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GUIDELINES



AGROFORESTRY IN ITALY: an opportunity for agricultural farms

Agroforestry in Italy: an opportunity for agricultural farms

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Introduction

In modern land-use practices, agricultural and silvicultural activities are typically managed separately. This was not the case until a few decades ago: for example, throughout the Mediterranean basin, agro-forestry systems, primarily featuring oak trees, have been widespread for millennia. In Italy, the combination of forest trees, arable land, horticultural crops, meadows, pastures, fruit trees, olive trees and vines have given rise to true arboreal agricultural landscapes, which are also of particular aesthetic quality (think of the paintings of the Tuscan Macchiaioli of the 19th century, where trees, groves, fields and meadows always appear closely interconnected). Since the post-World War II period of the last century, the rapid and widespread spread of intensive agriculture, based on mechanisation and synthetic chemicals, has transformed agricultural practices, with a significant simplification of agroecosystems towards monocultural forms.

On the other hand, some geographical areas still maintain important **agroforestry systems**, for example, Piedmont with maize, soybean or wheat intercropped among poplars, South Tyrol with grazing among larch trees and Sardinia with grazing in cork oak forests, Umbria with arable land intermingled with olive trees, while Campania with associations of horticultural crops and walnut groves to provide fruit and wood. These examples show that the cultivation of forest and fruit trees, arable land and domestic animals on the same land area is a viable land-use option even in a modern management context: modern **agroforestry** is inspired by them. It is based on the incorporation and maintenance of low densities of forest trees, as well as tree and shrub rows within agricultural systems. Many entrepreneurs are interested in adopting agroforestry practices: the main motivations are the preservation of soil fertility, the reduction of energy inputs, the strengthening of biological control, and the diversification of products.

In principle, agroforestry systems result in a more efficient use of natural resources than monoculture systems, despite their potential benefits, modern agroforestry practices are still relatively undervalued by policymakers and agricultural industries on a large scale. In light of this, the purpose of this monograph is to provide an **up-to-date knowledge and analysis reference** on the subject in the form of **guidelines** to support agricultural entrepreneurs, professional technicians, and the technical-institutional bodies responsible for the sector.

In a word: agroforestry

Agroforestry is a word that, together with others such as 'agroecology', 'biodiversity', 'resilience', 'climate change', is increasingly present, not only in scientific and academic circles but also in technical debates among agricultural, forestry and environmental professionals. The need to identify and consolidate the meaning of the term 'agroforestry' emerged a couple of years ago, members of the Italian Agroforestry Association (AIAF) identified the need to clarify the use of **agroforestry** terminology. This included addressing the varying lexical forms such as 'agroforestry', 'agroforestry associations', and 'agroforestry systems and practices'. A set of words that carry different meanings and concepts and that can create uncertainty in those who read and use them, having to identify with these terms, whether as a politician, a farmer, or a scholar.

2.1 WHAT DEFINES THE TERM

'agroforestry'?

Composed of the words agriculture and forestry, the term 'agroforestry' intends to go beyond the idea of linkage that the dash in some versions of the word would indicate, embodying, rather, the concept of integrating tree cultivation with agricultural cultivation and declining this concept with respect to production, the environment, and the physical and cultural landscape. Agroforestry, in fact, constitutes a combination that must represent, also lexically, the reconciliation of agriculture, animal husbandry and forestry: a renewed union of sectors and production procedures that, in the second half of the last century, important historical processes and social and economic transformations distanced one from the other, making them become the object of an increasingly clear-cut economic-productive compartmentalisation, on the one hand, and of increasingly specialised research programmes over the years, on the other. A physical and conceptual separation was created by barriers, resulting in forests and woods, agricultural crops, and livestock farms becoming isolated entities. This separation became more pronounced with the intensification of agriculture during the so-called **Green Revolution**. The growth of the population and urbanisation since the post-war period have led to the agricultural sector undergoing development processes. These processes are based on intensive practices, including monocultures, mechanisation, and large-scale cultivation. These practices are facilitated by the removal of trees from the land, particularly in lowland areas, and by weakening or abolishing forestry systems in these territories.

At the same time, the migration of populations from mountain and semi-mountainous areas towards urban centres has led to the weakening or loss, of economies linked to silvopastoral or agroforestry practices in these regions. This has resulted in the decline (or complete suppression in the cases of forest encroachment) of arboreal pastures, wood pastures, and other forms of agriculture that, in conjunction with tree crops, previously helped protect mountain territories.

Agroforestry is not a new concept. It refers to a conspicuous, multiform, vast, and diverse set of systems, practices, and rural landscapes characterised by the geography and history of places. It is the fruit of an agricultural culture that, over the centuries, has integrated trees as essential components of production systems. Today, we seek to recover, innovate, conserve, and promote this agricultural tradition, aided by a lexical form that encapsulates its complexity. As reported by the *Institut national de recherche pour l'agriculture, l'alimentation et l'environnement*,

agroforestry systems are a source of complexity and heterogeneity. They develop in space and time, involving different orders of magnitude, from the agricultural plot to the landscape scale (www.inrae.fr/en/news/agroforestry-trees-provide-way-forward-sustainable-farming). If, historically, agriculture had an almost exclusively productive value, today, the so-called sustainable forms of agriculture are attributed and recognised (even if not always and sufficiently), in addition to the primary function of production, also other functions such as, for example, environmental protection, which, in the past, were in some way implicit in the management of the farm and the land, because these also ensured the balance of the system.

In agroforestry, complexity manifests itself in different dimensions: in the relationships between productive plant and animal components, as well as between these components and abiotic elements. This complexity extends to the interactions between the agroecosystem and the economic, social, and cultural elements of the territories in which agroforestry systems develop. The high level of complexity in agroforestry results in the production of a wide range of ecosystem services, including carbon storage, reduction of nitrate leaching, improvement of microclimate, soil protection, biodiversity conservation, and cultural and social benefits. To effectively address this complexity, agroforestry, drawing from agricultural and forest ecology, must integrate scientific knowledge from various disciplinary fields to foster innovation and provide an integrated perspective on the production of goods and services. It is important to amplify the voice of agroforestry and articulate its complexity through national and regional **rural development policies**. This involves defining its meaning (or meanings) through a lexicon that facilitates its interpretation. After achieving unequivocal recognition of the topic at an international level, it is imperative to analyse linguistic aspects closely related to the multifaceted historical and geographical diversity of Italian territories.

Agroforestry systems in Europe: *landscapes* of a continent

In recent times, there has been a process leading to increased attention on the importance of agroforestry systems and the evaluation of promoting and enhancing them, necessitating introductory reflections. In Europe, rural areas cover more than 80 % of the territory and accommodate 30 % of the continent's population (www.pianetapsr.it; <https://eur-lex.europa.eu/legal-content/IT/TXT/HTML/?u-ri=CELEX:52021DC0345&from=EN>). Despite the growing awareness of their significance, these areas' value is still not adequately recognised. It is acknowledged that rural areas play a central role in sustainable food production, biodiversity conservation, and mitigating climate change, crucial for the EU to accomplish the objectives of the *Green Deal*, pursue producer-to-consumer strategies, and in safeguard biodiversity. Rural areas are pivotal in the European Green Deal's aspirations to make the EU the first continent to achieve climate neutrality by 2050 (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/climate-action-and-green-deal_en). The Preservation of natural resources, landscape restoration, including cultural landscapes, agro-ecological practices, and short supply chains, will bolster the resilience of rural areas, mitigating climate change, natural disasters, and economic crises. Serving as producers of ecosystem services and carbon-neutral solutions, rural areas will assume an increasingly significant role in climate change mitigation, the bioeconomy, and the circular economy (Piccinni, 2013).

The vast expanse of the European continent, characterised by different natural and climatic conditions and a variety of geographical features, stems from historical and cultural developments, geographical and socio-economic shifts, rendering Europe's rural territories as highly diverse landscapes. This distinctiveness is the result of a complexity that agroforestry systems still embody today in the landscapes of many European rural areas, functioning as both a productive system and as a remnant of agricultural practices of the past now abandoned.

Agroforestry systems, therefore, should be valued both as a historical and cultural heritage and as a heritage of environmental and productive interest. The transition from the agroforestry practices of the past to industrialised agriculture can be traced back to the 20th century when, through a process largely common to several countries on the continent, European agriculture took on the connotations of intensive practices increasingly directed towards the massive use of fertilisers and pesticides. The main objective, particularly since the post-war period, has been food production to meet the needs of a rapidly growing population. In this context, there has been an increase in the extension of agricultural systems more suited to monocultures and the use of heavy mechanical means, the introduction of which has led to the massive removal of trees and hedges from the fields (Takács and Frank, 2008). While trees were removed from the fields, forests, which were also widely used for grazing in the past, were used exclusively for forest production. The energy content of grazing vegetation was insufficient to meet the physiological demands of highly productive breeds of animals. During the 20th century, this situation led to an increasingly clear-cut separation of the agricultural and forestry sectors (Nerlich et al., 2013; Ivezić et al., 2021).

The close and complex link with which, over the centuries up to the 20th century, trees, shrubs, herbaceous crops, and animal breeding gave rise to multifunctional agricultural systems, today known as agroforestry systems, is the result of historical and socio-economic dynamics that over time have shaped both the agricultural and forestry production system and the landscape-cultural identity of many European territories. What happened abruptly in the 20th century with the so-called **Green Revolution** constituted a drastic change in agriculture with equally radical changes in the planning of rural territories and the aesthetics of different European landscapes. It is true, however, that today there is a tendency to look at the landscapes prior to this revolution as something that has not changed over time. Current debates on cultural and natural heritage and identity are based on the assumption of a static landscape of the past, but the hidden paradox in the relationship between preservation and change is that *'all change implies that something is preserved'* and that *'in the whole process of preservation there is some degree of change'* (Palang et al., 2004).

