Environmental challenges of the intensive woody crops: the case of super high-density olive groves

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Abstract

Super high-density olive groves (> 800 trees ha^{-1}) are rapidly expanding in olive oil producer countries, which entails a strong modification of the olive growing system with important agronomic, economic, sociocultural, and environmental consequences. Among them, the latter is particularly unknown. The aim of this paper is to bring the attention on the environmental impacts of super high-density olive groves, by systematically reviewing the current evidence and identifying knowledge gaps yet to be filled. As a result, we can argue that new super high-density olive plantations reduce habitat heterogeneity and complexity, and the younger trees of these plantations impoverish

habitat quality for farmland biodiversity. In addition, the high input use (e.g. phytosanitary treatments, fertilisers and water supply) may entail ecological impacts as well (e.g. freshwater contamination). Therefore, we conclude that i) new highly intensive olive groves should be limited to areas with lower ecological value; ii) consumers should have more information concerning how is produced the olive oil they buy, including the environmental impacts produced; iii) agricultural policies should be reformulated following the provider-gets principle; iv) input use (fertilizers, pesticides, water, etc.) should continue optimising to reduce the environmental impact; and finally, v) more research is necessary to foster decisions based on science.

Keywords: agricultural intensification; environmental sustainability; farmland biodiversity; *Olea europea*; woody crops.

1. Introduction

The olive tree (*Olea europea*) is an emblematic woody crop in the Mediterranean basin from ancient times, being currently one of the most important features of the Mediterranean agricultural landscape lined with the culture and economy of the region (Lomuou and Giourga, 2003). However, these landscapes have undergone substantial land-use changes in the last centuries, from a crop integrated in the environment to an intensive monoculture (Infante-Amate et al., 2016). More recently, the traditional olive groves characterized by larger old trees (easily over 100 years-old) with low tree density (< 100 trees ha^{-1}), rainfed and manual harvest is being replaced by younger smaller trees at higher densities (>300 trees ha^{-1}), drip-irrigated, with high phytosanitary and fertilisers inputs and highly-mechanised harvesting (Martínez-Sastre et al., 2017). The most prominent case is the super high-density olive groves, also known as super-intensive or hedgerow olive groves, which are typically irrigated and have densities higher than 800 trees ha^{-1} (Díez et al., 2016). This system shows high levels of profitability due to both decreasing production costs (especially labour-related) due to an almost full mechanization (including harvesting, pruning, and phytosanitary treatments) and a significant increase of per-hectare yield due to a higher radiation interception by olive canopies formed by many smaller trees (Barranco et al., 2017; AEMO, 2020)[1]. Moreover, in the smaller trees the rate of leaves and vegetative structures most directly involved in fruiting is higher than in larger olive trees, in which a higher energy is destinated to woody tissues, thus making many smaller trees more efficient than few larger ones in the same area (Lo Bianco et al., 2021). This system is the most productive and it can produce oil at competitive prices to cope with the increasing global demand (Rallo et al., 2013). However, the super high-density olive groves have some limitations, such as the difficulty of its implementation in areas with steep slope and scarcity of water resources, and only few cultivars (e.g. Arbequina and its hybrids) can be used with the subsequent loss of local genotypes (Lo Bianco et al., 2021). In addition, unlike for olive groves with lower densities, super high-density olive groves require the renewal of the plantation (i.e. the uprooting and planting of the new trees) every 20 years approximately.

While super high-density olive groves still account for 4.3% of the olive groves area worldwide (i.e. 0.5 million hectares) (Vilar et al., 2017), a rapid expansion of this system is taking place around the Mediterranean basin, including Spain, Portugal, Greek, Italy, Israel, Tunisia, and Morocco (e.g. Russo et al., 2015; Kazes et al., 2020; Morgado et al., 2020). For instance, in Andalusia (Southern Spain), the primary olive oil-producing region in the World, the area devoted to this olive groves system is increasing at rates over 25% per year (Junta de Andalucía, 2019). This phenomenon is motivated by a well-developed cropping technology (e.g. with ready-to-use specialized machinery already

[1] For example, AEMO (2020) estimates per-kg of olive oil production costs of €1.49 and €2.54 for super high-density and traditional mechanised rainfed olive groves respectively.

developed), diminishing direct payments and a general declining trend in olive oil prices (thus fostering competitive farms at these lower prices) (Gómez-Limón and Parras, 2017). In effect, entrepreneurial choices of planting super high-density olive groves are basically guided by profit maximising objectives, basically overcoming typical cultural barriers to replacing less productive olive groves (i.e. traditional, aged olive groves). The other important barrier relates to financial constraints; the fact that high financial resources are required at the beginning of the investment period often implies that only large farms with availability of these resources can actually plant these new olive groves.

