The green granary of the Empire? Insights into olive agroforestry in Sicily (Italy) from the Roman past and the present

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Highlights

- *Olive agroforestry of the Roman past is an example of a circular economy relying on internal inputs.*
- *Human design of the ecological space is related to adaptation strategies and natural responses.*
- *The ecological memory of local practices is key to ensure longevity of olive agroforestry systems.*

Abstract

Groves with ancient olive trees (*Olea europaea* L.) could be considered remnants of old agroforestry systems. Anything but static, these agro-ecosystems have undergone drastic transformational processes in Mediterranean countries, where abandonment or intensification have been observed far more than continuity, expansion or renaissance, leading to environmental degradation of rural areas.

Starting from this assumption and inspired by historical ecology and historical geography, we consider centuries-old olive trees as living archives of human-nature interactions and are thus proxies of past agroforestry. Our aim is to better understand what has driven dynamics of change and persistence, happening today as well as in the past. We first travel backward in time, looking at the ecology of land management systems during the Roman period (*ca* 200 BC-400 AD) and late Antiquity (*ca* AD 400-700). The special focus is the island of Sicily, the granary of the Empire, well known as a region where cereal production increased around the latifundia economy. We reconstruct the diversity of land tenure and the ecology of such complex systems, by combining records from Roman agriculturalists and palaeoenvironmental evidence of the past. We then zoom out, to look at today's management practices in olive groves, thus drawing a parallel between Antiquity and today. Our work provides valuable insights into the correlation between certain organisation models, ecological strategies and adaptation capacity over the long term, clearly showing that human and nature dimensions are interconnected. Such entanglement may be a key element for ensuring these agroecosystems resilience. All elements that may contribute to the re-invention of sustainable forms of their management, for the present and the future.

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Introduction

Mediterranean agroforestry is a complex system made of a variety of vegetation types and land usages, as a result of millennial scale human-nature interactions (Blondel 2006; Eichhorn *et al.*, 2006), with trees intercropped in a wide range of ways. These systems are significantly impacted by drastic transformational processes, where either abandonment or intensification that lead to environmental degradation have been more widespread than continuity, preservation or renaissance trends (Cramer *et al.*, 2008 Munroe *et al.*, 2013; Nerlich *et al.*, 2013; Burriel *et al.*, 2017; Fernández-Manjarrés *et al.*, 2018; Rois-Díaz *et al.*, 2018; Guillerme *et al.*, 2020; Morgado *et al.*, 2020; Wolpert *et al.*, 2020;

Karmiris *et al.*, 2022). Today agroforestry systems persist only in rural marginal areas, since due to their adverse geomorphological features (*i.e.,* steep slopes and dry environment) it is nearly impossible to practise intensive agriculture or monoculture. Another key feature of agroforestry systems is their multifunctionality: trees have traditionally served several purposes in the agrarian economy, such as the production of food, fodder and wood, as a very important ecological value supporting the biological diversity of habitats, species, and genotypes, maintaining soil quality while reducing erosion, improving water balance and air quality, lowering the risk of fires (Brunori *et al.*, 2020). Agroforestry could be considered a traditional form of land use and, for this reason, it is always associated with a rooted body of tacit knowledge and ecological memory, passed down from generation to generation in the local communities, which has guaranteed the persistence of these agroecological systems over the centuries. Given that the aim of agroforestry is the integration of environmental, social, and economic benefits (FAO, 2013), global interest in agroforestry practices has increased significantly in the past 50 years (Brunori *et al.*, 2020).

The olive tree (*Olea europaea* L.) is widely present in Mediterranean agroforestry systems (Loumou and Giourga, 2003). In a typical agroforestry model, the olive is cultivated in association with horticultural and arboreal crops; in combination with forage and grain species, or with surrounding forest trees (Lelle and Gold, 1994; Cullotta *et al.*, 1999; Eichhorn *et al.*, 2006; Barbera and Cullotta, 2014). Olive-based agroforestry systems are characterised by traditional and standard structural traits such as low planting density, low agronomic inputs, absence of irrigation, reduced degree of mechanisation, and the presence of ancient olive trees (Brunori *et al.*, 2020).

