The Olive Orchard Mosaic

Subjects: Agronomy
Contributor: Justino Sobreiro , Maria Isabel Patanita , Manuel Patanita , Alexandra Tomaz

The olive tree is an evergreen plant with a remarkable water control process under water stress conditions. The production of olive oil in Portugal and other countries of the Mediterranean region has greatly increased. Intensification efforts have focused on the growth of the planted area, but also on the increase of the orchards density and the implementation of irrigation systems. Concerns about possible negative impacts of modern olive orchard production have arisen, questioning the trade-offs between the production benefits and the environmental costs. Therefore, it is of great importance to review the research progress made regarding agronomic options that preserve ecosystem services in high-density irrigated olive orchards. To better understand these technical options, it is equaly important to define the different types of olive orchards that can be found in olive-growing countries, such as Portugal, where the olive orchards mosaic includes Traditional (TD: 50–200 trees ha^{-1}), Medium-Density (MD: 201–400 trees ha^{-1}), High-Density (HD: 401–1500 trees ha^{-1}), and Super-High-Density (SHD: 1501–2500 trees ha^{-1}) systems.

soil management | medium-density | super-high-density | olive orchards | high-density | irrigation management | agro-ecology

1. The Traditional Olive Orchards

When traveling in the Mediterranean area, one can often find olive orchards planted in the XIXth century or up to the mid-XXth century, with fewer than 50 trees ha^{-1} to a maximum of 200 trees ha^{-1}, that are still productive today. These were sometimes planted on sharp slopes or small and narrow terraces made with stone walls, as can mainly be observed in the north of Portugal, providing landscapes of great beauty.

In traditional olive orchards (TD), the management of cover crops is conducted by tillage or total herbicide coverage. Grain crops were traditionally grown within olives as primary sources of farmers' income. In these situations, soil erosion can be quite dramatic [1][2][3], and at the same time, the temperature of the soil's top layer is quite high in the summer (over 40 °C). Although olive is a well-adapted species to drought conditions, the soil's exposure to direct sun and the lack of canopy shade over the tree root zone leads to water and heat stress, and can induce summer dormancy in the trees [4][5][6].

The farmers use few fertilizers and apply a reduced number of chemical pest and disease treatments in the olive groves. They are pruned every four years by chain saw, and the pruning residue is generally burned. The alternate bearing is very strong, with a sparse yield in the year following pruning . Since these orchards are rainfed, the biodiversity of species is sometimes low due to the lack of water and cover crops [7][8][9].

Traditionally, the harvest is performed by hand with wood sticks, although nowadays, some growers use portable backpack shakers with or without nets covering the floor. The net production of these olive ecosystems is less than 3 t ha^{-1} of fruits. The quality of the oil produced is often affected by diseases like anthracnose (*Colletotrichum* sp.) [10] or by contamination of the fruit through direct contact with the orchard floor [11]. The overall sustainability of this traditional olive system is currently compromised due to the lack of workers and the labor price [12] (**Table 1**).

Table 1. Systematization of the most common olive orchards' agricultural systems in the Mediterranean climate and their features. Traditional (TD), medium-density (MD), high-density (HD), and super-high-density (SHD).

Orchard Type	Spacing Inter-row × Row (m)	Tree Density (trees ha^{-1})	Productivity (t ha^{-1})	Soil Conservation	Tree Architecture	Pruning	Irrigation and Soil Management	Harvest	Common Cultivars
Traditional (TD)	8–15 × 6–15	50–200	0.5–3	Slopes: 0 to 30%. Strong erosion.	Trichotomic vase canopy. Strong alternate bearing.	Every 4 years. Chain saw. Pruning residue is burned.	Non-irrigated. Soil tillage, inter-row grain crops. Herbicides.	Hand branch shakers, with or without floor nets.	Galega, Verdeal, Cordovil.
Medium-density (MD)	7–8 × 3.5–6	201–400	3–6	Slopes: 0 to 15%. Some erosion.	Trichotomic vase canopy. Alternate bearing.	Every 2 years. Chain saw. Pruning residue is burned.	Non-irrigated or low-irrigated. Soil tillage, herbicides, or spontaneous weed cover, some used for animal pasture.	Trunk shaker, floor nets. Wrap around the tree collector.	Galega, Verdeal, Cordovil, Cobrançosa, Picual, Frantoio
High-density (HD)	4–7 × 1.7–3.5	401–1500	6–12	Slopes: 0 to 10%. Low erosion.	Dichotomic vase or hedge row. Some alternate bearing in orchards over 20 years old.	Every 1–2 years. Manual shears, electric or air compressed. Tractor disc trimmers. Pruning residue is	Drip irrigation 250–500 mm year^{-1}. Spontaneous or sowed cover crops. Herbicide in the tree rows or no herbicide.	Trunk shaker and wrap around the tree collector, or over-the-row.	Cobrançosa, Picual, Arbequina, Frantoio.
Super-high-density (SHD)	3.5–4 × 1–1.7	1501–2500	12–22						Arbequina, Arbosana, Koroneiki.

