Chapter 28
Pedoclimatic and Landscape Conditions of Olive Groves in Portugal and Alentejo

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Abstract Olive groves in Alentejo have exponentially increased their extent over the past 30 years through irrigation and technological intensification, including also the use of exogenous breeds and cultivars. This has been facilitated by the implementation of the Alqueva irrigation network. This rapid process of change has permitted overcoming many of the bio-physical limitations of the regional soils and climate. Ultimately, the expansion and intensification of olive groves have focused on the areas with most productive agricultural soils and access to water, with traditional cultivars and farming systems restricted to marginal agricultural areas, now frequently in risk of abandonment. Besides their multiple ecological, social and economic impacts, these rapid changes have also marked their scars upon the traditional rural landscapes. Nonetheless, when looked in further detail, the differentiations between intensive and extensive farming systems, and their sustainability impacts, become fuzzier than originally thought. In such a complex context, the novel concept of "sustainable intensification" might open new opportunities to progress towards more realistic solutions for the future.

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28.1 Introduction

Alentejo, which covers 1/3 of Portuguese mainland, is the Portuguese region where olive groves have expanded more substantially over the past 30 years (Silveira et al., 2018), with 17.5% in surface growth. Circa 48% of agricultural land and 96% of the land devoted to fruit tree growing in Alentejo are nowadays covered by olive groves, summarizing approximately circa 1.35 million olive trees (Silveira et al., 2018). Vegetative growth in the region starts around February–March and ceases in October–November, while flowering occurs in April–June, and fruit maturation is observed from September to December, in most cases. With temperatures sufficiently mild, and thus not acting as a limiting factor, and water availability having proven as a historical deficiency, over 52% of the Portuguese olive groves can now be found in the Alentejo, largely triggered by the recent process of intensification, technological infrastructure implementation and expansion linked to the Alqueva water reservoir, which is located in the eastern part of the region and which is the largest artificial water body in Europe.

28.2 Climate Conditions: Opportunities and Limitations

Mainland Portugal belongs to the temperate climate zone of the Northern Hemisphere, being located at the interface between the semi-humid oceanic (Csb) and semi-arid Mediterranean (Csa) climates, according with the Köppen-Geiger climate classification (Peel et al., 2007).

Regarding the Mediterranean climate where olive trees grow, across Portugal, it is characterized by average annual temperatures that can be lower than 10 °C in some mountainous areas of the northeast, while they can reach values of 18 °C in the southern plains of Baixo Alentejo. In general, a decreasing rainfall gradient exists from west to east and from north to south, with annual mean values ranging between 350 mm and over 2500 mm and with main records in the Mediterranean regions concentrated in the months between October and May.

The region of Alentejo, occupying approximately 30% of Continental Portugal, is fully embedded in a semi-arid Mediterranean (Csa) climate. The bioclimate of the Alentejo region is Mediterranean rain-stational oceanic (Monteiro-Henriques, 2010). In this region, olive groves are spread over four ombrotypes (lower dry, upper dry, lower subhumid, upper subhumid) and two thermotypes (upper thermomediterranean and upper mesomediterranean). Based on the data provided by Monteiro-Henriques (2010), in the area covered by olive groves in 2018, the mean compensated thermicity index is 346.53 (s.d. = 13.74), the annual ombrothermic index is 3.28 (s.d. = 0.52), the mean annual temperature of the coldest month is 9.35 °C (s.d. = 0.50 °C), and the mean annual temperature of the warmest month is 23.76 (s.d. = 0.63).

The rainfall gradients are somehow fractally distributed, and in Alentejo a sub-gradient between 1200 mm and 300 mm of mean annual rainfall can be found from west to east. However, the temporal distribution of rainfall shows higher inter-annual variability as showed by Carvalho and Lourenço (2014) for the regional capital of Évora, with a mean annual value of 680 mm but with records ranging between 320 and 1080 mm. The mean positive rainfall in the areas covered by olive groves in Alentejo is 625.71 mm (standard deviation = 82.00 mm).

Typical challenges related to climate change that increasingly affect olive yields on an annual basis may include milder than standard winters (Kjellström et al., 2007; Viceto et al., 2019); long dry periods (e.g. February to October; Costa et al., 2012); increased frequency, intensity and severity of droughts (Vicente-Serrano et al., 2014; Jenkins & Warren, 2015; Coll et al., 2017; Paulo et al., 2016); longer and earlier heat waves (Parente et al., 2018; Viceto et al., 2019); non-typical rainy conditions during the flowering season and increases in the occurrence of heavy precipitation (Costa et al., 2012; Espírito-Santo et al., 2014; Nunes et al., 2016); and, lastly, higher than expected frequency of periods with atmospheric instability (Viceto et al., 2017).