On the island of Sicily, the presence of very old trees (even several centuries old) indicates that the olive has been a widespread plant since prehistory, as an endemic species in its wild variety capable of survival in refugia during the Last Glacial Maximum (Langgut *et al.*, 2019). The high environmental heterogeneity of the island has led to the historical development of very diverse olive-cultivating systems (Ferrara and Wästfelt, 2021). The typical Sicilian agroforestry model lies at the interface between agriculture and silvicultural practices. These are intercropped systems where the fruit trees play a central ecological role, and these could have been not only olive, but also carob, almond, hazelnut and chestnut. Furthermore, olive trees are often found in hilly zones, associated with grasses and shrub species regularly grazed after fruit harvesting (autumn) and, to a lesser extent, during summer (Cullotta *et al.* 1999; Rühl *et al.*, 2011). Unfortunately, today we witness to severe ecological degradation trends in Sicily, as it is happening in the whole southern Europe, marked by huge changes in the historical landscapes, from polyculture and agroforestry systems to monoculture or, even worse and more widespread, rural abandonment (Testa *et al.*, 2015; Baiamonte *et al.*, 2015). The ancient olive trees still present in the landscape, thanks to their longevity and fixed location, are remnants of past agroforestry systems. Therefore, these trees are not only a long-lasting biocultural heritage, but they represent important and precious historical archives in rapidly changing landscapes, which provide the unique scientific opportunity to study long term human-nature dynamics over centuries and even millennia (Ferrara *et al.*, 2020).

Starting from these assumptions and adopting a cross-disciplinary methodological approach inspired by historical geography and historical ecology, we look at centuries-old olive trees as *living archives of human-nature interactions* (Grove and Rackham, 2001; Taxel, 2021), wondering if a diachronic examination of the ecology of these systems may provide useful insights for their present and future management. In historical geography, the location and spatial configurations of land use activities are key to the interpretation of past dynamics, since they reflect functional and socio-cultural investments made by different societies through history (Helmfrid, 2000). Historical ecology focuses on the ecological dimension of these land use spatial dynamics over the long term (Crumley, 2019). In this paper we specifically read the spatiality of land use practices as a function itself (Howarth, 2008; Jupiter, 2020), driven by the human intentional design of an ecological space which should be as much functional as possible for livelihood purposes. This is an ecological space shaped not only by least-cost related considerations (von Thünen in Chisholm, 1962), but deeply transformed by (human) adaptation practices and natural responses (Ferrara and Ingemark, 2023). A parallel between olive agroforestry in Antiquity and today is drawn, by first reconstructing the diversity of land tenure and the ecology of olive agrosystems during the Roman past, and then coming back in time to current management practices. Our work provides valuable insights into the correlation between certain organisation models in agroecosystems, ecological strategies and adaptation capacity over the long term, which proves that the human and nature dimensions are interconnected. Such entanglement may be a potential key element for ensuring the longevity of these agroecosystems. All elements that may contribute to the re-invention of sustainable forms of their management, for the present and the future.

Materials and Methods

Methodologically, our diachronic look at the ecological space drew a parallel between the olive agroforestry systems in Antiquity and contemporary Sicily, adopting a perspective that use intangible concepts from the natural sciences (in this case, the modern concept of agroforestry and agroecology) to open up and extract new knowledge from ancient texts of the Roman tradition.

Zoom into the past – Antiquity and late Antiquity

To reconstruct the ecological space of agroforestry systems in Antiquity and late Antiquity Sicily, we zoomed into the temporal period that goes from the 3rd century BC to the 9th century AD (Figure 1), looking at land tenure and land management systems of the countryside.

The reason why we chose to focus on this historical period is twofold: i) Antiquity and late Antiquity represent the longest period of external homogeneous political and cultural presence on the island (a period covering an overall time span of nearly 1 millennium); ii) quite famous for the first significant increase of cereal production in the island, with its monoculture latifundia and villas.

The data we used are primary written sources from that time and palaeoevidence from ancient pollen. The scope was first to understand and reconstruct the ecology of the agro-ecosystems from the descriptions provided in the ancient texts and then see if it would be possible to cross-validate this information with other types of evidence, namely palaeoenvironmental reconstructions of past land use.

We extracted information on the ecology of agroforestry systems during Antiquity and late Antiquity in the Roman agricultural handbooks written by Cato the Elder (234-149 BC), Varro (116-27 BC), Columella (fl. AD 50), Gargilius Martialis (AD 210?-260), Palladius (c. mid-5th c. AD), and in the collection *Geoponika* (*ca.* 9th c. AD). Information useful to the reconstruction of the agroforestry ecological space of the period have been also found in the encyclopaedia *Historia naturalis* written by Pliny the Elder (AD 23/4-79), the law codex *Digesta* (533 AD), and the late collection of poetry of earlier dates *Anthologia Palatina* (*ca*. 10th c. AD). The work of the two poets Lucretius (94-55/51 BC) and Virgil (70-19 BC) have been reviewed as well.