References

1. Soriano, M.-A.; Álvarez, S.; Landa, B.B.; Gómez, J.A. Soil Properties in Organic Olive Orchards Following Different Weed Management in a Rolling Landscape of Andalusia, Spain. Renew. Agric. Food Syst. 2014, 29, 83–91.

Orchard Type	Spacing Inter-row × Row (m)	Tree Density (trees ha^{-1})	Productivity (t ha^{-1})	Soil Conservation	Tree Architecture	Pruning	Irrigation and Soil Management	Harvest	Common Cultivars
						shredded on site.			

...ems on
...ty or
Abandonment? J. Environ. Manag. 2008, 89, 86–98.

2. The Medium-Density Olive Orchards

The most common olive orchards in the Mediterranean area are those with medium density (MD; 201–400 trees ha^{-1}), which are very likely to be observed in lime soils of the southern parts of Portugal or Spain. They are rainfed or little irrigated, and the soil is kept weed-free by tillage or by partial (in the rows) or total herbicide application. Many have spontaneous cover plants, mainly in the interrow, which are used to some extent as grazing lands. In this case, animal manure provides some nutrient recycling for the ecosystem and complements annual fertilization. The pruning is carried out in alternate years and is less intense than in traditional orchards. The pruning residue is often burned.

The sun exposure of the soil is lower due to the improved tree shade, resulting in better development of resident herbaceous vegetation that increases insect populations, improves biodiversity, and provides more protection against soil erosion than in the TD systems.

The harvest is carried out by tree shaking using floor nets or wraps around the trees as collecting systems. These orchards have been upgraded over time by increasing plant density and providing better irrigation. This agricultural system is undergoing a fast transition to a higher-density system [13][14][15].

3. The High- (HD) and Super-High-Density (SHD) Olive Orchards

The success of the higher-density olive agricultural systems is based on water availability [16]. The olive tree is an evergreen specie with a remarkable water control process under water stress conditions [17][18][19]. Nevertheless, in a region with 562 mm $year^{-1}$ of average rainfall [20], 250 mm to 500 mm $year^{-1}$ of supplemental irrigation water are the necessary values for the trees to achieve their maximum productivity. This demand is lower when compared to the 500–800 mm $year^{-1}$ required by other perennial species (**Figure 1**). Under these conditions, higher densities lead to increased productivity. The HD and SHD olive orchards are planted with 401–2500 trees ha^{-1}. Plantation is sometimes conducted in ridges of 1.0 m × 0.5 m (width × height) that are meant to prevent waterlogging and improve soil temperature in the early spring. These ridges must be made with special care; otherwise, they can prevent the natural rainfall flow and worsen the waterlogging [21].

4. Fernández, J.-E. Understanding Olive Adaptation to Abiotic Stresses as a Tool to Increase Crop Performance. Environ. Exp. Bot. 2014, 103, 158–179.

5. Haworth, M.; Marino, G.; Brunetti, C.; Killi, D.; De Carlo, A.; Centritto, M. The Impact of Heat Stress and Water Deficit on the Photosynthetic and Stomatal Physiology of Olive (Olea europaea L.)—A Case Study of the 2017 Heat Wave. Plants 2018, 7, 76.

