specific field intervention needs. One prominent example of a nitro-ammonia fertilizer is ammonium nitrate.
- **Urea nitrogen**: Requires enzymatic and microbial transformation before becoming available; highly soluble but subject to volatilization and leaching if mismanaged. The fundamental product is urea (N=46%), the solid mineral fertilizer with the highest nitrogen content.
- **Organic nitrogen fertilizers**: Derived from organic matter; release nitrogen gradually through mineralization, improving soil structure and long-term fertility. Among the main organic fertilizers are leather, hornwort, dried blood, meat and fish meal, manure and dried manure.
- **Organo-mineral fertilizers**: Combine organic and mineral nitrogen sources, ensuring both immediate and sustained nutrient availability.
- **Slow-release fertilizers**: Designed to release nitrogen gradually, improving efficiency and reducing environmental losses.
- **Cyanamide fertilizers**: Require multiple transformation steps before becoming available, resulting in delayed nitrogen release.
- **Organic amendments and livestock effluents:** Vary widely in composition and nutrient availability:
  - Cattle manure: Primarily improves soil structure; provides slow and sustained nutrient release over several years.
  - Bovine slurry: Offers moderate immediate nutrient availability with a residual effect; composition varies depending on management.
  - Poultry manure: High in readily available nitrogen, similar to synthetic fertilizers, but requires careful handling due to volatilization risks.
  - Compost: Stabilized organic material with balanced nutrient release and strong soil conditioning properties. Its quality depends on raw materials and processing methods.

The selection and application of these materials must consider their nutrient content, mineralization rate, and potential environmental risks (*e.g.,* heavy metals in compost).

B. Phytosanitary protection

Phytosanitary protection within the framework of GAP is based on the rational, responsible, and regulated use of plant protection products to ensure crop health while minimizing risks to the environment, human health, and product quality. The application of phytosanitary products must be limited to those officially authorized and carried out in strict compliance with label recommendations, including dosage, timing, safety intervals, and application methods. Chemical interventions should not be routine but instead guided by technical criteria. In particular, treatments against insect pests should be performed only when established economic thresholds are exceeded, whereas disease management should rely on preventive measures when environmental conditions favor pathogen development, and on curative treatments when infections are detected.

For fungal and bacterial diseases, integrated strategies combining agronomic practices and targeted treatments are essential. In the case of viral diseases, control relies primarily on the use of certified, healthy propagation material compliant with phytosanitary regulations, along with effective management of insect vectors responsible for disease transmission.

Farmers adopting GAP must follow a structured and traceable approach to crop protection. This includes:

- Strict adherence to GAP principles, ensuring that all plant protection measures are justified, targeted, and environmentally sustainable;
- Maintenance of a detailed field record ("campaign notebook"), documenting all phytosanitary treatments, including product type, dosage, timing, and purpose, as well as other agronomic practices such as fertilization, pruning, tillage, and irrigation;
- Continuous monitoring and technical updating, through regular assessment of phytosanitary conditions in the orchard and consultation with agricultural advisors, extension services, technical bulletins, and specialized publications.

III – Conclusions

This chapter provides a comprehensive overview of the fundamental principles and practices required for effective olive orchard management, with a strong emphasis on GAP and sustainability. It brings together key agronomic components necessary to optimize both productivity and product quality under diverse pedo-climatic conditions.

The framework presented outlines the importance of proper orchard establishment, including site suitability, cultivar selection, planting systems, and training forms, as the foundation for long-term performance. It further highlights the role of balanced nutrition, supported by soil analysis and foliar diagnostics, in maintaining soil fertility and preventing nutrient imbalances.

Particular attention is given to sustainable soil and water management strategies, such as grassing, reduced tillage, and efficient irrigation methods, which contribute to improved soil structure, water use efficiency, and environmental protection. In parallel, the adoption of integrated pest management and responsible phytosanitary practices is emphasized to ensure effective control of pests and diseases while minimizing chemical inputs and associated risks. The present work also addresses optimal harvesting practices and post-harvest handling, underlining their critical role in preserving fruit integrity and ensuring high-quality olive oil production.

Overall, the approaches presented in this chapter aim to support the development of productive, resilient, and environmentally sustainable olive production systems. Their implementation will contribute to improving yield stability, enhancing product quality, and promoting the long-term sustainability of olive cultivation.

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