Commencing with the Republican author Cato the Elder and continuing throughout history until the Late Roman Palladius, the Roman agricultural works were grounded in practical farming experience (White, 1970; Marzano, 2021). This does not mean that we can approach these sources uncritically and without a certain degree of caution (see discussions in Hollander, 2018; Roselaar, 2021). Indeed, it has been pointed out that they were imbued with ideological values as they were aimed at a land-owning elite running large-scale and slave-run estates (Marzano, 2021). The different works have been perceived in diverse ways – in particular Cato's work, which has been described as a haphazard collection of advice – but nevertheless these works provide invaluable information about Roman agriculture, horticulture and viticulture since they are very rich technical manuals on plants and trees, built on experiential and tacit knowledge, as well as previous agronomic traditions (Greek and Punic); thus showing how agriculture was already integrated in a Mediterranean system of exchange of knowledge and best practices.

Works on the Roman agrarian structures in Mediterranean rural areas is not new (for a detailed overview and critical approaches cfr. Barker and Lloyd, 1991). The most probable reality was a complex mosaic of different rural sites co-existing at once, their slow progressive transformations into forms of increasing specialised and market-oriented agriculture, together with the perdurance, not only in small farms, of subsistence agriculture as a local response to specific conditions of spatial and social organisation. Nonetheless, few studies have looked at the ecology of these agricultural systems as described by the ancient authors (Mattingly, 1996; Sallares, 2007). We reviewed this body of written evidence using the technique of close reading (Barry, 2010), in which the focus is equally put on the author's writing technique, the content and structure of the text, the different levels of meaning communicated. We complemented the close reading of primary sources with results of previous research on Roman agricultural authors (Reay, 2005; Dueck, 2011; Reitz, 2013; Doody, 2013; Nelsestuen, 2015; Doody, 2017; Hollander, 2018), land tenure regimes (Thommen, 2012; Launaro, 2015; Christie, 2016; Marcone, 2019; Colognesi, 2021), land management practices (Frayn, 1979; Brun, 2003; Brun, 2004; Kehoe, 2008; Thibodeau, 2011) and regional differences (Bowman and Wilson, 2013).

Archaeological and archaeobotanical evidence provides useful information to understand and reconstruct land use practices (Alonso, 2005; Rathbone, 2008; Bowes *et al.* 2011; Ghisleni *et al.*, 2011; Bowman and Wilson, 2013; Vaccaro *et al.*, 2013; Bowes *et al.*, 2015; Michelangeli *et al.*, 2022), above all when combined with written sources (Pagnoux, 2019). To have the possibility to focus precisely on the area of Sicily proverbial known as the Granary of the Roman Empire, we compiled and reviewed all the published evidence from the analysis of ancient pollen collected in the archaeological sites Villa Romana del Casale (Montecchi and Mercuri, 2018; Mercuri *et al.*, 2019) and Philosophiana (Mercuri *et al.*, 2019), as well as from the palaeolake Lago di Pergusa (Sadori *et al.*, 2013; Sadori *et al.*, 2016) (Figure 2).

The sites Villa Romana del Casale, Philosophiana and Pergusa Lake are very close to each other. Villa Romana del Casale was built in the 4th century AD, on a previous *villa rustica* (a countryside settlement) dated from between the 1st and the 3rd century AD. Philosophiana is located approximately 6 km south-west of the Villa, and it has been identified as a *statio* or *mansio* (*i.e.*, a stopping place), mentioned also in the Itinerarium Antonini (3rd-4th c. AD) (Mercuri *et al.*, 2019). The palaeolake Pergusa is located almost in the centre of Sicily, at 667 metres above sea level. It is an endorheic lake fed solely by rainfall and groundwater, with a catchment area of Pliocene marine deposits (Sadori *et al.*, 2013; Sadori *et al.*, 2016).

Zoom back to the present

Once we zoom into the Roman period, we zoom out and back to current management practices. To reconstruct the ecology of olive agrosystems today we compiled data co-produced with locals and collected within the EU LIFE project Olive4Climate. We looked at present-day correlations between the diversity of man-