According to Valverde et al. (2015) permanent crops well adapted to the Mediterranean climate, such as olive trees and vineyards, show less variation in irrigation requirements in face of adverse climate change scenarios. The results obtained by Fraga et al. (2020) pointed out to the negative impacts of changes in the temperatures and rainfall records affecting olive yields in Alentejo in rainfed olive groves, with the adoption of irrigation becoming a key possible adaptation measure, although now largely brought into question, to maintain productivity. The eco-physiological response of olive trees to irrigation is largely positive (Palese et al., 2010; Jiménez-Herrera et al., 2019; García et al., 2020; Gonçalves et al., 2020), allowing the stabilization of its inter-annual productivity which is a marked characteristic of olive trees. However, the optimization of the irrigation schemes is variety dependent, given the differences in the phenology of olive cultivars, and these changes may produce effects not only in the productivity (*stricto* sensu) but also in flowering, fruiting, fruit ripening and also in fruit retention and detachment forces limiting mechanical harvest efficiency (Camposeo et al., 2013).

It is also relevant to consider that the availability and quality of water for irrigation (either through groundwater abstraction or from surface reservoirs) are already shifting as a result of climate change and also of the expansion and intensification of olive groves. This is especially problematic in a region that progressively increases the area of crops that are dependent on extra availability of water.

Thus, under the current intensification trends, water availability is a critical factor, and the growing dependence on this scarce resource raises the level of threat foreseen in the most common business-as-usual scenarios for the future (Costa, 2011).

Although this is partly tackled through the increasing technological control of key production factors, especially water, which is largely linked to the process of intensification, the future resilience against a likely scenario of climate change and desertification is increasingly raising doubts regarding the resilience of currently prevailing models of soil and water use (Fig. 28.1).

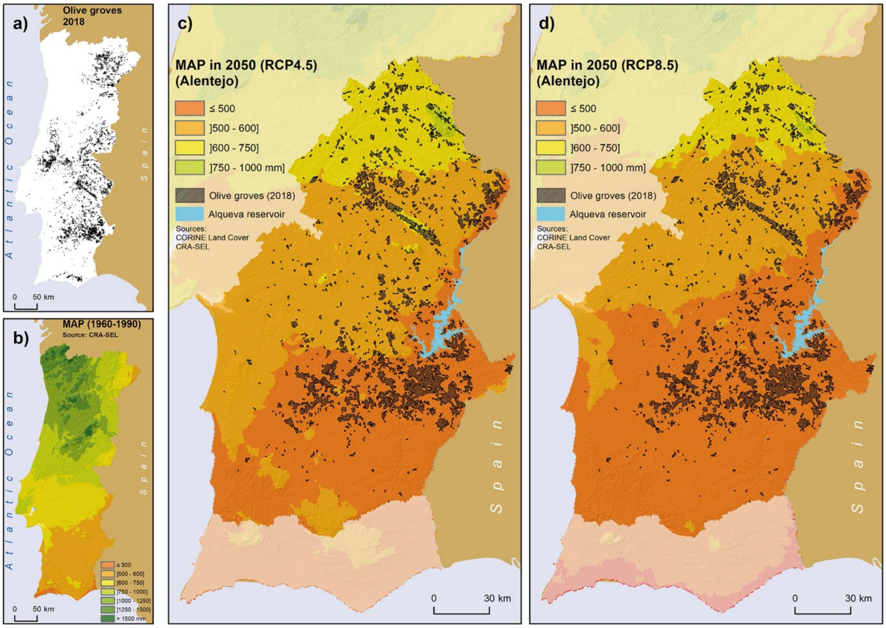

Fig. 28.1 Distribution of olive groves (**a**) and mean annual rainfall records between 1960 and 1990 (**b**) in mainland Portugal and estimated mean annual rainfall (MAP) in 2050 in Alentejo, considering two likely scenarios of climate change: RCP 4.5 (**c**) and RCP 8.5 (**d**). (Source: Climate data have been generated with the ClimateEU v4.63 software package, available at http://tinyurl.com/ClimateEU, based on methodology described by Wang et al., 2016)