These dynamics are elucidated in E. Turri's insights as presented by G. Piccinni in 'Paesaggi Raccontati' (Piccinni, 2013): *'Humans have told the landscape for their own use, but then it is clear that the landscape, in turn, has also told and tells the stories of men, the events, i.e. the minimal or memorable events of which it has been the scene: It tells the everyday stories, the obvious ones that can be forgotten, and also the deeds that have marked the course of history and left their mark on the land, the stage on which they took place; it then tells of its continuous building up over time, the sedimentations that from episode to episode, from generation to generation, have been grafted onto the legacies of the past.'*

This seemingly static yet dynamic nature of agriculture often perceived as rooted in the distant past, serves to underscore the complexity of European rural landscapes today. It also assists us in identifying optimal strategies to highlight not only the historical significance but also the potential contemporary and innovative roles of agroforestry systems within their context.

The potential of agroforestry has garnered recognition in the context of strategic global policies, including those endorsed by the United Nations and FAO. The imperative to augment global food production while containing environmental impacts (Foresight, 2011; FAO, 2014) is widely documented. Agroforestry is devoutly aligned with the 2030 Agenda for Sustainable Development and its **Sustainable Development Goals**, which strive to strike a balance between fostering positive change for human well-being and upholding and enhancing environmental integrity (<https://unric.org/en/agenda-2030>).

In Europe, numerous agricultural systems can generate high-value production; however, they often do so at the expense of ecosystem services, leading to issues such as the release of greenhouse gases, depletion of soil nutrients, loss of landscape aesthetics, and biodiversity decline (Burgess and Rosati, 2018). Therefore, the objective of European policies and spatial planners should be to maintain or enhance the value of agricultural production by reducing socio-economic costs and increasing social and environmental benefits through a process known as **sustainable intensification** (Burgess and Rosati, 2018). Agroforestry systems have historically been and continue to be integral parts of European rural landscapes and can play a pivotal role in achieving these objectives.

It has been estimated that in Europe (EU27), agroforestry systems occupy an area of 15,400,000 hectares, accounting for 8.8% of the utilised agricultural area (den Herder et al., 2017).

Among the various types of agroforestry systems, several traditional examples can be mentioned, including the *dehesa* in Spain, the *montado* in Portugal, hedgerow systems such as the *bocage* in France and *hedgerows* in the United Kingdom, the *streuobst* in Central Europe, and the *vite maritata* in many parts of the Italian peninsula. These and many other traditional agroforestry systems possess significant cultural value and could qualify as 'Global Important Agricultural Heritage Systems' (GIAHS), an initiative launched in 2002 by the FAO to identify landscapes worldwide that are particularly rich in biodiversity, possessing noteworthy aesthetic and cultural-historical significance due to the sustained application of traditional agricultural techniques, which reflect the co-adaptation of human communities (<https://www.landscapeunifi.it/fao-giahs>).

As of now, only eight GIAHS landscapes are registered in Europe (<https://www.fao.org/giahs/giahsaroundtheworld/designated-sites/europe-and-central-asia/en>), among which a few in Spain could also be classified as agroforestry systems.



Figure 1

a) Montado, Southeast Portugal
Photo by Joao Palma, AGFORWARD
Project
<https://www.flickr.com/photos/agforward/13626081635/>;

b) fruit Trees Orchards Fruit Fields
Cherry Trees <https://pixabay.com/photos/fruit-trees-orchards-fruit-fields-7264215/>;

c) Chinon Indre et Loire Image
by Johan Puisais from Pixabay
<https://pixabay.com/photos/chinon-indre-et-loire-sky-bocage-2831013/>;

d) dehesa con amapolas junto a la entrada a la Estación de Espelúy.
Veinticuatro de Jahén https://commons.wikimedia.org/wiki/File:Dehesa_Estaci%C3%B3n_de_Espel%C3%BAy.jpg

3.1 FOR A *new* AGROFORESTRY

The desire to draw attention to agroforestry practices and landscapes within the European agricultural, animal husbandry, and forestry sectors, as well as the necessity of placing agroforestry at the forefront of research, were solidified between 2000 and 2005 through the collaboration of several European countries in the SAFE project (*Silvoarable Agroforestry for Europe* - <https://www1.montpellier.inra.fr/safe/english/index.htm>). This project demonstrated how agroforestry practices are compatible with modern agriculture (<https://revolve.media/agroforestry-the-age-old-future-of-europes-agriculture>).

During that period, a confrontation (https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_fg_agroforestry_final_report_2017_en.pdf) emerged between agroforestry practitioners and researchers from various parts of Europe. This confrontation, a few years later, led to the establishment of the *European Agroforestry Federation* (www.euraf.net). Issues such as soil erosion, groundwater and river pollution, rural biodiversity loss, countryside depopulation, and animal welfare scandals began to raise the awareness among national authorities, prompting them to make concerted efforts to address these pressing concerns (Worms, 2021). Since its foundation in 2012, EURAF has successfully engaged with nearly all European countries, as well as non-European countries like Switzerland, Ukraine, and Israel, thereby achieving one of its primary objectives to foster the development of national agroforestry associations across Europe.

Another key objective of EURAF is to promote and invest in multidisciplinary research to comprehend the complexity and dynamism of agroforestry systems. Recently, EURAF established a scientific committee to analyse the research needs in the agroforestry sector in the upcoming *EU Research Framework Programme* (2025-2027). In pursuit of this objective, collaboration in significant and wide-ranging European projects such as AGFORWARD (www.agforward.eu), and AFINET (<https://euraf.isa.utl.pt/afinet>) has been strengthened in recent years. This collaboration has expanded to include other projects like AGROMIX (<https://agromixproject.eu>), MIXED (<https://projects.au.dk/mixed/about-mixed>), FIRE-RES (<https://cordis.europa.eu/project/id/101037419>), as well as participation in projects directly involving EURAF such as DIGITaf (<https://digitaf.eu>), DISTENDER (<https://distender.eu>), ResAlliance (<https://resalliance.eu>), and CREDIBLE.

Regarding the objective of supporting the development of European policies to bolster agroforestry, EURAF engaged in lobbying efforts with the European Commission's Directorates General responsible for agriculture, environment, and climate. This involvement led to various measures being incorporated into the Common Agricultural Policy (CAP), such as direct subsidies and support for the cultivation of trees on farms. EURAF also played a role in advocating for the inclusion of agroforestry in the European Green Deal and the Biodiversity Strategy and introduced agroforestry as a key agricultural measure to be developed under the *Carbon Farming* initiative. Additionally, further support measures for agroforestry have been included in the new EU Forestry Strategy (https://environment.ec.europa.eu/strategy/forest-strategy_it).

Some European member states have more clearly recognised agroforestry as **a promising set of agricultural practices to support environmentally friendly food production**. A pioneering action in Europe has been that of France, which, in 2005, promoted agroforestry and agroecology plans through the **4 per 1000 initiative** (<https://4p1000.org/the-governance/?lang=en>), encouraging farmers to put four parts per thousand of carbon into the soil each year through appropriate management practices (Worms, 2021). EURAF has set itself the goal of promoting agroforestry practices in Europe and, to this end, has developed a series of communication and *networking* actions to support the adoption of often complex measures by agroforestry operators. For this reason, it periodically publishes a series of information documents on European policies of interest to agroforestry operators and decision-makers at **www.euraf.net**.

European Member States have the flexibility to integrate spatial data on organic soil and related environmental conditions with data provided by the *Land Parcel Identification System* (LPIS), a component of the *Integrated Administration and Control System* (IACS - https://agriculture.ec.europa.eu/common-agricultural-policy/financing-cap/assurance-and-audit/managing-payments_en). The aim is to delineate agricultural areas subject to *Good Agricultural and Environmental Conditions* (GAECs) ([https://ec.europa.eu/eurostat/statistics-explained/index](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Good_agricultural_and_environmental_conditions_(GAECs)).

[php?title=Glossary:Good_agricultural_and_environmental_conditions_\(GAECs\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Good_agricultural_and_environmental_conditions_(GAECs)))), which are delimited by the geographical extent of the **agricultural areas** defined by Member States based on the definition of arable land, permanent grassland, and permanent crops, as specified in Article 4 of the EU Regulation 2021/2115 (<https://eur-lex.europa.eu/legal-content/IT/TXT/PDF/?uri=CELEX:32021R2115>). This definition encompasses agroforestry systems that may be classified according to the aforementioned categories of land cover. Member States' identification of landscape characteristics, defined by IACS, can assist farmers in adopting agroforestry practices.

The EU has encouraged individual member states to develop their own selection criteria, in a legislative process that the CAP implementation entrusts to them through the development of national plans.

It is hoped that each Member State, recognising its shared belonging to Europe, will accept this invitation and strive to elevate its agroforestry heritage as a key element of rural development on the continent.

Agroforestry in *Italy*

In Italy, there are currently approximately **1.3 million hectares of agroforestry land**, accounting for 11% of the utilised agricultural area (UAA), with silvopastoral systems being predominant (Table 1; den Herder et al., 2017; Paris et al., 2019).