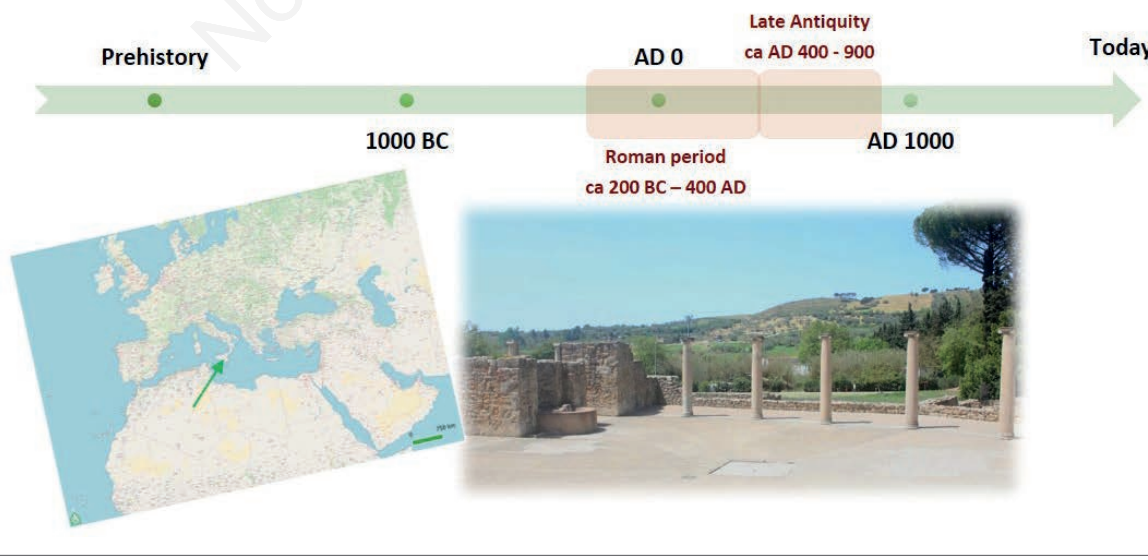

Figure 1. Timeline with chronology of the Roman period and late Antiquity in Sicily.

agement practices and carbon sequestration efficiency in three selected case study areas. The aim was to evaluate the balance, in terms of biomass and carbon sequestration, in different olive systems: traditional agroforestry/intercropping groves, intensive (up to 400 trees/ha) and superintensive (up to 2000 trees/ha) orchards. The biomass of the orchards was modelled and calculated both in the above- and below-ground tree components (Trotta *et al.*, 2018; Trotta, 2019). The dry matter of the vegetation removed by pruning was evaluated (Sala *et al.*, 2021; Brunori *et al.*, 2019). The enlargement of the trunk cross sectional area, the dry matter accumulated in the cover crop and the root biomass were measured (Brunori *et al.*, 2019; Mousavi *et al.*, 2019; Sala *et al.*, 2019).

Results

From Roman written sources

The diversity of land tenure systems showed that the villa economy was in reality a complex system, made of different-sized holdings with various management regimes and ownership rights (*i.e.*, share-cropping, free peasantry, *colonus*, *servus quasi colonus, vilicus*, *etc*.). Even though the slave mode of production was dominant, the social relationships were many and diverse, as were the types of production and relationships with the markets (Colognesi, 2021; Barker and Lloyd, 1991). Our look at the ecology of this complex land tenure system has elucidated three key elements (Figure 3): i) the Roman agroforestry model was based on a functional use of space; ii) managed according to principles of agroecology; iii) such a model was an authentic circular system, based on the flexible use and re-use of internal resources, following a back-up plan, which was a pure ecological strategy to solve livelihood and economic problems by ensuring yield if some failed while complementing the diet.

The Roman agroforestry model: a functional space managed according to agroecology

Written sources give the picture of an integrated agroforestry model, based on the functional use of space. Here olive trees were often planted according to the multi-cyclical interaction dynamics between plants (intercropping or poly-cropping, as it is often termed in the works on Antiquity, cf. Horden and Purcell, 2000; Kehoe, 2008) and between plants and animals.

A functional space

Roman sources seem to suggest that the olive trees were planted in specific patterns to accommodate other crops. The recurrent pattern may well be the olive trees protecting and/or giving support to some other crop. Columella states clearly that olive trees must be planted at wide intervals, not only to allow their crown to expand with age, but also to have the space to grow other plants in between (Columella, *De re rustica*, 5.10.5; Columella, *De re rustica*, 5.8.7; Pliny the Elder, *Historia naturalis*, 17.19.93–94). It is immediately clear how the spatial dimension becomes a key functional element to improve the wealth of the whole agro-ecosystems. The first spatial function that olive trees can perform is to mark boundaries (Lucretius, *De rerum natura*, 5.1373–1378) or at the edge of vine beds (Palladius, *Opus agriculturae*, 3.18.1). However, in some cases, an olive grove could be spatially surrounded by other tree varieties thought to be more useful than olive, as defensive borders around the farm (such as elms or poplars, cfr. Cato the Elder and Varro, *De agricultura*, 6.1–6.3; Varro, *De re rustica*, 1.24.3; or pines, cypresses and elms, cfr. Varro, *De re rustica*, 1.15.1). The Roman olive grove was integrated in an ecological system with other trees as well. In any case, equal spatial attention given to the central areas of a farm must also be given to the outer areas (Palladius, *Opus agriculturae*, 1.6.6), and this testified as to how Romans had understood and seen the potential of spatial logics in agriculture and land management. The focus on boundaries continues also with warning against 'bad'