6. Brito, C.; Dinis, L.-T.; Moutinho-Pereira, J.; Correia, C.M. Drought Stress Effects and Olive Tree Acclimation under a Changing Climate. Plants 2019, 8, 232.

7. Guzmán, G.; Montes-Borrego, M.; Gramaje, D.; Benítez, E.; Gómez, J.A.; Landa, B.B. Cover Crops as Bio-Tools to Keep Soil Biodiversity and Quality in Slopping Olive Orchards. In Proceedings of the 20th EGU General Assembly, Procceedings from the Conference, Viena, Austria, 4–13 April 2018; p. 9957.

8. Guzmán, G.; Boumahdi, A.; Gómez, J.A. Expansion of Olive Orchards and Their Impact on the Cultivation and Landscape through a Case Study in the Countryside of Cordoba (Spain). Land Use Policy 2022, 116, 106065.

9. Gomez Calero, J.A.; Campos, M.; Guzman, G.; Castillo Llanque, F.; Giráldez, J.V. Use of Heterogeneous Cover Crops in Olive Orchards to Soil Erosion Control and Enhancement of Biodiversity. In The Earth Living Skin: Life and Climate Changes; Castellaneta Marina, Italy, 2014; Available online: http://hdl.handle.net/10261/159778 (accessed on 3 July 2023).

10. Peres, F.; Talhinhas, P.; Afonso, H.; Alegre, H.; Oliveira, H.; Ferreira-Dias, S. Olive Oils from Fruits Infected with Different Anthracnose Pathogens Show Sensory Defects Earlier Than Chemical Degradation. Agronomy 2021, 11, 1041.

11. Mele, M.A.; Islam, M.Z.; Kang, H.M.; Giuffrè, A.M. Pre-and Post-Harvest Factors and Their Impact on Oil Composition and Quality of Olive Fruit. Emir. J. Food Agric. 2018, 592, 592–603.

12. Gomez, J.A.; Amato, M.; Celano, G.; Koubouris, G.C. Organic Olive Orchards on Sloping Land: More than a Specialty Niche Production System? J. Environ. Manag. 2008, 89, 99–109.

13. Morgado, R. From Traditional to Super-Intensive: Drivers and Biodiversity Impacts of Olive Farming Intensification. Ph.D. Thesis, UL, Lisbon, Portugal, 2022. Available online: https://www.repository.utl.pt/handle/10400.5/27582 (accessed on 3 July 2023).

14. Mairech, H.; López-Bernal, Á.; Moriondo, M.; Dibari, C.; Regni, L.; Proietti, P.; Villalobos, F.J.; Testi, L. Is New Olive Farming Sustainable? A Spatial Comparison of Productive and