The tree component of agroforestry systems in Italy varies based on latitude and altitude: from larch at higher Alpine altitudes, to beech and chestnut at lower altitudes in the Pre-Alps and Apennines, to deciduous and evergreen oaks in the Mediterranean hills and coastal plains, often coexisting with olive trees.

Grazing is often conducted in an ad hoc manner between fruit plantations, primarily in olive groves and vineyards. The exact extent of this practice is not accounted for in Table 1. The current area of arboreal pastures has significantly diminished compared to the recent past, primarily due to socio-economic changes resulting in decreased pastoralism and natural reforestation. However, current arboreal pastures, along with grazing in mixed herbaceous-arbustive areas, play a vital role in preserving the productive use of marginal lands. They serve ecological functions such as protecting plant and animal biodiversity, maintaining native animal breeds, and defending against forest fires while contributing to landscape preservation. Arboreal pastures could offer a sustainable alternative to forest encroachment in many Alpine and Apennine areas.

Data from studies conducted so far still lack a high degree of accuracy to provide a comprehensive understanding of the prevalence of agroforestry systems in Italy. Official statistics do not yet include specific survey categories for these systems. Recently, a method was developed by the Istituto di Ricerca sugli Ecosistemi Terrestri del Consiglio nazionale delle ricerche (CNR - IRET) to identify agroforestry systems using remote sensing satellite data (Sarti et al., 2021) in an area of 200 km² north of Lake Bolsena. This study revealed a significant presence of quercine rows along the perimeter of the fields, with an average of about 67 metres of rows per hectare, equivalent to a tree cover of 3% of the UAA. Such remote sensing studies will become increasingly crucial for fine-tuning subsidy policies for agro-environmental measures in agroforestry and for quantifying *carbon farming* for the benefit of farmers.

Table 1: Classification, description, extent of agroforestry in Italy, addresses and support in the National Strategic Plan (NSP 2023-27) of the Common Agricultural Policy and the National Forestry Strategy (SFN).

System	Subsystem/culture practice	Extent (ha)/use	PSN 2023-27
1) Silvoarable systems	Arboured arable land	15,800 ha	The UAA receives the Basic Payment (PB), and the trees fall under Enhanced Cross-Compliance (CR) for arable crops with 4% of the farm's UAA uncultivated.
	Planted	?	As above, but it is not clear whether fruit plants traditionally present in plantations fall within the CR of 4% uncultivated.
	Alley cropping (with tall/cedar trees)	Sper./S. com.	Only for high alley cropping: the plant is supported and maintenance for the first 5 years with Actions SRD05 and SRA28 in 5 regions (see chapter 11)
2) Silvopastoral systems	Arboreal pastures	1,303,600 ha	The UAA receives the Basic Payment (PB), CR of 4% is not foreseen, but the tree crown projection is not subtracted from the UAA for the PB
	Forest pasture	?	There are no clear addresses in either NSP or SFN
	Grazing in woody plantations (tall trees or coppices)	Sper./S. com.	There are no specific addresses in either NSP or SFN
	Selva eggs	S. com.	There are no specific addresses in either NSP or SFN
3) Agroforestry systems of permanent crops	Fruit trees associated with arable crops	90,300 ha	They are excluded from the NSP as the definition of agroforestry only covers forest trees. Associated olive trees are eligible for DB, coupled payment, Ecoscheme 2 (grassland) or 3 (olive groves of landscape value) and 5 (association with trees of interest beekeeping)
	Fruit trees with pasture	116,200 ha	As above, with Ecoscheme 2 and 5
	Fruit orchards with poultry grazing	S. com.	There are no specific addresses in either NSP or SFN
	Forest trees and trees for fruit	?	They are classified as agroforestry systems in the NSP, where forest trees are accounted for as part of the fallow land required for meeting the Enhanced Cross-Compliance, which mandates coverage of 4% of the farm's UAA.
4) Agroforestry systems linear	Arboreal rows and hedges	?	They fall within the definition of silvoarable and silvopastoral systems of the NSP, with forest trees falling within the CR of 4% of the arable farm UAA. Planting and maintenance first 5 years supported by Actions SRD05 and SRA28 in 5 regions (seeChapter 11)
	Windbreak	?	
	Arboured buffer strips	?	
5) Urban agroforestry	Mixed urban gardens	?	They are excluded from PSN

UAA: Utilised Agricultural Area

PB: Basic payment under the First Pillar of the CAP

S. com.: commercial farming system in use on individual farms

Sper.: system in experimentation

?: extent of the system not known at national level

PSN: National Strategic Plan of the Common Agricultural Policy

SFN: National Forestry Strategy

CR 4%: Enhanced Cross-Compliance - Good Agricultural and Environmental Conditions (GAEC8) - 4% minimum percentage of agricultural area not used for production (fallow land or non-productive landscape features)

4.1 *Sylvoarable* SYSTEMS

In our country, arable land currently amounts to 6.8 million hectares, compared to approximately 13 million in 1950. This significant reduction has primarily affected marginal arable land in hilly and sub-mountainous areas, where forests have substantially increased due to agricultural land abandonment. As a result, forests in Italy have expanded in recent decades to cover more than one third of the entire territory, totalling over 12 million hectares of forested area. Unfortunately, many forested areas are unsuitable for the growth of wood species suitable for valuable timber.

This deficiency in high-quality timber resources persists in Italy, leading to reliance on imports and contributing to deforestation in tropical and subtropical countries. This situation is concerning, particularly amidst the current climate crisis, which necessitates urgent economic shifts towards a circular bioeconomy, where wood serves as a critical renewable raw material.

Research on innovative forestry systems has predominantly concentrated on species utilised in wood arboriculture, such as poplars and walnuts, mirroring global trends observed in countries like India, China, Europe and North America.

The common walnut (*Juglans regia* L.) has traditionally been cultivated for its valuable timber and fruit production, often in association with agricultural crops. However, this tradition has experienced a significant decline due to fruit imports from foreign markets (such as the USA and Chile), the influx of tropical timber, and the emergence of specialised fruit cultivation in Italy. Specialised walnut cultivation for timber has faced notable constraints in Italy, primarily due to the limited availability of fertile soils to be exclusively dedicated to wood production, necessitating production shifts of at least 30 years to obtain a product suitable for the processing industry. The development of modern silvicultural systems for walnut trees could revive cultivation on fertile soils, particularly in association with agricultural crops. Rural Development Programmes (RDPs) have the potential to finance this new cultivation approach. Walnut trees are particularly suited for saw log production, but they are especially valuable for veneer log production, a category commanding the highest market values. Additionally, interspecific hybrids, notably *Juglans nigra* L. × *Juglans regia* L., can also be utilised. Numerous traditional walnut varieties/populations are available, widely distributed across different parts of Europe. In Italy, noteworthy varieties include Sorrento (southern Italy), Feltrina (central Italy) and Bleggiana (northern Italy). To ensure technical and economic success in agroforestry walnut tree planting, the appropriate selection planting material is crucial. Late leafing is vital to mitigate damage from late spring frosts, a significant risk factor for walnuts. Moreover, late leafing minimises shading of adult trees on associated crops.

The profitability of silvoarable systems hinges greatly on achieving a balanced relationship between tree density and the duration of the associated crop production, which tends to diminish as trees age and grow larger. Thus, it is crucial to establish a correlation between herbaceous crop production and tree age using simple parameters such as tree basal area (G, as indicated in Figure 2 legend). Research conducted in Italy within experimental plantations of hybrid walnut mixed with wheat, threshing, and grassland has revealed a negative correlation between tree basal area and the relative production of shaded versus unshaded crops (PR%). For soft wheat, the equation $PR\% = -6.21G + 100$ applies; for clover: $PR\% = -0.04G + 100$; and for natural grassland: $PR\% = -3.9G + 100$ (Perali et al., 2009). These equations serve to optimise cropping patterns based on planting density and growth rates. For instance, at a density of 50 plants per hectare, the PR% of associated wheat remains above 80% for up to 23 years following walnut planting, representing more than two-thirds of the crop cycle of the plantation.

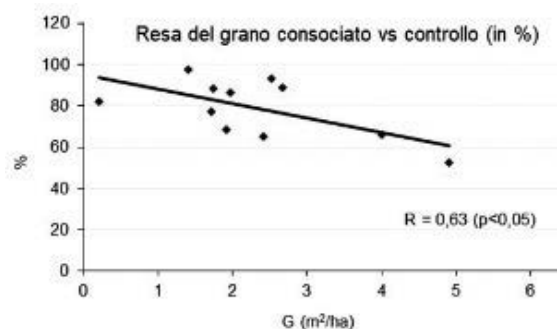


Figure 2

Left: Experimental plots of hybrid walnut wood intercropped with wheat, former CNR IRET experimental fields, loc. Biagio (Colli Vulsinii, prov. di Terni). Photo by P. Paris.

Right: Relation between walnut growth (expressed as basal area) and relative production of the associated crop compared to the same non-associated crop. R = correlation coefficient of linear regression. p = degree of statistical significance. G = basal area in m^2 per hectare = $(\pi/4 \times DBH^2) \times d$, with DBH = trunk diameter at 1.3 m; d = planting density in number of plants per hectare (Perali et al, 2009).