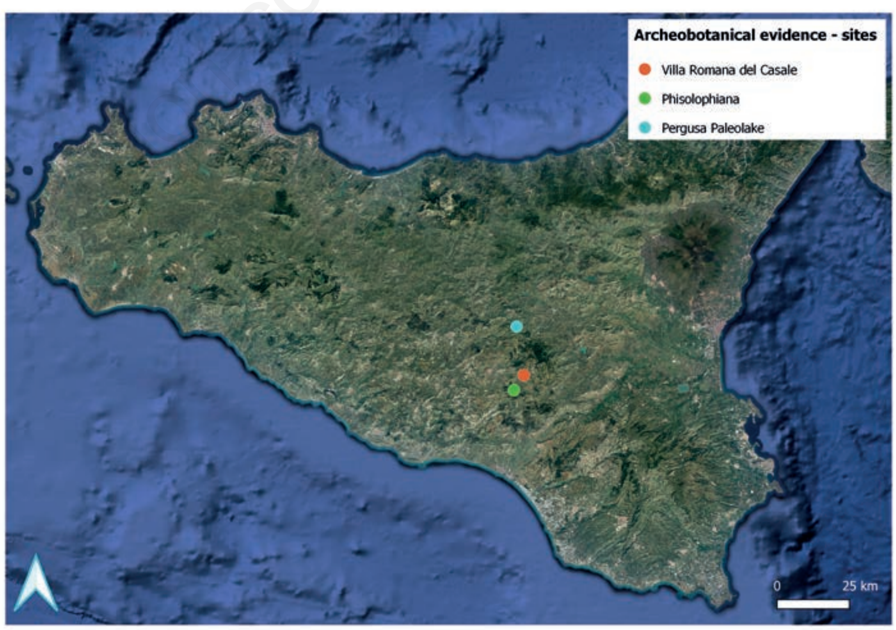

Figure 2. Map of the location of the two archaeological sites (Villa Romana del Casale and Philosophiana) and the palaeolake (Pergusa) with published pollen data.

plant associations which worsen competition, as in the case of the presence of a neighbour oak grove or a great quantity of walnut trees near the farm boundary (Varro, *De re rustica*, 1.16.6). But the reason why trees are kept as borders is not only to mark boundaries, but to ensure the right amount of leaves for the animals operating in the farm (Cato the Elder and Varro, *De agricultura*, 5.8), so to save the dry fodder as storage for the winter (Cato the Elder and Varro, *De agricultura*, 30; Columella, *De re rustica*, 6.3.6–7).

Intercropping: the olive tree and other plants

In the agroforestry functional space, the olive tree was intercropped with vines (*Anthologia Palatina*, 9.130; Pliny the Elder, *Historia naturalis,* 17.35.199–200) and fig trees (Cato the Elder and Varro, *De agricultura*, 50.2), among other fruit trees (Lucretius, *De rerum natura*, 5.1373–1378). Cereals (Columella, *De re rustica*, 2.9.5–6; Palladius, *Opus agriculturae*, 3.18.5) and nitrogen-fixing plants as lupine (Cato the Elder and Varro, *De agricultura*, 10.4–5; Columella, *De re rustica*, 2.14.5) were widely present as well. From the written sources, it emerges that, while no Roman farm was an example of monoculture, on larger farms most crops were grown separately from others, always according to some functional spatial logic, which responded clearly to agroecology principles of land management. One emblematic example of the benefits of intercropping and the adoption of cover crops can be found in Columella: *When the olive grove is established and has reached maturity, you must divide it into two parts, so that they may be clothed with fruit in alternate years; for the olive-tree does not produce an abundance two years in succession. When the ground underneath has not been sown with a crop, the tree is putting forth its shoots; when the ground is full of sown crop, the tree is bearing fruit ; the olive-grove, therefore, being thus divided, gives an equal return every year* (Columella, *De re rustica*, 5.9.11–12). Some examples of intercropping also responded to green fertilisation intentions. The difference between these is blurred: if legumes such as lupine were grown alongside vines, among fields and were harvested, then such practice was intercropping. Instead, if the same lupines were ploughed down before harvest, it was an example of green fertilisation (Cato the Elder and Varro, *De agricultura*, 37.2; Pliny the Elder, *Historia naturalis*, 18.35.134; Palladius, *Opus agriculturae*, 9.2). Intercropping practices in this agroforestry model responded also to agroecology strategies taking into account temporal cycles of plants interaction dynamics, together with their spatial features. Columella explains this very clearly, when talking about a field intended primarily to grow vines: *a field intended for growing vines first was planted with trees and wheat, and only later when the trees had a certain height, vines were planted* (Columella, *De re rustica*, 2.9.5–6). The same advice is given in Varro (*De re rustica,* 1.23): *in young orchards, when the seedlings have been planted and the young trees have been set in rows, during the early years before the roots have spread very far, some plant garden crops, and others plant other crops; but they do not do this after the trees have gained strength, for fear of injuring the roots*.