In spite of the remarkable expansion of super high-density olive groves, the ecological and socio-economic consequences of this transformation have been poorly studied to date. In this context, the aim of this paper is to discuss the plausible environmental consequences of the expansion of super high-density olive groves.

2. Environmental consequences

The expansion of super high-density olive groves represents an important landscape change with consequences on the ecosystem services never evidenced before. In some cases, older traditional olive groves have been replaced by young super high-density olives, entailing a loss of habitat heterogeneity and complexity, which has been identified as one of the main causes of biodiversity loss in agroecosystems (Fahrig et al., 2011). The semi-forestry structure of traditional olives groves provides to this agroecosystem a strong potential for biodiversity conservation (Martínez-Núñez et al., 2020). For instance, olive groves can harbour 165 bird species and 549 herb species (Rey et al., 2019) and support a complex arthropods structure when natural grass occurs (Castro et al., 2021). Moreover, the old and large trees (up to hundreds of years old) that characterise the traditional olive groves have a more complex morphology (two-three trunks with many hollows and cavities), which serves as a high-quality habitat for nesting, winter, and shelter for arthropods, reptiles, small mammals, and birds (Lomuou and Giourga, 2003; Carpio et al., 2017; Kazes et al., 2020). Recently, Morgado et al. (2020) showed that cavity-nester insectivores' birds were the most affected group of the shift towards super high-density systems. Interestingly, European rabbits (*Oryctolagus cuniculus*) usually built their warrens under aged olives trees, and eventually favouring the recent colonization of traditional olive groves by the Iberian lynx (*Lynx pardinus*) (Garrote et al., 2020).

On the other hand, since new olives groves are often planted in arable land (Büttner and Kosztra, 2011), the proliferation of super high-density olive groves could reduce the habitat availability of steppe birds and other farmland birds associated to more open agricultural landscapes (Contreras et al., 2018). Besides, night mechanised harvesting of the hedgerow olive groves can kill an important number of songbirds from central and northern Europe which winter in the Mediterranean basin coinciding with the harvest season (da Silva and Mata, 2019). As a consequence, the night harvesting of olives is now forbidden in some Mediterranean regions (e.g. Andalusia) trying to minimise the impacts as they are discovered.

The establishment of super high-density olive groves also implies a more intensive agrochemicals use (namely fertilisers and biocides) per area. For instance, up to 129 kg N ha^{-1} are applied in super-high density olive groves, whereas only 45-52 kg N ha^{-1} are applied in traditional conventional ones (Romero-Gámez et al., 2017), and 16 times more Dimethoate are used annually in super-high density olive groves (0.8 kg ha^{-1}) than in traditional systems (0.05 kg ha^{-1}) (Abdallah et al., 2021). It is arguable, however, that its -habitually- more highly-professionalised management may result in a lower risk of pollutant emissions in this sense. Notwithstanding, this may refer to fertiliser use, for which doses may be more suitably applied (in time and quantity, using fertigation) compared to traditional olive groves systems. Yet, for the case of biocides, the total amount dramatically increases (Abdallah et al., 2021), negatively impacting biodiversity. This may be behind Carpio et al. (2016)'s results, who prove a negative relationship between irrigated intensive olive groves and amphibian species richness at a regional scale in Southern Spain.

Paradoxically, most of the super high-density olive groves have been planting in the drier and warmer areas (Mairech et al., 2020) in which a higher irrigation amount is required. In this sense, year doses usually fall within the 2,500-3,600 m^3 ha^{-1} interval (Romero-Gámez et al., 2017; Abdallah et al., 2021), whereas rarely they exceed moderate to low doses of 1,500 m^3 ha^{-1} in irrigated olive groves with lower tree densities (Gómez-Limón et al., 2013). In many Mediterranean regions, two intensification trends are occurring simultaneously, which are conversion of rainfed to irrigated olive groves and increasing tree density, which may be rising pressures on water resources. This is particularly worsening due to climate change, as the Mediterranean basin is already suffering serious consequences of the global warming (Cramer et al., 2018). These phenomena will substantially reduce freshwater availability (by 2–15% for 2 °C of warming) and water reservoirs will be critically low (Cramer et al., 2018), which means that it can endanger the crop irrigation in further dry seasons. Indeed, this demand for water may be putting at risk aquifers and surface water bodies are being over-exploited (Gómez-Limón et al., 2012). In addition, energy used to irrigate has an important weight in the environmental impacts of olive groves (Romero-Gámez et al., 2017), and an inadequate irrigation may have also negative consequences such as greater soil compaction and erosion (Rodríguez Sousa et al., 2019).