4.2 Silvopastoral SYSTEMS

In Italy, the pasture area currently stands at approximately 3.3 million hectares, a significant decrease from 5.7 million hectares in 1861 and 5.1 million hectares in 1950. This reduction in pasture area can be attributed to rapid socio-economic changes, including agricultural mechanisation and broader socio-economic shifts. Conversely, the livestock population has seen a notable increase, totaling approximately 23 million head of cattle and buffalo (6.3 million), pigs (8.5 million) and sheep and goats (7 and 1 million, respectively). Additionally, there are approximately 662 million poultry (https://www.assal-zoo.it/wp-content/uploads/2023/02/Annuario_2022_web.pdf). Data on animals in intensive and free-range farming are unavailable, but it is estimated that the majority of sheep and goats are raised on pasture. National feed production amounts to 15 million tonnes per year, with 40 % allocated for poultry, 26% and 23% for cattle and pigs, and only 2% for sheep. Intensive animal husbandry, while efficient for animal production, poses significant ecological challenges for modern agriculture, including pollutant emissions, especially greenhouse gases, and soil and water contamination from manure. Alternatively, livestock farming in agroforestry systems can enhance animal welfare by improving certain quality aspects of production and utilising fodder resources integrated with the tree component (such as acorns and fodder-grass). Droppings are managed directly on-site, and the root system of trees intercepts leached nitrogen, reducing nitrate pollution of groundwater and mitigating the risk of eutrophication.

According to the most recent estimates, silvopastoral systems in Italy encompass an area of 1.3 million hectares, constituting 10% of the Utilised Agricultural Area (UAA). While statistical data on the historical size of these areas are unavailable, a significant reduction is evident, with oak species predominating in arboreal pastures, and olive trees being prevalent in pastures with fruit trees.

The practice of arboreal pastures originated over two millennia ago. Around 2500 B.C. in the south-west of Spain, studies on pollen stratifications indicate a transition from solely forest species (such as oaks and pines) to a mixture of oaks and spontaneous herbaceous species suitable for grazing by early herds. This transformation also occurred in Italy, resulting in the emergence of new silvopastoral systems adopted by the Etruscans in central-northern Italy and by the Greeks in southern Italy. Agro-sylvo-pastoral systems, primarily featuring oak trees, spread across the Mediterranean basin, with the most significant concentration still evident in the Iberian Peninsula through landscapes like the *dehesas* and *montados*. In Italy, remnants of this ancient landscape of arboreal pastures persist, notably in Sardinia, where *meriagos* hold significant prominence. In Sardinian silvopastoral systems, livestock, primarily consisting of sheep, goats, beef cattle, and occasionally pigs, graze year-round, utilising a diverse array of nutrient resources including grass, shrubs and trees. It's estimated that the total area covered by oak-based agroforestry systems in Sardinia exceeds 400,000 hectares. These systems are predominantly characterised by cork oak and holm oak, with tree densities ranging from 7 to 250 per hectare, concentrated in the hilly regions. The land is typically tilled every 2-8 years to sow mixtures of species for grazing and/or hay production. Studies conducted in Sardinia highlight the significant role of *meriagos* in biodiversity enhancement and carbon absorption within woody biomass and soil. Consequently, the expansion of such systems to other parts of Italy, especially in the Mediterranean climate zones of the peninsular areas and Sicily, is recommended. These regions are particularly susceptible to the adverse effects of climate change, notably the rise in temperature. The integration of trees into pastures serves to mitigate thermal stress on grazing animals, decreasing their energy consumption and improving overall health.

Innovations in Mediterranean silvopastoral systems encompass the integration of mixtures of fodder species that are tolerant of tree shade. Additionally, research is underway to explore innovative approaches for rearing free-range pigs in the Po Valley, utilising fast-growing poplars for cover. Similarly, alternative methods for pig grazing in wooded areas within the hilly regions of Piedmont are being investigated, with the additional aim of controlling the American grapevine, which serves as a host for the *Scaphoideus titanus* Ball insect, a vector of the flavescence dorée phytoplasma that poses a threat to cultivated vines.

Historic *agroforestry* landscapes in Italy

5.1 HISTORIC *silvopastoral* SYSTEMS

These management models have their roots in the history of mankind, being present on all continents in correspondence with the main centres of rural civilisation. They are part of the agroforestry systems, which globally involve 43% of the population living in areas with more than 10% tree cover. Arboreal pastures represent the interaction between herbaceous and tree crops and animal husbandry and can be divided into two broad categories: pasture woodlands and arboreal pastures are an expression of biocultural diversity, a particular aspect of biodiversity typical of rural landscapes, as defined by the Florence Declaration between UNESCO and the Convention for Biological Diversity (www.cbd.int/portals/culturaldiversity/docs/21040410-declaration-florence-en.pdf) and indicated as an objective in the Ministerial Decree that established the National Rural Landscape Observatory (ONPR) at MASAF in 2012. Biocultural diversity is also indicated as the scientific approach referred to in the **agrobiodiversity** criterion of the FAO's **Important Agricultural Heritage Systems** (GIAHS) conservation programme (see § 3). They are also an important part of the typology of landscapes and agricultural practices registered in the National Register of Rural Landscapes of Historical Interest of Traditional Agricultural Knowledge and Practices, established at MASAF, which is the result of several years of investigations carried out by the Landscape and Cultural Heritage Laboratory of the DAGRI Department of the University of Florence.

5.2 *Historical* ORIGIN

According to Piccioli (1908), the term "arboreal pasture" refers to grazing areas '*in which there is a tendency to keep the trees which, isolated or in groups, more or less regularly cover the ground so that their number can never be to the detriment of herbaceous production*'. In Italy, their presence is well documented for the Molise, Abruzzo and the Tuscan-Emilian

Apennines where written sources on systems for the production of hay, meadow and leaf fodder can be found in early 16th century maps of summer pastures. The most common practices described in such systems concern stubble cutting, scalping, and scaling for the production of fodder branches. In fact, it should be noted that it is not only a type of landscape made up of a variable number of plants scattered over a portion of land but also practices that also act at the level of individual plants. As far as terminology is concerned, the term '**defence**' was very common in the southern Apennines, indicating those arboreal pastures or grazing woods that belonged to the municipality and were encumbered by civic rights such as woodland, acorns and grazing for the benefit of the local population. To this day, the term 'defence' still recurs frequently as a place name in southern Italy, and, as the meaning of the word itself indicates, they were particularly protected by the local populations, who in fact built dry-stone walls around the perimeter of the properties concerned, where possible, to mark them off. Presently, the spread of arboreal pastures is concentrated along the Alpine arc where, at the highest altitudes, the larch is the tree, while the beech replaces it at lower altitudes. The Ligurian and Maritime Alps conserve traces of tree pastures with larch and silver fir, as found in the Monregalese valleys (CN) and the Gerbonte Alps (IM). Along the Apennine ranges (especially in the central and southern regions), beech and oak trees (downy oak and turkey oak, depending on the altitude and stationary conditions) form the tree stand, while on the islands and in the coastal areas, both downy oak and, more frequently, holm oak and cork trees prevail. Among the various areas of Italy, Sardinia is worth mentioning as a place of choice for arboreal pasture, which still occupies vast areas of the territory. Further examples can be found in other Mediterranean countries such as in Spain and Portugal (the so-called *dehesas* and *montados*) or in Greece. In the Hellenic peninsula *Quercus cocci-fera* L. is preserved in shrub form, as the young shoots constitute the only available food for goats. Other tree species, including beech and holm oak, can also be transformed into intricate bushes for intense and prolonged grazing. In Italy, the most serious threat to their preservation is linked to the abandonment of wild grazing and reforestation processes, as well as to forest management guidelines and the structure of landscape protection. Since 1939, the forest area has more than doubled in Italy and the process of recolonisation, especially in the mountains, has led to a gradual increase in the density of grazing woods and arboreal pastures, transforming them into dense woods. Since 1985, with the Galasso decree, all woods have been subject to landscape restrictions, and since then, also due to the legal definition of woodland, which also covers smallwooded areas, the recovery and conservation of these formations have been very difficult. With the implementing decrees of the Testo Unico delle Filiere Forestali (TUFF) (Legislative Decree no. 34 of 2018), it is now possible to restore such surfaces through an authorised process, while in Regions such as Tuscany, which have included this possibility in their forestry regulations since 2015, recovery and/or restoration has been largely simplified. It is also possible to create new areas of arboreal pasture from cultivated bare land

or otherwise. According to the definition of the Catasto Agrario (1929), the distinction between the various qualities of arboreal pasture is as follows:

- Bushy pasture: pasture land covered with scattered bushes that limit herbaceous production to restricted areas;
- Arboreal pasture (and meadow): pasture (or meadow) on which there are aligned or scattered woody plants, the product of which significantly increases the land revenue. The degree of ground cover of the crowns must be between 5 % and 50 %.

The TUFF, in Article 3, gave a definition of both grazing forest and arboreal pasture:

(m) "Arboreal pasture": areas currently under cultivation with a forest tree cover of less than 20 per cent, used mainly for livestock grazing, also in the framework of established local practices. They produce fodder that cannot be economically mown and are characterised by the presence of tree or shrub plants.



Figure 3 - The canopy of an existing beech until a few years ago in the Bosco di Sant'Antonio, at Pescocostanzo in the Maiella National Park (AQ). The prohibition of tree cutting and the activities of shepherds have led to a sharp reduction in these monumental plants. The lack of knowledge of their origin often causes these beeches to be classified as natural monuments, whereas they are the product of centuries-old grazing culture.