Trees and animals

Another key element of the Roman agroforestry system was the integrated presence of animals. Cato the Elder mentions swine and sheep, besides oxen and mules, as the "proper equipment" for an olive farm (Cato the Elder, *De agricultura*, 10.1–2). The presence of swine and sheep suggests self-sufficiency in terms of meat

FUNCTIONAL SPACE	AGROECOLOGY	CIRCULAR ECONOMY
The spatial arrangements of olive trees is functional to support the other elements of the ecosystem Cato the Elder, *De agricultura* Varro, *De re rustica* Lucretius, *De rerum natura* Columella, *De re rustica* Pliny the Elder, *Historia naturalis* Palladius, *Opus agriculturae*	**Olive trees intercropped with other plants** Cato the Elder, *De agricultura* Varro, *De re rustica* Lucretius, *De rerum natura* Columella, *De re rustica* Pliny the Elder, *Historia naturalis* Palladius, *Opus agriculturae* *Anthologia Palatina* **Olive trees and animals** Cato the Elder, *De agricultura* Varro, *De re rustica* Columella, *De re rustica* Palladius, *Opus agriculturae*	**Olives as winter food** Cato the Elder, *De agricultura* **Stone seeds as fuel and fertiliser** Cato the Elder, *De agricultura* *Digesta* **Olive wood as fuel and ash as fertiliser** Cato the Elder, *De agricultura* Virgil *Georgica* Columella, *De re rustica* Pliny the Elder, *Historia naturalis* Palladius, *Opus agriculturae* *Geoponika* **Olive timber** Pliny the Elder, *Historia naturalis* **Amurca: the multi-functional residue from olive oil extraction** Cato the Elder, *De agricultura* Varro, *De re rustica* Columella, *De re rustica* Pliny the Elder, *Historia naturalis* Gargilius Martialis, *De arboribus pomferis* Palladius, *Opus agriculturae* *Geoponika.*

Figure 3. The three key elements of the Roman agroforestry system, according to the written Roman sources (listed in chronological order).

and dairy products. But these animals may have also fulfilled other tasks, such as grass removal, seed dispersal and provision of natural fertiliser (above all sheep, cfr. Varro, *De re rustica*, 1.19.3) thanks to their grazing activity among the trees. Clear evidence of animals grazing in olive orchards have been found in Columella (*De re rustica*, 12.52.1), Palladius (*Opus agriculturae*, 12.4.2), and Varro (*De re rustica*, 1.2.15–16; 1.2.21). Varro in particular specifies how some animals (*i.e.,* goats) can be dangerous to graze in an orchard, thus he warns not to introduce them in the field (*De re rustica*, 1.2.17–19; 1.2.19–20; 2.3.7).

A circular economy

It can be argued that olive cultivation constituted a system with zero waste, in other words it was a circular economy, but equally important was the use of all products as well as all by-products of olive cultivation: as food, fuel, fertiliser, preservative, pesticide and insecticide. The wide variety of products and by-products this plant yielded – and the manifold uses of these – made the olive tree unique in Roman agriculture.

Olive – whether in the form of olive-oil or table olives – was the singular most important source of essential fats in the Roman diet regardless whether it was in rural or urban contexts. Better quality table olives were picked and pickled, whereas olives blown down by winter storms were salted and given to slaves at the farms (Cato the Elder and Varro, *De agricultura*, 23). In addition to this, olive oil was employed for hygienic purposes, as well as being a source of light when burnt in lamps. These functions in themselves made the olive tree one of the keystones of Roman agriculture, but it is also clear that olive cultivation played a fundamental role in Roman agriculture through the use of its by-products.

It was linked to the cultivation and storage of two other crucial crops: grapes and grain. The toxic waste-water known as amurca – with its contents of polyphenols – functioned as a pesticide. Cato the Elder provides his readers with a recipe including this, which would protect vines against a type of moth – the vine leafroller tortix (*Sparganothis pilleriana*) – that caused serious damage to grapevines (Cato the Elder and Varro, *De agricultura*, 95.1–2, see also Columella, *De arboribus*, 14). Equally, amurca was used to protect grain against various pests – insects and mice – when sowing (Virgil, *Georgica*, 1.193–196), threshing (*Geoponika*, 2.26) and later storing it indoors (Cato the Elder and Varro, *De agricultura*, 92; see also Niaounakis, 2011; Mattingly, 1996; Gargilius Martialis, *De arboribus pomferis*, 1, about amurca applications as a preservative for other fruits as well). Both the pulp and seeds of olives left after olive-oil production also functioned as a fertiliser, returning nourishment to the olive groves.