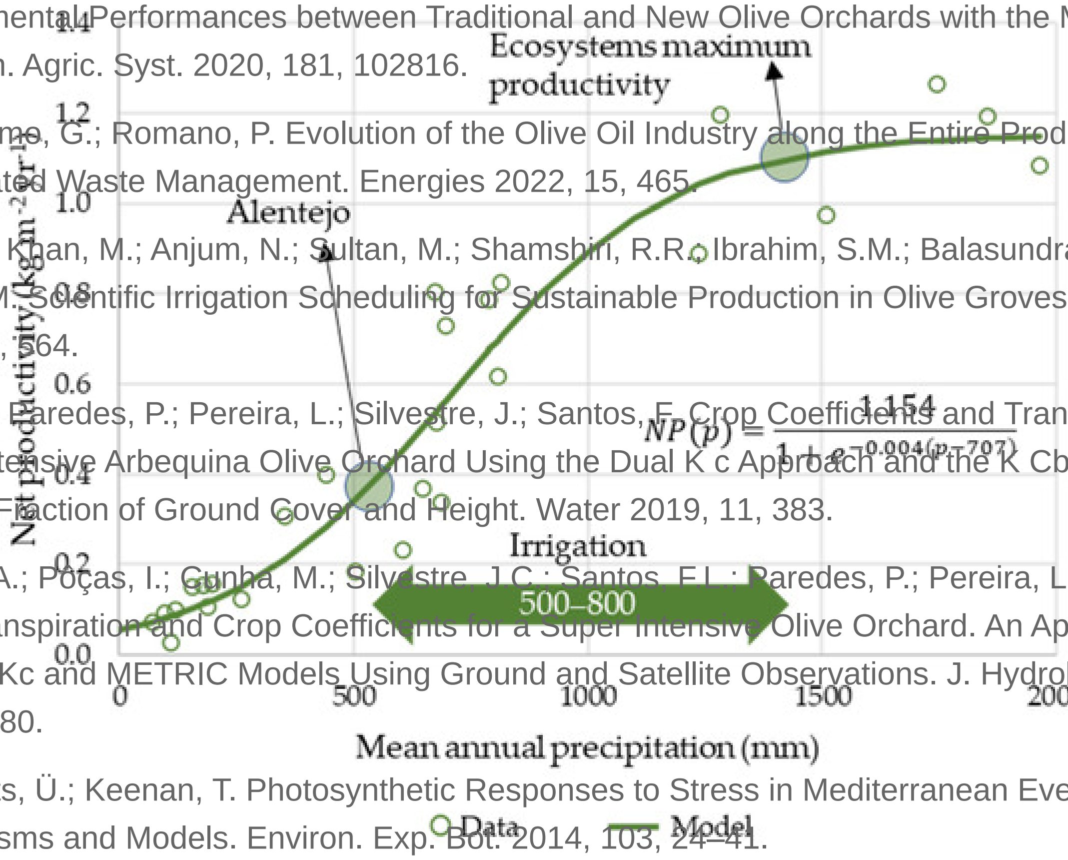

Figure 1. Biomass productivity by world ecosystems. The Mediterranean rainfall in Alentejo is signaled as well as the irrigation requirements, calculated as the difference between the ecosystem's maximum productivity and the average Alentejo rainfall. (Data from Taiz et al. [22]). NP—net productivity (kg m^{-2} year^{-1}), p—precipitation (mm).

Considering soil management, the soil is normally covered with spontaneous or sowed herbaceous vegetation to minimize soil erosion. The sowed cover species could be *Fabaceae* sp., like *Medicago sativa*, *Vicia* sp. or *Trifolium* spp., which are quite important nitrogen recyclers. Every 2–8 t ha^{-1} of olive fruits extract 9–28 kg ha^{-1} of nitrogen (N), 2–8 kg ha^{-1} of phosphorus (P_2O_5), and 12–48 kg ha^{-1} of potassium (K_2O) [23]. The cover species can provide an important contribution in the form of N balance in the cases of HD and SHD olive orchards. The spontaneous or sowed cover crops are also important refuges for beneficial insects or pollinators, which improve the general biodiversity of HD and SHD orchards [24][25][26][27][28][29][30]. Interrow weed management is usually carried out by shredding 3 to 5 times a year to keep weeds below 0.5 m in height. The shredding also recycles the pruning residues left in the topsoil of these orchards. The recycling of pruning residues is a good practice that allows the reposition of 2.9 kg t^{-1} N, 1,1 kg t^{-1} P_2O_5, and 2.9 kg t^{-1} K_2O [23], apparently without side effects related to the improvement of orchard diseases [31]. Nevertheless, soil diseases caused by *Verticillium dahliae* may occur [32].

If irrigation lines are directly on the soil surface, they do not allow for weed mowing in the tree lines. Therefore, weed control in the tree row normally requires herbicide application. This issue should be addressed in the near future, as the herbicide glyphosate could be banned, and other chemical solutions are currently less economical [33][34].

Environmental Performances between Traditional and New Olive Orchards with the Model OliveCan. Agric. Syst. 2020, 181, 102816.