A historical example: alnoculture in Liguria

Historically, there have been many forms of arboreal pastures. Often, this was not a stable landscape over time but represented a moment in a cycle that alternated between woodland, cultivation, and grazing. An interesting case in point is the practice of alnoculture, widespread in the Val d'Aveto in the Ligurian Apennines between the 18th and 19th centuries, linked to a practice established by written regulations.

The cycle lasted approximately twelve years (Fig. 4) and consisted of successive stages, which were given different names depending on the evolutionary stage of the forest they were in.

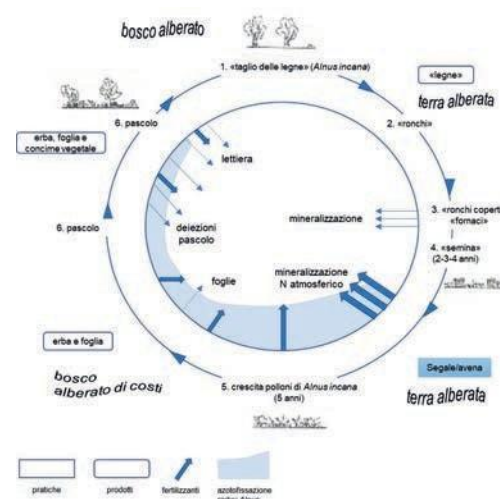


Figure 4 - Alnoculture cycle in the Ligurian Apennines (Agnoletti 2018).

The practice began by clear-cutting the alders present in 3-12 year shifts, depending on the fertility of the plots. The other species present (beech and turkey oak) were either chopped down (beech - Figure 3) or scaled every 1-3 years (turkey oak). In addition to the strictly economic value of the cereal production that could be obtained from the cultivation of the woodland, we know that this was also carried out with the function of defending the tree vegetation in the renewal stages of grazing. In order to cultivate the land, they practised the *ronco* (fire), using wood from the cutting of alder coppice and thorny shrubs (such as brambles and hawthorns). In autumn, they sowed wheat, and if the soil was acid and poor, oats. Branches and thorny bushes were placed around the ditches to prevent access to grazing animals. The practice of using fire confined to small furnaces (covered *ronco*) is likely to have helped preserve fruit trees such as cherry and other forage trees such as turkey oak and ash; large trees of these species can still be found at historic alnocultural sites. The *ronco* allowed the **soil to be enriched** with ashes and removed thorny shrub species, while some thorny shrubs, especially hawthorn, were maintained as hedges to protect the temporary arable land (rye or oats) from grazing. The arable land lasted 2-5 years. The next phase was referred to as coppiced woodland and wooded woodland, both of which indicated two evolutionary phases following the coppicing of the alder. The first described a young stand where the alder stumps were beginning to grow back. Grazing of livestock, generally sheep and goats, and to a lesser extent cows, was carried out after the last harvest, when this did not constitute an obstacle to the growth of the young suckers, and the grazing lasted until the woodland was ripe for subsequent coppicing. The peculiarity of this agroforestry practice lies in the knowledge of the fertilising properties of alder.

5.3 *Management* PRACTICES

Forestry technical literature has given relatively little consideration to the issue of arboreal pastures and grazing woods. In recent years, the environmental and landscape values of agroforestry systems have seen a growth in the scientific literature, especially at the descriptive level of agroforestry systems. It, therefore, seems appropriate to report some management indications in the literature, even if they are linked to a different socio-economic context, because the choice of reintroducing this form of land use can now reconcile the needs of silviculture and pastoralism with those of environmental and landscape protection. The reconstitution or formation of arboreal pastures has been advocated by various authors over time, highlighting its numerous benefits:

- The progressive formation of humus, created by the accumulation of litter, improves the chemical and structural characteristics of the soil, enriching it with organic substance and enhancing its drainage and water retention capacity;
- Tree canopies, by intercepting rainwater, reduce its rate of flow to the ground, particularly during heavy rainfall, common in autumn and spring. During dry summer months, they mitigate ground heating effects with their shade, reducing temperature fluctuations and excessive evaporation caused by intense solar radiation;
- The grass sward underneath benefits from these improved soil and climatic conditions, allowing for homogeneous and continuous development over time with decent productions, even during summer. Additionally, the nutritional value and palatability of grass species improve, with the gradual emergence of legumes and grasses with respectable fodder value;
- livestock benefit from the presence of these trees, finding shelter during sunny summer days or inclement weather;
- the needs of farmers and foresters can be reconciled by adopting farming practices and techniques suited to the preservation and
- perpetuation of pastures and forests;
- historical landscapes can be restored by combining their touristic potential with quality dairy production.

For the reconstitution of arboreal pastures, one can speak of reforestation, while for newly formed pastures, it is afforestation. When it comes to planting, it is crucial that the arboreal area is not too large, and that the plants, whether scattered or in groups, are spaced out in such a way that there are areas of land between individual trees or groups of trees that are never completely deserted, but rather largely sun-drenched for a few hours of the day. The operations to reconstitute these forest formations begin by subdividing the area to be reforested into fenced areas of a size proportionate to the productivity of the herbaceous pasture and the animal load to be introduced. Fences can be either temporary or permanent, with mobile fences being a more cost-effective option currently. The tradition of building dry-stone walls has fallen into disuse, especially in the Alpine and calcareous areas of the central-southern Apennines. Operations preceding the planting of tree species must include soil tilling and the elimination of pre-existing vegetation through clearing, excluding forest species (such as beech, hazel, green alder, laburnum) that are consumed by livestock. Likewise, regeneration cores that have grown due to effective protection offered by thorny shrubs should not be eliminated.

The reaction to cattle bites results in the emission of several apical-dominant shoots, forming compact formations with plants living in close contact with both crown and stem and sharing the same root system.

Some of the mechanisms of vegetation adaptation to grazing are particularly interesting. In areas where spruce is associated with beech, the former tends to spread in beech clusters that have originated as a result of repeated cattle biting (Figure 5). The seedlings of the latter react with the emission of numerous epicormic shoots by unfolding the dormant buds below the cattle line, while the central suckers grow freely because they escape the bite. With time, these **bushy groups** enlarge and take on a characteristic profile, and when they are so large that the cattle can no longer graze them inside, a beech or spruce plant develops from the middle of the stump.

Reforestation, aimed at or creating the pasture's trees, must be located in areas where trees can perform multiple functions: protective, productive, and landscaping. However, it must be borne in mind that, whatever the purpose of reforestation, pastureland must never be overgrazed to avoid competition with the development of the herbaceous sward in terms of light, water, nutrients and root space. As seen in the literature, many authors agree that the area covered by trees should not be too large, it should not be more than 1/4 or 1/3 of the total area (2,500-3,300 m² per hectare), regardless of the arrangement of the plants (in strips or groups).



Piccioli (1908) recommended reforestation in the form of rectangular groves, with the longest side following the line of maximum slope, in order to intercept and retain rainwater and at the same time protect the surrounding pasture areas from wind and solar radiation. According to this author, *'plantations are made in groups in the form of rectangles measuring 15 by 60 metres, arranged in horizontal lines, 40 metres apart; a distance of 50 metres is kept between one horizontal line and the next, with the rectangular groves arranged in such a way that the gap in a line is matched by a grove above and below it'*. Thus, by adopting this method, three or four groves of 900 m² per hectare would be formed. According to D'Errico (1971), *'the most convenient system is to use the planting of around 300 plants per hectare, with a planting distance of 5-6 metres if they are equidistant, otherwise an arrangement in groups can be adopted, in strips occupying no more than 2,500 m² per hectare'*. Whichever planting method is chosen, it is necessary to protect the seedlings from being bitten by animals with *'coarse hedges of branches or brambles, with dry stone walls or with live hedges of holly, barberry, sea buckthorn, hawthorn, spruce and elder'*. These methods have fallen into disuse but the need for fencing remains essential. Reforestation should involve planting 400 to 500 seedlings per grove that are at least three or four years old to allow sheep grazing after only five years. After a further five or six years, cattle will also be able to enter the grove and the advantage of arboreal grazing will be seen with them. According to other authors, however, these groves should be permanently fenced off and protected from livestock in order to avoid damage to plants and regeneration. The arrangement of scattered trees or rows of trees (Figure 6) may be suitable for those species such as larch, pine and oak, whose foliage does not support the growth of herbaceous vegetation and does not intercept rain as much as spruce and beech do. However, it is always a good idea to release nuclei or isolated plants within the pasture to provide shelter and a resting place for livestock, taking care not to release single individuals in windswept areas (such as mountain ridges) to avoid the risk of crashing. The species that can be used in the establishment of tree pastures are many and varied, depending on the ecological conditions of the station. It is worth mentioning that arboreal formations in pastures can also be grouped together in thickets, ranging in size from a few hundred to a few thousand square metres, being the most suitable, especially in subalpine and mountainous areas. The species suitable for alpine and mountain pastures are eminently shade-tolerant (with the exception of larch and pine), i.e. shade-tolerant species that tolerate, in the seedling state, the cover of the adult stand above. On the other hand, they often suffer from competition for light from shrubs and tall nitrophilous grasses, which are quick to enter natural or natural clearings and glades, or those created as a result of over-intensive cutting and prolonged breaks in ground cover.

The arrangement of plants in arboreal pastures in clusters of a few individuals, or rather in scattered groups, is the most effective in performing a primarily protective function against avalanches soil erosion, wind damage and stone-rolling.