There were also uses linked to animal husbandry, sheep with scab were treated with amurca-mixtures (Pliny the Elder, *Historia naturalis*, 15.8.33–34), the pomace substance produced as a leftover from olive oil production was also widely used in households to kill off bedbugs (Palladius, *Opus agriculturae*, 1.35, 2-3-4; cfr. Varro, *De re rustica*, 1.2, 25), and to protect and preserve clothes and leather shoes (Cato the Elder and Varro, *De agricultura*, 97-98; Pliny the Elder, *Historia naturalis*, 15.8.33–34). At the farmsteads poor quality olive-oil provided fuel for lamps, and olive-tree cuttings and wood functioned as an important source of fuel for heating and cooking (Cato the Elder an Varro, *De agricultura*, 55; Pliny the Elder, *Historia naturalis*, 15.8.33–34).

From palaeoenvironmental evidence

The available archaeobotanical reconstructions from ancient pollen collected at the Roman sites Villa Romana del Casale (Montecchi and Mercuri, 2018; Mercuri *et al.*, 2019) and Philosophiana (Mercuri *et al.*, 2019), and from the palaeolake Pergusa (Sadori *et al.*, 2013; Sadori *et al.*, 2016), provide us with a general overview of the plant cover and land use of this area during Antiquity and late Antiquity.

The analysis of Montecchi and Mercuri (2018) shows that the site Villa Romana del Casale lay in an open area, characterised by the presence of pasturelands and low forest cover, with evidence of complex anthropogenic activities, for the entire period from the 1st to the 4th century AD. Arboreal pollen never exceeds the 30%, with main curves of *Pinus, Juniperus type, Fraxinus, Hedera, Olea* and *Quercus*. Trees and shrubs producing edible fruits (*e.g.*, *Corylus*, *Prunus*, *Sambucus nigra* type, *Capparis*, *Morus*, *Myrtus* and *Pistacia*) are well present in the pollen record. Similarly, the 'OJC' group (*Olea*, *Juglans* and *Castanea*, representing the trees with key cultural and economic role, *sensu* Mercuri *et al.*, 2013b) increases during the Roman phase, with a singular high presence of *Vitis* (20%). The seven API ('anthropogenic pollen indicators', *Artemisia*, *Centaurea*, *Plantago*, *Trifolium* type, *Urtica*, *Cerealia* and *Cichorieae*, *sensu* Mercuri *et al.*, 2013a) are represented as well with 4-5% on average (excluding *Cichorieae*). They reached very high values in the second half of the 2nd and the 4th century AD provided, respectively, by *Centaurea nigra* type, *Artemisia* and *Plantago*. Montecchi and Mercuri (2018) interpreted these data as a good indicator of pastures, furthermore confirmed by the high value of *Cichorieae* (51% on average). A significant, but not high, evidence of cultivated herbs emerges from the pollen collected at Villa Romana del Casale for this period. The average value of cereals increases from 0.2 to 1.3% from the end of the 1st century AD, reaching its maximum at the beginning of the 4th century AD. Other cultivated herbs are represented by some *Apiaceae* (including aromatic/vegetable-garden species) and *Fabaceae*.

Mercuri *et al.* (2019) stretch the pollen analysis in Villa Romana del Casale (VdC) to the Late Antiquity period (until the 7th century), adding more evidence from the site Philosophiana (Ph). In both sites, the pollen spectra continue to show insignificant forest cover (10%) and the predominance of *Cichorieae* (51%), followed by the other anthropogenic pollen indicators (*e.g.*, *Poaceae* 12%, *Brassicaceae* 4%, *and Chenopodiaceae* 3%). The pollen spectra from Philosophiana show a higher relevance of cereals (Ph 3%, VdC 1%). *Olea* is the core arboreal crop in the 3rd century AD (VdC 3%, Ph 2%), leading Mercuri *et al.* (2019) to suggest the presence of an agro-pastoral system of cereal fields and tree crops. The agro-pastoral nature of this system is particularly evident from the macchia pollen near Philosophiana (pistachio, *Cistus*, *Erica*, *Helianthemum*, *Juniperus* type, *Myrtus*, *Phillyrea*) and the abundance of *Cichorieae*. The average percentage of API is more than double in Ph (10%), than in VdC (4%), which leads Mercuri *et al.* (2019) to infer that pastures may have been more extensive than cereal fields in Philosophiana. Nonetheless, a peak of cereals is attested in Philosophiana in the 4th century AD (11%), together with OJC 2.8% interpreted by Mercuri *et al.* (2019) as testimony of the importance of crop trees during the period. Finally, the Mediterranean wood may have had also evergreen oaks and probably wild olives as the dominant trees at both sites (Mercuri *et al.*, 2019). Data from the Pergusa palaeolake (Sadori *et al.*, 2013; Sadori *et al.*, 2016) confirm the low forest cover (20%), testifying that an open landscape was a general feature of the area. Pollen from the continuous cultivation of *Vitis*, *Olea*, and herb crops (*e.g.*, *Linum*, cereals) gives a continuous signal over the period. Olive tree (*Olea*) pollen is always present in the diagram and this may have been due to long distance transport of pollen or to the presence of small orchards in the vicinity according to Sadori *et al.*