28.3 Soil Types and Implications for Olive Grove Farming and Productivity

Soil classes in Portugal differ largely across biogeographic and ecological regions. According to the soil map of Portugal at 1:1.000.000 scale (SROA, 1971), Cambisols, Lithosols and Rankers prevail in the mountainous and humid regions of the north of the country, while Luvisols, Planosols and at time Podzols, Vertisols and also Lithosols are spread across the plains, hills and valleys of Ribatejo and Alentejo regions, in central and southern Portugal, respectively. Overall, most of the Portuguese soils are poor in organic matter. According to Carvalho and Lourenço (2014), 70.4% of the Portuguese soils have contents of less than 1% of organic matter. Low phosphorus content, a determining factor for plant nutrition, is a further limitation of Portuguese soils of relevance. Most of the samples analysed by Arrobas and Coutinho (2002) showed levels of total phosphorus below 1000 mg.kg^{-1}. Such low values imply the need to add fertilizers to turn them into fertile agricultural soils. Approximately 70.2% of the Portuguese soils have moderate cation exchange capacity (between 10 and 20 meq. per 100 g of soil), but only 4.2% exceed this level (Carvalho & Lourenço, 2014).

Most of the soils nationally are acid, with 82.9% having a pH lower than 5.5. Under such conditions, either aluminium (Foy, 1984) or manganese (Foy et al., 1978; Carvalho et al., 2015) toxicity problems may easily occur. Nearly 49.61% of the soils have low levels of permeability, with only 21.21% of the Portuguese soils being more than 50-cm thick, thus also being commonly shallow and rocky (about 45.22% of soils have medium texture, and 40.12% of them have coarse texture according to the spatial data provided by the EPIC-WebGIS data infrastructure). In such context, the most productive ones are generally restricted to the sedimentary terraces of the main rivers.

The main Portuguese olive cultivars are well adapted to such poor soils, with low soil organic matter, as is also the case of most soils around the Mediterranean, which are also largely characterized by also steeper slopes that too frequently result in great rates of soil erosion (Van Walleghem et al., 2011). The cultivation and productivity of olive groves in poorer soils are made possible by their significant genotypic variability, resulting in the traditional breeding of cultivars that are well adapted to the climatic challenges of each area. However, more recent olive tree cultivation, largely intensive and super-intensive, is concentrated in slightly sloping and mainly plain slopes, with richer soils (Fig. 28.2c).

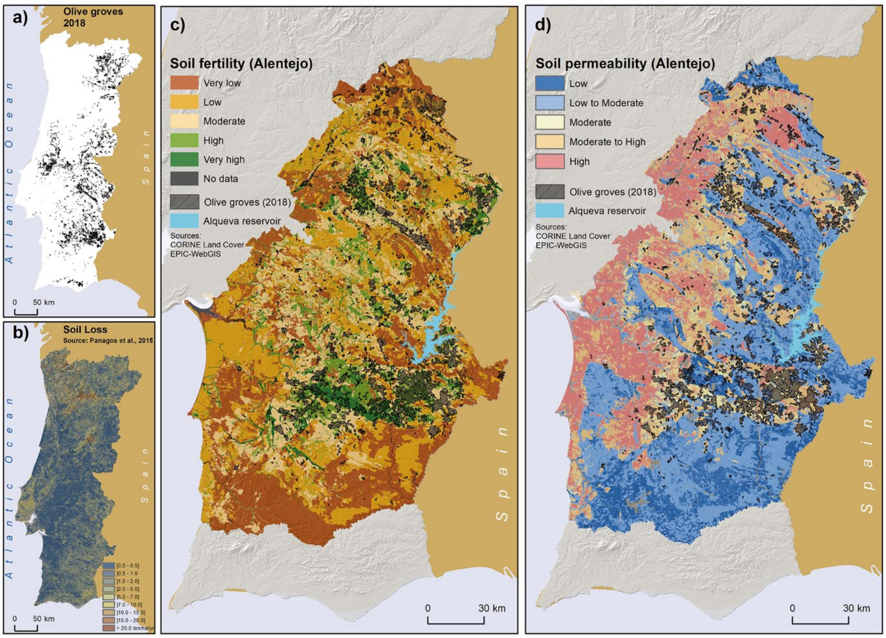

Fig. 28.2 Distribution of olive groves in 2018 (**a**) and soil loss estimates (**b**) in mainland Portugal and distribution of soil fertility (**c**) and soil permeability (**d**) in the Alentejo region. (Data sources: Panagos et al., 2015; CORINE Land Cover 2018; EPIC-Web GIS http://epic-webgis-portugal.isa.ulisboa.pt/; the soil classes were reclassified in soil fertility classes based on CEEM, 1996)