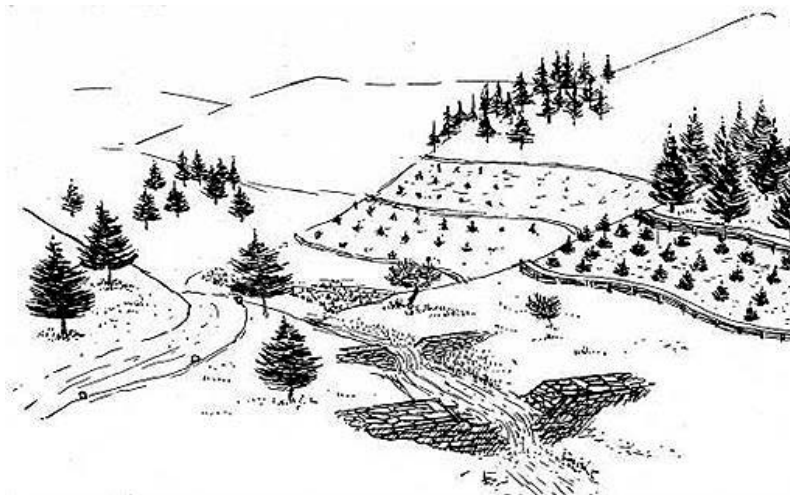


Figure 6 - Arrangement of trees in rows and scattered in the arboreal pasture, for hydrogeological protection purposes (note the hydraulic systems carried out in conjunction with reforestation)
(Agnoletti, 2018)

In the upper subalpine belt, larch and stone pine plantations can be used for this purpose, in association with spruce at lower altitudes. Reforestation is to be carried out in such a way as to create small, compact groups (with a circular area of 300-2,000 m² and a radius of 10-25 m) that are monospecific and separated from each other, when they have reached the adult state, by a length of twice that of the branches of the adult plants (7-10 m) so that corridors are formed between the groups.

Over time, the plants within these clusters will naturally form compact clumps. However, to prevent contact between the groups, intervention becomes necessary. When the stand reaches a dominant height of 10 m, selective thinning within the clusters is required. This process involves releasing 3-5 plants with the lowest slenderness ratio, indicative of better stability and a deeper root system. These released plants are typically arranged in a circle or triangle, providing protection for the remaining plants within the cluster. The thinning will affect the plants between these anchoring groups, allowing them to form corridors. The aim is to facilitate better development of the released edge plants while also mitigating the effects of snow and wind, which can cause crashes and uprooting.

In the mountainous zone of the Alpine sector, reconstitution through compact groups can be implemented similarly to the subAlpine zone, utilising different species: Scots pine and larch at higher altitudes, larch and spruce, or spruce with fir, beech, sycamore maple, greater ash at lower altitudes. In the Apennine areas, recommended species include beech and silver fir, with mixtures for small, scattered groups of heliophilous broadleaves (greater ash, sycamore and sycamore maple, cherry, linden, mountain and bird rowan, elm, etc.). If planting has been conducted in rugged or poorly fertile stations along ridges (for hydrogeological protection purposes such as avalanche, stone-rolling or windbreak defence), the same considerations applicable to the sub-alpine belt should be applied. Otherwise, if there's the possibility of achieving natural regeneration or conducting regeneration cuts, they can be integrated, if necessary, with artificial regeneration. Successive cuts can then be carried out in groups of very moderate intensity, with recourse to integration with undergrowth

5.4 MIXED CULTURE, ANCESTOR

OF MODERN *silvoarable* SYSTEMS

In Europe, there were once numerous cultivation systems that combined permanent and temporary crops on the same agricultural area. In Italy, these systems achieved a particularly high degree of complexity: the Italian term "*coltura promiscua*", which is internationally recognised (Meynier, 1958; Zimmermann, 1981; Meeus, et al., 1990; Pinto Correia 2004; Zimmermann, 2006), refers to the association between arable land, trees and vines, which is characteristic of the Italian peninsula.



Figure 7 - Distribution of promiscuous vine cultivation in Italy in the 1950s (Desplanques, 1959)

Grapes were also cultivated in promiscuous cultivation in other regions of southern Europe, characterised by very wet winters and hot summers, such as northern Portugal (Stanislawski, 1970), the Basque region and some areas of southern France (Lavignac, 2001). However, in central Italy and the Po-Venetian Plain, promiscuous cultivation was the predominant practice. These regions held absolute primacy in promiscuous cultivation, both in terms of the complexity of the associations and the variety of species involved and, as well as the agricultural area allocated to them.

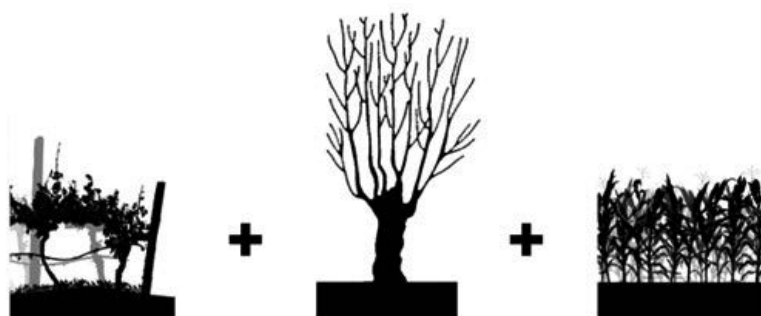
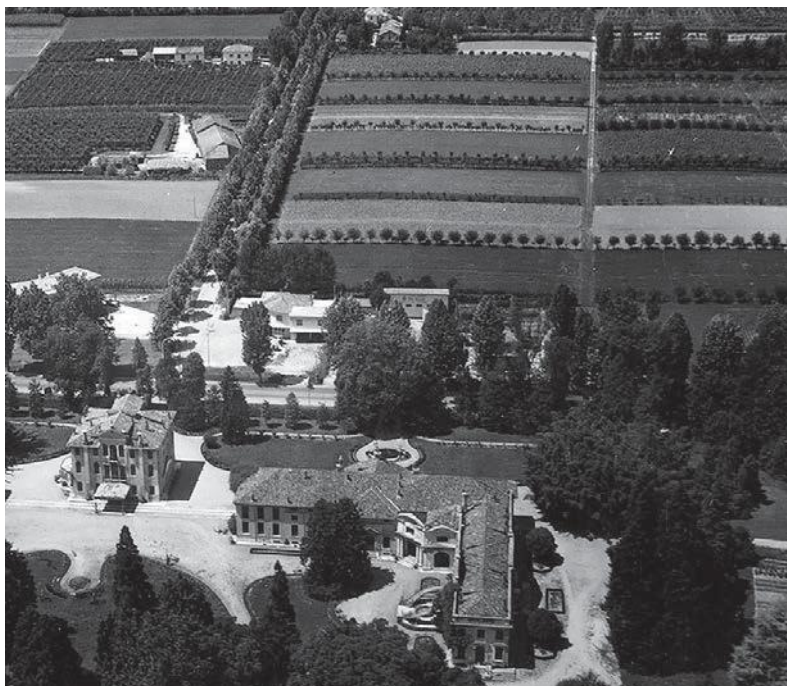


Figure 8 - The components of promiscuous vine cultivation

Agricultural treatises, agricultural surveys and aerial photographs offer extensive information on the various forms this cultivation system took in different regions and morphological situations (Ferrario, 2012; 2019). In the plains, the fields were typically divided into long strips of arable land, separated by **rows of vines intertwined with trees** used as living supports.

Figure 9 - The landscape of promiscuous cultivation in the Veneto plain in the 1960s (FAST - Photo Archivio Storico Trevigiano della Provincia di Treviso, Fondo Gnocato, 7774, detail)



In the hills, the rows of trees and vines followed the terraces or verges. Vine shoots were often intertwined in garlands, stretching from one tree to another along the same row, known as “**piantata**” in the Po Valley, and “**alberata**” in central Italy. Cereals, vegetables, flowers and fodder were cultivated between the rows. According to contemporary descriptions (Babo, 1866), **promiscuous cultivation** was a perfect multifunctional agricultural system which, in a limited space, provided various services: food (cereals, wine, fruit), fodder (hay from the meadow strips under the rows, the leaves of the trees), fuel and building materials (timber). The trees offered protection for birds and other small animals, mitigated excessive sunlight on vines and fields by limiting evapotranspiration, and diminished the negative effects of drought periods.

Promiscuous cultivation was almost completely abandoned in the 19th century during the rapid modernisation of Italian agriculture (Sereni, 1957; Desplanques, 1959; Gambi, 1973). It has been demonstrated that since the mid-nineteenth century, experts began to advocate for crop specialisation and to deem the tradition of cultivating different crops in the same field as irrational (Ferrario, 2019). However, in large parts of Italy, rows of trees and vines only began to be perceived as obsolete and subsequently removed on a large scale during the 20th century. In some areas, such as the Emilia-Romagna and Po-Veneto plains, uprooting occurred at an extremely rapid pace between the 1960s and 1970s (Ferrario, 2019).

The reasons for the discontinuation of mixed cultivation reported by observers of the time are many: the spread of plant diseases (such as phylloxera affecting vines and graphiosis affecting elms); the mechanisation of agricultural practices, where trees in the fields became obstacles; the introduction of modern building materials and fossil fuels for heating, rendering wood from living supports unnecessary; the expansion of irrigated crops, which appear hardly compatible with the presence of vines; the emergence of a new market agriculture

Spurred by the increasing ease of transportation, which makes it less convenient to utilise land that is not particularly suitable for producing goods that can be imported instead; the declining utility of foliage as fodder, given the prevalence of fodder crops in the crop cycle and the introduction of animal feed; the crisis of sharecropping as a form of tenure, resulting in tenant farmers being freed from the obligation to cultivate crops required as payment; the new EU agricultural policies, initiated with the 1957 Treaty of Rome, along with EU wine-growing regulations from the 1970s and the Green Plans (Tirone, 1996); and finally, the significant decrease in self-production and family consumption, the formation of smallholdings, and the separation of animal husbandry and wine-growing. Despite these profound transformations, some traces of promiscuous cultivation still persist in contemporary agrarian landscapes, albeit in fragmented forms.