(2016), since the Pergusa palaeolake is not covered by the natural distribution area of the wild olive tree (*Olea europaea* var. *sylvestris*). The presence of cereals (*Triticum* and *Hordeum*) suggests the presence of lowland agricultural activity (Sadori *et al.*, 2013), and a significant increase of *Secale* during late Antiquity attests to montane agrarian activity (Sadori *et al.*, 2016). Finally, even though evidence of the presence of *Poaceae* and other anthropogenic taxa (*i.e.*, *Urticaceae*, *Chenopodiaceae*) are collected at Pergusa, the presence of *Cichorieae* is more evident at the archaeological sites (Montecchi and Mercuri, 2018; Mercuri *et al.*, 2019) than the lake core, according to Sadori *et al.* (2016).

From modern evidence

Data collected from the olive orchards surveyed in the project Olive4Climate show the potentialities of olive agroforestry systems in terms of energetic, ecological and economic value. The evaluation of the potential use of olive residual biomass for energy generation (by estimation of calorific value and ash) demonstrated that olive residual biomass may represent an important resource for energy production, as well as an integrative income for the farmer (Sala *et al.*, 2021). The same has been demonstrated for the reuse of olive by-products as fertilisers (Brunori *et al.*, 2019). The main ecological advantages of such practices are the reduction of emissions deriving from combustion, increased biodiversity, and improvement of soil structure (Brunori *et al.*, 2019). It seems that a circular system may have side benefits. Data collected showed how carbon sequestration efficiency in traditional olive groves is greater than in intensive and superintensive orchards. This contributes to shed light on how different management practices affect the ecology of the different systems studied (Sala *et al.*, 2019). Of more interest are the results obtained by the project in terms of understanding the key elements fostering the capacity of olive to resist and adapt to strong climatic variations. In other words, it is the delicate balance between tree architecture (plant habit, plant vigour and plant bearing), plant density, grove structure and soil geo-morphological conditions which guarantees the strong adaptation capacity and the ability to grow and produce, even under high temperatures and in low water regimes of olives. A key component of this balance is associated with local ecological memory and tacit knowledge, a complex and integrated body of practices in the use and transformation of space and ecosystems, verified by long-term collective experience, transmitted through generations and incorporated into the cultural complex of local communities (Mousavi *et al.*, 2019; Olive4Climate - Annex A2.4, 2019).

Other factors determining the response of the olive grove to environmental conditions are the microbiome of the root system and soil conditions, the spontaneous plants that coexist with olive trees and any cover crop used to cover the soil. In particular, with the use of cover crops and/or intercropping varieties, positive impacts have been observed in soil stabilisation and consolidation, increased water reserves, reduction of nitrate leakage losses, and increased biodiversity (Brunori *et al.*, 2019). This is quite similar to an (olive) agroforestry model. In such a system, the presence of wild olive rootstocks and weeds is also very important. Wild olives, growing in areas under specific environmental conditions, have been naturally selected for their adaptation to these conditions, thus their use as rootstocks can play an important role in increasing the tolerance of the future trees to local environmental constraints. A similar assumption may be made concerning the positive role played by the weeds present in the olive orchards (Mousavi *et al.*, 2019).

Conclusions

Roman authors and combined palaeoevidence can give a picture of olive systems during Antiquity and late Antiquity. What emerges is an organisational model based on four main features, which ensured flexibility and adaptation capacity over the centuries: i) the plurality of crops; ii) the multifunctional use and reuse of internal resources; iii) a complex land tenure, which diverse levels of ownership; iv) the transmission of traditional ecological knowledge as an adaptive cumulative body of knowledge.

Furthermore, the comparison with modern evidence lets emerge how the importance of these intercropping agroecosystems does not rely only on their high nature value, but on the total circular system they embody at many levels: environmental, economic and cultural. More importantly, olive agroforestry is the living evidence of an agroecological system capable of enduring a complex symbiotic relationship with humans (Blondel, 2006; Rühl *et al.*, 2011). The functional diversity recognised today as a driver of biodiversity and other benefits in agrosystems (cf. Vardermeer *et al.*, 1998; Malézieux *et al.*, 2009; Santos *et al.*, 2021; Staton *et al.*, 2022;), was in the past a multi-functional agroforestry model based not only on mixed species cropping systems, but *also* on the internal re-use of resources.

In face of the current climatic challenges, geo-political crisis and our vulnerability to external inputs, these ancient sources give us an idea of a sustainable system, something that we can be inspired by in creating our *modern* systems for the present and the future.

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