15. Di Giacomo, G.; Romano, P. Evolution of the Olive Oil Industry along the Entire Production Chain and Related Waste Management. Energies 2022, 15, 465.
16. Aziz, M.; Khan, M.; Anjum, N.; Sultan, M.; Shamshiri, R.R.; Ibrahim, S.M.; Balasundram, S.K.; Aleem, M. Scientific Irrigation Scheduling for Sustainable Production in Olive Groves. Agriculture 2022, 12, 564.
17. Paço, T.; Paredes, P.; Pereira, L.; Silvestre, J.; Santos, F. Crop Coefficients and Transpiration of a Super Intensive Arbequina Olive Orchard Using the Dual K c Approach and the K Cb Computation with the Fraction of Ground Cover and Height. Water 2019, 11, 383.
18. Paço, T.A.; Poças, I.; Cunha, M.; Silvestre, J.C.; Santos, F.L.; Paredes, P.; Pereira, L.S. Evapotranspiration and Crop Coefficients for a Super Intensive Olive Orchard. An Application of SIMDualKc and METRIC Models Using Ground and Satellite Observations. J. Hydrol. 2014, 519, 2067–2080.
19. Niinemets, Ü.; Keenan, T. Photosynthetic Responses to Stress in Mediterranean Evergreens: Mechanisms and Models. Environ. Exp. Bot. 2014, 103, 24–41.
20. IPMA—Séries Longas. Available online: https://www.ipma.pt/pt/oclima/series.longas/?loc=Beja&type=raw (accessed on 21 February 2023).
21. Tombesi, A.; Tombesi, S.; Saavedra, M.M.S.; Fernández-Escobar, R.; d'Andri, R.; Lavini, A.; Ali Triki, M.; Rhouma, A.; Ksantini, A. Production Techniques in Olive Growing, 1st ed.; International Olive Council: Madrid, Spain, 2007; ISBN 978-84-931663-6-6.
22. Taiz, L.; Zeiger, E.; Møller, I.M.; Murphy, A. Fisiologia e Desenvolvimento Vegetal; 6a Edição; ArteMed Editora Lda: Porto Alegre, Brazil, 2017; ISBN 978-85-8271-367-9.
23. Diário da República 2 Série, 25. Available online: https://files.dre.pt/2s/2018/02/025000000/0413204170.pdf (accessed on 19 February 2023).
24. Carpio, A.J.; Castro, J.; Tortosa, F.S. Arthropod Biodiversity in Olive Groves under Two Soil Management Systems: Presence versus Absence of Herbaceous Cover Crop. Agric. For. Entomol. 2019, 21, 58–68.
25. Alcalá Herrera, R.; Ruano, F.; Gálvez Ramírez, C.; Frischie, S.; Campos, M. Attraction of Green Lacewings (Neuroptera: Chrysopidae) to Native Plants Used as Ground Cover in Woody Mediterranean Agroecosystems. Biol. Control 2019, 139, 104066.
26. Vasconcelos, S.; Pina, S.; Herrera, J.M.; Silva, B.; Sousa, P.; Porto, M.; Melguizo-Ruiz, N.; Jiménez-Navarro, G.; Ferreira, S.; Moreira, F.; et al. Canopy Arthropod Declines along a Gradient of Olive Farming Intensification. Sci. Rep. 2022, 12, 17273.

One advantage of HD and SHD olive orchards is the soil temperature. Some studies reported that, in the same location, the temperature of the topsoil in the summer, measured with a FLIR (Forward Looking InfraRed) device, was about 20 °C lower at the top of the cover grass when compared to bare topsoil [35][36].

Finally, HD and SHD olive orchards are more regular in yield but do not show evidence for strong alternate crop behavior when compared with the other systems. The cultivars in use have less vigor and, therefore, provide more regular production, at least during the first 20 years of the orchard's life [37][38][39]. The low number of olive cultivars used in these orchards and its impact on lowering the landscape diversity is also a major concern.

Harvests in HD and SHD olive orchards require tractor trunk shakers with wraps around the tree collectors or over-the-row self-propelled machines. The latter can harvest up to one hectare per 1 h (12–22 t of fruits). As the fruits are never in contact with the ground, they are quite suitable for virgin or extra-virgin oil production [15]. In Portugal, the harvest is restricted to the period from sunrise to sunset in order to prevent involuntary bird losses, since these animals often use olive trees as refuges overnight [40].

27. Novara, A.; Cerda, A.; Barone, E.; Gristina, L. Cover Crop Management and Water Conservation in Vineyard and Olive Orchards. Soil Tillage Res. 2021, 208, 104896.