Figure 10 a and b - *Two relicts of mixed cultivation*

Today, **plantations** are increasingly recognised as heritage, serving as living archives of the historical landscape. This recognition seems to inspire three types of reaction in the scientific world, agricultural operators, and in citizens and institutions.

Firstly, there is growing emphasis on the preservation of surviving fragments, whose cultural-historical and environmental value is beginning to be recognised. For instance, the Veneto plantation was included in the National Register of Rural Landscapes of historical Interest by the Ministry of Agriculture, Food Sovereignty and Forestry in 2018.



Figure 11 - *Recent reconstruction for demonstration purposes of a vineyard 'à la Bellussi', marinated in mulberry trees*

The Aversana alberata (refer to case study 'Alberata di Asprinio') was also included in the same register. Additionally, the Ministry of Culture has designated a fragment of promiscuous cultivation (the so-called Vigneto di Bayer) as of significant cultural value.

Secondly, numerous instances of reconstruction for educational, demonstration, cultural or tourism purposes of promiscuous cultivation specimens modelled on traditional systems have been observed for some time (Ferrario, 2019).

Last but not least, traditional arable farming inspires the development and proliferation of new forestry systems that incorporate some of the principles reminiscent of past agrarian landscapes: multifunctionality, resilience, and sustainable intensification. In recent years, there has been a clearer recognition of the importance of trees in arable farming, and there has been growing interest, both scientifically and operationally, in afforestation in viticulture.



Figure 12 - A very recent arboretum vineyard planting in the Berici Mountains (Vicenza)

In summary, ancient promiscuous crops provide valuable lessons in sustainability for the agriculture of the future (Ferrario, 2021).

Therefore, the preservation of fragments of promiscuous culture still present in our agrarian landscapes is not only a matter of conserving historical and cultural heritage but also serves as an open-air laboratory for scientific analysis. These fragments can further studies on the positive interactions between different crops, interactions that were hastily dismissed in the era of specialisation but are now being fully re-evaluated.

Research results on *agroforestry* *systems* in Italy

6.1 EFFECTS OF TREES ON THE MICRO CLIMATE, *the edaphic environment* AND BIODIVERSITY

The introduction of trees into arable land and pastures results in microclimatic and soil environment changes, the extent of which depends on the design of the agroforestry system. This includes factors such as density and arrangement of the trees, as well as the choice of species. The presence of trees primarily impacts shading and wind-break effects, altering evapotranspiration flows, air temperature, and soil surface horizons (Panozzo et al., 2022a).

Light is typically the most limiting factor in the productivity of tree-associated crops within agroforestry systems (Mantino et al., 2020). Indeed, the biomass produced by a crop, and to a large extent its yield, are generally closely related to the amount of light (or more precisely, photosynthetically active radiation) intercepted by the crop itself, especially in the absence of other strongly limiting factors such as water and nutritional stress. Therefore, the most effective and productive associations often involve autumn-spring crops combined with deciduous tree species, allowing for the exploitation of complementarity in light usage. This principle also applies to crops associated with the majority of orchards, predominantly composed of deciduous species. Lauri et al. (2019) provide an analysis of the main agroforestry systems with fruit trees in Europe and the Mediterranean.

The olive tree is evergreen, thus providing ample shade even during winter. However, maximum oil productivity is achieved from olive groves

intercepting approximately 55 % of light (Villalobos et al., 2006). Higher tree densities result in excessive shading, leading to reduced fruit set and oil content, as well as phytosanitary issues. Consequently, even within olive groves, there remains sufficient light on the ground for many crops. Rosati et al. (2019) provide an overview of the primary agroforestry systems feasible within olive groves.

Light transmitted to the ground in agroforestry systems is not uniform in space or time and also varies in spectral composition. Rosati et al. (2020) report how the intermittence of high and low light levels filtering through tree canopies reduces the photosynthetic efficiency of associated crops despite the same incident light. In the same paper, and in Rosati et al. (2021a), the heterogeneity of ground-transmitted radiation levels is described in deciduous orchards and in traditional and super-intensive (hedge) olive groves, respectively. Rosati et al. (2022, 2023) describe the quality of light transmitted under tree canopies (in comparison with that transmitted under photovoltaic panels), focusing on spectral composition. In new silvicultural plantations with poplar in the Veneto plain, featuring a density of 40-50 trees per hectare and an inter-row spacing of about 40 m, trees in their fourth year (reaching a height of about 12 metres) cause a moderate reduction in photosynthetically active radiation (PAR) on the ground. This reduction ranges from -4% at 12 metres from the tree row, to -16% at 6 metres (averaged data for June-August) (Piotto et al., 2023). However, the presence of trees can mitigate heat stress and water loss from the soil, benefiting herbaceous production and grazing animals. In silvicultural systems with poplar on the Sasse Rami farm of Veneto Agricoltura (Ceregnano, Rovigo) (refer to case study), an important buffering effect of the trees on air temperature was observed. On average, there was a reduction in temperatures during the central hours of the day (10:00 - 17:00, June - August) by 0.5°C, with peaks reaching -2.3°C on specific days and times, and a slight increase (+0.3°C on average over the considered period) in the late afternoon to night (Piotto et al., 2023; Panozzo et al., 2022b). This effect has been documented in the literature with different tree species and plant densities. However, the impact of trees on the water cycle at different soil depths and distances from the trees remains more contentious. In Ceregnano, with soybeans in the row spacing, an increase in soil moisture was observed, ranging from 19% (by volume) at the furthest points from the tree row (20 metres distance) to approximately 28 % at 6 and 12 metres distance from the trees (period June - August) (Piotto et al., 2023).

The benefits of trees on agroecosystem microclimatic parameters are particularly interesting in the soil and climate context of central Italy. At the agro-environmental research centre "Enrico Avanzi" (Pisa) (refer to case study), an experimental trial was conducted in 2020 within an alley-cropping system comprising rows of very short-cycled poplars with a 13.5 m inter-row spacing. The aim was to measure the microclimatic conditions during the summer months, including air temperature and humidity, wind speed and direction, and solar radiation at three locations within the row spacing (West 2.5 m - Centre 6.75 m - East 2.5 m), as well as at one location outside the agroforestry system. Heat stress was quantified using several indices: Temperature Humidity

Index, Temperature Humidity Index adjusted, Black Globe Humidity Index, and Heat Load Index. The air and black globe temperatures exhibited the highest values during the midday hours under sunny conditions, while wind, represented by a breeze, reached its peak in the control position (non-agroforestry), providing a cooling effect. Within the agroforestry row, the dense tree canopy hindered air movement. Lower relative humidity values, likely attributed to temperature rise, were recorded within the agroforestry row. The indices showed optimal values in the control section during midday; however, conditions within the agroforestry system varied based on exposure (east-west) and time of day (Mantino et al., 2022). In 2021, the same agroforestry row was used to evaluate microclimatic conditions, water status, and maize crop production. Results indicated that the two poplar rows reduced wind speed by 50-70 %, with tree height at the end of the production cycle shading approximately one third of the inter-row area. This shading emerged as a major limiting factor for crop growth. Additionally, competition for water varied within the inter-row, with modifications to evapotranspiration due to tree presence. Soil moisture was higher in the central part of the inter-row. While shading facilitated water status recovery, it negatively affected production, resulting in a decrease of over 25% compared to the least shaded central part of the plot. Notably, in excessive drought, the presence of tree rows led to a 54% difference in production compared to the control (www.gonewton.it).

In addition to studying the effect of trees on the evapotranspirative fluxes of the system, several research groups, supported by the NEWTON project (PSR REGIONE TOSCANA 2014-2020), have been engaged in analysing the impact on the nutrient cycle and biodiversity of the soil environment.

At the Tenuta di Paganico (refer to case study), an agro-forestry and pastoral farm located in Tuscany (GR), covering approximately 1500 hectares, where Maremma cattle are reared in a semi-wild state within turkey oak stands (*Quercus cerris* L.), the impact on the soil component was assessed. Four different grazing intensities were evaluated: i) intensive grazing with calves; ii) grazing with high-intensity cows; iii) grazing with low-intensity cows; iv) ungrazed area. Specifically, chemical parameters (soil organic carbon; total nitrogen), physical parameters (bulk density and soil infiltration) and the QBS-ar index (arthropod-based soil biological quality) were analysed. Results indicate that grazing and grazing intensity significantly influence the physical and biological characteristics of the soil. The QBS index reveals a high value of biological quality in the forest, with values exceeding 200, indicative of undisturbed, natural soils. Agroforestry grazing management, which allows livestock to graze without concentrating on specific points, has a limited impact on the biological quality of the soil, with

values comparable to or slightly lower than those measured in non-grazed areas. Infiltrometry values indicate a reduction in infiltration capacity due to animal trampling, with lower values (8.24 mm h^{-1}) observed in areas with high grazing intensity, which are more prone to trampling, compared to ungrazed areas. Consequently, water penetrates the soil more rapidly in ungrazed forest areas (13.05 mm h^{-1}). In areas occupied by calves, the effect on infiltration capacity is more pronounced, depending on the distance from the stable. Saturated hydraulic conductivity (K_{sat}) values range from a minimum of 0.091 mm h^{-1} in heavily trampled areas near the stable to a maximum of 21.99 mm h^{-1} in less trampled areas farther from the stable.