Table 28.1 Percentage of the area covered by olive groves in Alentejo in 2008 and 2018 (calculated upon spatial data from the CORINE LC database in 2008 and 2018), considered by the soil fertility classes defined in the classification by CEEM (1996)

Classes of soil fertility	Alentejo region	Olive groves in 1990		Olive groves in 2018	
		[a]	[b]	[a]	[b]
Very low	31.01	7.61	3.04	5.78	2.51
Low	30.21	17.76	1.24	14.37	1.30
Moderate	22.40	35.19	3.23	35.56	3.51
High	11.27	31.94	8.65	32.91	11.70
Very high	5.12	7.50	15.60	11.38	21.52

[a]Percentage in relation of total area covered by olive groves
[b]Percentage in relation of the total area covered by each soil fertility class

In 1990, 74.63% of olive cultivars were located on soils with moderate to very high fertility rates, with this percentage increasing to 79.85% when considering the impacts of the latest intensive and super-intensive olive groves (Table 28.1). As a result, olive groves currently occupy more than 20% of the most fertile soils in the Alentejo region (Table 28.1).

Among the soil risks associated with olive groves, there are two that should be highlighted in this context: water erosion and salinization/sodification. According to the datasets produced by Panagos et al. for European regions (2014, 2015), mean soil erodibility in the areas covered by olive groves in Alentejo is 0.33 (standard deviation = 1.63), and the mean soil loss by water erosion was estimated in 1.83 tonnes ha-1 per year (standard deviation = 1.12) (Fig. 28.2b), neither of which cannot be nonetheless considered as too high, when considered in their wider Mediterranean context (Panagos et al., 2015). Nonetheless, when looked at a finer scale (Rodríguez Sousa et al., 2021), the potential for soil loss through erosion can be considered as substantial in the olive groves of Alentejo with negative farming conditions, such as eliminating herbaceous cover vegetation, use of fertilizers and inadequate slopes.

Annual rainfall patterns, and its recent changes, affect the spatial and temporal variability in the accumulation of salinity excesses and crusts in the soil, but this process depends mainly on the quality of the water used for irrigation.

The current irrigation standard practices seem to have relatively low risks of soil salinization/sodification, but climate change scenarios point out to a clearly increasingly high level risks of soil salinity in the future (Ramos et al., 2019), a problem that demands a strong attention from both farmers, land managers and the key policy institutions and actors alike.

28.4 Landscape Structure and Dynamics

The recent rise in intensive and super-intensive olive groves in Alentejo is at the core driver of shifting regional agricultural landscapes (Silveira et al., 2018). Olive oil produced under intensive and super-intensive models is frequently a commodity and associated farming systems on which foreign and private financial capital investment, rapid intensification and strong technological inputs are strongly driving the rapid transformation of the traditional regional landscapes that were shaped by extensive and smaller-scale olive groves, Montado silvo-pastoral systems, vineyards and extensive cereals (Muñoz-Rojas & Pinto-Correia, 2019). This is a transition process that is undoubtedly affecting the structure of the supply chain and power relationships in the production of food commodities in this region of Portugal more strongly than in any other areas of the country (Silveira et al., 2018).

Specifically, the main concentration of intensive (and super-intensive) olive groves happens in the area leaning towards the northern edge of the lower Alentejo sub-region, around the district capital of Beja (Fig. 28.3). This is an area characterized by plain slopes with productive soils and extensively cultivated landscapes that were traditionally occupied by rainfed crops, mainly cereals (Pelúcio-Pimenta, 2014).

It is important to acknowledge that, in addition to the availability of water arising from the construction of the Alqueva reservoir (the dam was completed in 2002), other key bio-physical and ecological drivers exist that have clearly determined the magnitude and spatial distribution of the recent expansion of intensive and super-intensive olive groves in the region (Neves et al., 2013; Reis, 2014). These drivers include the location of lower slopes and related rich agricultural soils, the strict prohibition for new olive groves to substitute other traditional land-uses and landscape elements that are effectively protected by law (e.g. Holm Oaks and Cork