28. Sánchez-Fernández, J.; Vílchez-Vivanco, J.A.; Navarro, F.B.; Castro-RodrIguez, J. Farming System and Soil Management Affect Butterfly Diversity in Sloping Olive Groves. Insect Conserv. Divers. 2020, 13, 456–469.

29. Rey, P.J.; Manzaneda, A.J.; Valera, F.; Alcántara, J.M.; Tarifa, R.; Isla, J.; Molina-Pardo, J.L.; Calvo, G.; Salido, T.; Gutiérrez, J.E.; et al. Landscape-Moderated Biodiversity Effects of Ground Herb Cover in Olive Groves: Implications for Regional Biodiversity Conservation. Agric. Ecosyst. Environ. 2019, 277, 61–73.

30. Cano, Á.G.; Alejandro, H. Semi-Natural Habitats and Natural Enemies in Olive Orchards: Abundance, Function, Trophic Interactions, and Global Climate Change. Ph.D. Thesis, Universidad de Granada, Granada, Spain, 2021. Available online: http://hdl.handle.net/10481/70690 (accessed on 29 June 2023).

31. Álvarez, B.; Couanon, W.; Olivares, J.; Nigro, F. EIP-AGRI Focus Group "Pests and Diseases of the Olive Tree" Biocontrol Agents and Cropping Practices to Control Olive Diseases; EIP-AGRI; European Commission: Brussels, Belgium, 2019.

32. Montes Osuna, N.; Mercado-Blanco, J. Verticillium Wilt of Olive and Its Control: What Did We Learn during the Last Decade? Plants 2020, 9, 735.

33. Glyphosate: Commission Responds to European Citizens' Initiative and Announces More Transparency in Scientific Assessments. Available online: https://ec.europa.eu/commission/presscorner/detail/en/IP_17_5191 (accessed on 29 May 2023).

34. Andriukaitis, V. Pesticides in the European Union—Authorization and Use. Available online: https://ec.europa.eu/commission/presscorner/api/files/attachment/855260/Pesticides_factsheet.pdf (accessed on 29 May 2023).

35. Caruso, G.; Palai, G.; Tozzini, L.; Gucci, R. Using Visible and Thermal Images by an Unmanned Aerial Vehicle to Monitor the Plant Water Status, Canopy Growth and Yield of Olive Trees (Cvs. Frantoio and Leccino) under Different Irrigation Regimes. Agronomy 2022, 12, 1904.

36. Taguas, E.V.; Marín-Moreno, V.; Díez, C.M.; Mateos, L.; Barranco, D.; Mesas-Carrascosa, F.-J.; Pérez, R.; García-Ferrer, A.; Quero, J.L. Opportunities of Super High-Density Olive Orchard to Improve Soil Quality: Management Guidelines for Application of Pruning Residues. J. Environ. Manag. 2021, 293, 112785.

37. Pastor, M.; García-Vila, M.; Soriano, A.; Vega, V.; Fereres, E. Productivity of Olive Orchards in Response to Tree Density. J. Hortic. Sci. Biotechnol. 2007, 82, 555–562.

38. Gomez-del-Campo, M.; Connor, D.J.; Trentacoste, E.R. Long-Term Effect of Intra-Row Spacing on Growth and Productivity of Super-High Density Hedgerow Olive Orchards (Cv. Arbequina).

Front. Plant Sci. 2017, 8, 1790.

39. Díez, C.M.; Moral, J.; Cabello, D.; Morello, P.; Rallo, L.; Barranco, D. Cultivar and Tree Density As Key Factors in the Long-Term Performance of Super High-Density Olive Orchards. Front. Plant Sci. 2016, 7, 1226.
40. Morgado, R.; Santana, J.; Porto, M.; Sánchez-Oliver, J.S.; Reino, L.; Herrera, J.M.; Rego, F.; Beja, P.; Moreira, F. A Mediterranean Silent Spring? The Effects of Olive Farming Intensification on Breeding Bird Communities. Agric. Ecosyst. Environ. 2020, 288, 106694.