Finally, traditional olive plantations have also aesthetic, cultural, geographical, historical, and ethnological associated values (Ojeda-Rivera et al., 2018). Indeed, the "Olive Grove

Landscapes of Andalusia" has been included in the list of candidates to become part of the UNESCO World Heritage List (Ref: 6169) under the typology of Cultural Landscape. For these reasons, the sustainability of olive groves should be evaluated under the multifunctional agriculture approach, considering not only the profitability, but also their environmental, social, and cultural services (Rodríguez Sousa et al., 2020). Nevertheless, most of these biodiversity-related, social, and cultural services are in jeopardy with the significant expansion of super high-density olive growing where a complete replacement of aged trees occurs and the trees will be replaced by new ones every 20 years. This intensification promotes the conversion of multi-functional landscapes into simple, more productive and mono-functional ones (Martínez-Sastre et al., 2017), thus deteriorating the human-agroecosystem interplay such us loss of traditional ecological knowledge, local cultivars, traditional landscapes and lower labour requirements.

3. Final considerations for a "greener" future of the intensive olive groves

Some authors (e.g. Russo et al., 2015; Mairech et al., 2020; Abdallah et al., 2021) together with sectoral stakeholders (e.g. olive oil companies and olive growers associations) claim the environmental sustainability of super high-density olive groves in comparison with traditional ones, arguing that they show a more efficient water use; a higher soil organic carbon sequestration particularly when pruning residues are incorporated and irrigation is applied in dry areas (Mairech et al., 2020); a lower evaporation due to a higher ground cover; and a reduction of drainage owing to an increase in root biomass and density. What is more, due to their higher yield per area, super high-density olive groves can have lower environmental impacts per olives tonne (Pellegrini et al., 2016; Abdallah et al., 2021), thus making them more suitable if a land-sparing strategy (i.e. that consisted of separating land for conservation from land for crops) is promoted (Phalan et al., 2011). Nevertheless, super high-density irrigated olive system has the largest environmental impacts per area caused by the high level of mechanization, and the larger use of water, fertilizers, and pesticides (Romero-Gámez et al., 2017). Therefore, the traditional olive groves with lower densities and lower agrochemical inputs may offer a better trade-off between economic and environmental concerns, that is, a greater eco-efficiency (Gómez-Limón et al., 2012). Moreover, the traditional olive groves with not fully-mechanised harvesting could be more suitable to sustain the economic activity of the rural population (e.g. due to higher labour requirements) (Rallo et al., 2013; Colombo et al., 2020), which could also offer a better socio-cultural sustainability (Villanueva and Gómez-Limón, 2017). According to the exposed trade-off between socio-environmental cost and economical benefits when comparing traditional low density and super high-density olive orchards, intensive olive groves with intermediate tree density (e.g. lower than 400 trees/ha) may represent an adequate balance between economic, socio-cultural, and environmental functions.

In the light of these considerations, the fast current expansion of the area devoted to super high-density olive groves should be revised not only from the perspective of the short-term productivity but also including ecosystem services and socio-cultural sustainability into the trade-off equation. Here we propose five main lines of action: i) the implementation of new super high-density olive groves should be carefully analysed before implanted in areas of special ecological interest, such as Important Bird and Biodiversity Areas (IBAs) and High Nature Value (HNV) farmlands (land-sparing strategy); ii) since there is a wide variety of olive growing systems with different environmental impacts, the development of an scale measuring the sustainability of oil production could improve the competitiveness of the oil produced in traditional olive groves (a subsequent certification may be implemented afterwards to raise consumers' awareness, as suggested by Salazar-Ordóñez et al., 2021), which would let consumers make decisions on the bases of a scale of eco-friendly systems; iii) the implementation of some compensatory measures in super high-density olive groves (land-sharing strategy) such as herbaceous cover crops (e.g. Carpio et al., 2017), keeping some isolated old olive trees, natural vegetation patches, and hedges (e.g. Castro-Caro et al., 2014), incorporate pruning residuals (Mairech et al., 2020), or reducing excessive tillage (Vicente-Vicente et al., 2016) should be promoted to boost biological diversity and carbon sequestration while often negligibly affecting farm productivity (these compensatory practices are suggested -e.g. by Rescia et al., (2017) to be used as criteria for funding farmers subsidies, and basically stems from the provider-gets principle (Pe'er et al., 2019); iv) the optimisation of input use, including the use of regulated deficit irrigation (Fernández et al., 2020; Vita Serman et al., 2021) and recycled wastewater and saline water (Regni et al., 2019), the use of renewable energy (Todde et al., 2019), and an efficient pesticides use, hence eventually reducing the environmental impact of this type of olive groves; and v) the lack of knowledge concerning the environmental, economic, and socio-cultural impacts of the expansion of super high-density olive groves makes the development of evidence-based policy difficult, and therefore, research efforts -particularly fieldworks- are necessary to boost the knowledge concerning impacts and solutions to ensure the effectiveness of conservation actions.

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