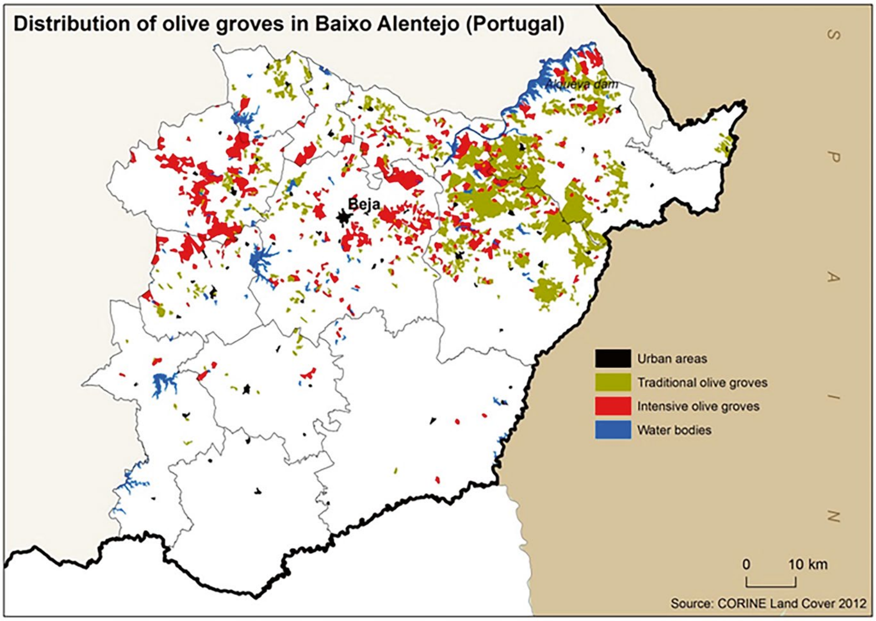

Fig. 28.3 Spatial distribution of olive groves, distinguishing between intensive and traditional olive groves in the lower Alentejo sub-region of Portugal. (Based on data by produced by co-author Nuno Guiomar)

Oaks) and the concentration of intensive and super-intensive groves on certain strains and cultivars of olive trees, such as Arbequina and Picual, both original from NE Spain.

Despite of the recent expansion of intensive and super-intensive of olive groves in the region, a complex landscape mosaic of traditional (extensive) and intensive olive groves is still found occupying large areas, especially in the northern edge of Alentejo, with poorer soils and more rugged terrain.

In addition, nature and landscape conservation designations are frequently indicated as key territorial factors influencing changes in farming systems, in this case by limiting the expansion of intensive olive groves. In Alentejo, these (e.g. the Parque Natural do Vale do Guadiana, to the east of the region and neighbouring Andalusia, in Spain) are located in areas with the poorest soils and bio-physical conditions for intensive agriculture. Consequently, this is also where the main opportunities may be identified for adding value to traditional extensive crops, such as olives, a target that could be achieved by implementing novel rural development strategies and action plans underpinned by what has been generically termed as "territorial agriculture" (Cairol et al., 2009).

We also find examples of alternative funding schemes that are intended for maintaining traditional olive groves and their associated landscapes. These are still largely underdeveloped in the region but include green capital investment funds of international origin, payment for ecosystem services schemes and innovation projects (e.g. SmartFarmers) funded under associations for the protection of rural heritage and landscape such as ADPM, operating in Mértola (http://adpm.pt/).

Although they are still minor in the wider context of the region and sector, examples of success are scattered around the region, many of which comprise mid-range farms (10–100 ha) which have managed to set sustainability targets successfully. However, it is pertinent to indicate that many of these initiatives are foreign in their origin, detracting from the potential for endogenous development in the region. It is gradually becoming increasingly clearer that only a certain number the olive grove farms and businesses in the region manage to deliver multiple functions and services besides olive oil production, including the production of table olives, livestock (mainly sheep) grazing and tourism and landscape-ecological functions.

Despite this having been traditionally thought of as restricted to extensive production systems with regional or local olive strains and cultivars, lately some very few and yet innovative farmers have managed to implement sustainable farming systems that while being intensive, or even super-intensive, end up becoming certified as organic and even as bio-dynamic. In such a complex territorial and agronomic context, the traditional equation under which local cultivars plus extensive farming systems and landscapes equals higher sustainability standards, while exogenous breeds plus intensive farming systems equals less sustainable landscapes, becomes fuzzier. Perhaps the focus should shift towards testing the role to be potentially played by sustainable intensification (Buckwell et al., 2014) in creating novel olive landscapes in the region that are economically successful while also help tackle the imminent threats of climate change, soil degradation, landscape simplification and biodiversity loss.

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