The soil is a key component of the agro-ecosystem, acting as a strategic reservoir for carbon storage depending on the applied practices. At the Berchidda-Monti long-term observatory in northeastern Sardinia, which represents Mediterranean agroforestry systems featuring trees of the genus *Quercus*, extensive studies have been conducted for over 15 years. These studies focus on the intricate interactions between management practices and the provision of ecosystem services, particularly carbon sequestration. Findings from these studies indicate that, in addition to factors such as vegetation composition and structure, soil and climate characteristics, land-use practices play a significant role in influencing soil properties and carbon content. Specifically, land-use practices impact the amount of biomass input from trees (especially litter), herbaceous vegetation (aerial residues and roots) and animal dung (Seddaiu et al., 2018). Various studies have observed that the accumulation of soil organic carbon in a cork oak forest at the same soil profile depth does not significantly differ from that measured in an arboreal pasture under identical environmental conditions. In forest soils, more than 75% of the carbon content is concentrated in the top five centimetres of soil, whereas in an arboreal pasture subject to periodic tillage, carbon accumulates over a longer horizon (approximately 40 cm). This indicates that the latter systems are more resilient to potential disturbance factors compared to forests (Seddaiu et al., 2013). Additionally, Rossetti et al. (2015) demonstrated that in a silvopastoral system where cork oak was the tree component, the carbon and nitrogen content, as well as the cation exchange capacity, were not significantly influenced by the presence of the tree.

6.2 INTERACTIONS BETWEEN TREES AND CULTIVATION IN *silvoarable systems*

Interactions between trees and associated crops evolve over time, primarily as the trees undergo progressive growth. In the case of young trees (1-5 years old), characterised by a poorly developed root system and crown, herbaceous stands typically exhibit greater competitiveness. Hence, it becomes necessary to mitigate their competitive pressure to avoid impairing tree growth. To address this, it is advisable to utilise developed planting material with a deep root system, such as poplar stems or seedlings with a soil loaf. Additionally, maintaining a fallow land radius of at least 1-1.5 metres around the young trees or applying mulch can help alleviate competition (Paris et al., 1994).

In adult silvicultural systems, the influence of trees on associated herbaceous crops is contingent upon the extent of the interactions between the two components and the threshold of competitiveness/complementarity in resource utilisation (e.g., solar radiation, water and nutrients). Shading is widely recognised as the main factor impacting herbaceous species (Artru et al., 2017; Dufour et al., 2013). The adaptability to semi-shade conditions varies depending on the genetic characteristics of the herbaceous species. Plants with C3 metabolism, such as autumn-winter cereals and various summer crops like sunflower, soybean, and beet, exhibit a lower photosynthesis saturation point at lower radiation intensity compared to plants with C4 metabolism, such as maize and sorghum. Consequently, C3 plants optimise photosynthetic efficiency at lower solar radiation levels, rendering them more suitable for the semi-homogeneous environments of sylvan systems. In agroforestry systems with deciduous trees, the productivity of autumn-spring crops is less affected by tree competition than that of summer species, as they can complete the majority of their vegetative development before the trees leaf out. The Department of Agronomy, Food, Natural Resources, Animals and the Environment (DAFNAE) of the University of Padua is studying the impact of different poplar clones on the most cultivated grain crops at the Sasse Rami experimental farm of Veneto Agricoltura in Ceregnano (Rovigo) (refer to case study). They observed that during the first four years of the trees' growth, when they eventually reach 24 centimetres in diameter at breast height and approximately 12-14 metres in height, the grain yield is similar, and in some years even higher, compared to those growing in full sun (with increases of up to +20 %, depending on the wheat cultivar and distance from the row). On the other hand, the grain yield of a summer crop such as soya was reduced, with progressively greater effects when approaching the tree row, ranging from -6 % at 12 metres to -40 % at 6 metres distance. (Panozzo, 2022). Among the autumn-winter cereals, barley proves to be more adaptable to shading than wheat. This adaptability stems from its shorter cultivation cycle, which allows it to avoid prolonged exposure to the shade of deciduous trees for a significant portion of its growth period. Additionally, barley exhibits lower solar radiation requirements (reaching the saturation point of photosynthesis), and greater tolerance to water and salt stress. At the Casaria farm in Masi (PD) (refer to case study), the CNR-IRET conducted similar research on poplar agroforestry. This study investigated the productivity of poplar-associated crops for approximately two-thirds of the cultivation turn, spanning from 2014 over seven years. The crops under investigation included sugar beet, soya, wheat, barley and alfalfa. The tree component of the agroforestry system comprised rows of poplar (clone 'I-214') and English oak, with a density of 57 trees per hectare. These trees were planted along drainage ditches spaced 33-35 metres apart, oriented in a North-South direction. Aggregate data collected over the seven-years of observation period revealed variations in crop yield. These variations included a decrease of approximately 11 % at a distance of 3 metres from the tree row, and an increase of approximately 11% at a distance ranging from 7 to 10 metres from the tree row (Paris et al., *in preparation*). Notably, there was no reduction in crop yield observed until two-thirds of the poplar tree cycle had elapsed. In 2022, poplar trees were deemed for harvesting, with prices averaging approximately 100-120 € per plant, corresponding to 2800-3360 € per hectare. Regarding the performance of summer-cycle crops in a Mediterranean environment, a field trial was conducted in Pisa in 2018 and 2019. The objective was to assess the effects of soil characteristics and variations

in light availability, influenced by the presence and growth of biennial poplar rows (*Short Rotation Forestry*) which were spaced 13.5 metres apart, on the yield of soya and sorghum. Both the aerial biomass and the grain yield exhibited a significant reduction, with the maximum reduction of 74 % in the areas closest to the tree row. Sorghum demonstrated to be less tolerant to light reduction compared to soybean. Although light availability is the most limiting factor for sorghum cultivation, the grain yield was influenced by soil pH, while soybean was affected by the soil's water retention capacity (Mantino et al., *in press*).

Furthermore, a meta-analysis based on literature data on the productivity of grain crops in silvicultural systems in temperate climates found that the presence of tree rows is all the more beneficial, leading to stable or increased yields, especially in crop cycles characterised by thermal extremes and water shortage (Panozzo et al., 2022.c; Panozzo et al., 2023). To maximise the sustainability of agroforestry systems, it is fundamental to detect yield variations of different herbaceous crops, as well as assess the quality of the productions. Field trials conducted in various geographical areas of Italy, incorporating several tree species and planting densities, consistently reveal an increase in the quality of grain obtained in the area of interaction with the trees, resulting in a positive effect on product prices. For instance, in soft wheat, an increase in protein content (up to +2% in absolute value) is observed, which can be attributed to improved microclimatic parameters and edaphic interactions with trees (Piotto et al., 2023; Panozzo et al., 2020). Similarly, in barley and wheat, an increase in the content of certain minerals in the grain, such as calcium, magnesium, phosphorus and potassium (up to +10%, depending on climate and variety), was observed, enhancing the nutritional value of flour and derived products (Panozzo et al., 2022d). Regarding soybean grains, it has been observed that shading can sometimes increase or have no effect on the protein content, while it increases the content of isoflavones, phenolic compounds with strong antioxidant activity (Barion et al., 2021).

An essential aspect of maximising the sustainability of silvicultural systems is the identification of the best varieties, based on existing gene variability, in terms of grain yield. Additionally, it's crucial to identify morphological characteristics that are useful in pinpointing the most shade-tolerant varieties. Several research groups in Italy are actively involved in screening commercial varieties with the primary objective of identifying the most suitable ones. These studies involve subjecting plants to different intensities of shade, achieved either artificially with shade nets and wooden staves or through field trials conducted in the area of interaction with trees. For instance, in soft wheat, significant phenotypic variability in response to reduced solar radiation has been observed. Varieties have been identified that achieve a yield comparable to that of full sun even in moderate shade, while others experience a yield reduction of more than half (Panozzo et al., 2020; Panozzo et al., 2022d). Some old soft wheat varieties showed a lower yield reduction compared to modern varieties;

however, they unfortunately remain less productive in associated terms (Panozzo et al., 2022d; dos Santos et al., 2023). The adaptability of wheat to shading is linked to variations in ear fertility, an increase in leaf-stem angle, and a delay in leaf senescence. These parameters are indicative of a morpho-physiological plasticity, with some varieties implementing these traits more effectively than others to maximise radiation interception and enhance productive responses.

Concerning agroforestry systems with semi-green tree species like olive trees, the most appealing associated crops are those with high income potential, particularly food crops. Autumn-spring-cycle crops are preferable over summer-cycle crops as they compete less for water, unless there is irrigation available. Short-cycle crops, such as many vegetables, are favoured as they complete their cycle early in spring, avoiding water competition with olive trees as the dry season approaches. Leguminous crops are preferred as they fix nitrogen and do not compete with the olive trees for this element; instead, they enrich the soil. However, not all crops can be cultivated, as the spacing between the rows may not accommodate the necessary machinery. Cultivation of fodder is more flexible, allowing for mowing or direct grazing. Harvesting fodder can be adjusted earlier in the event of an early drought, thereby controlling water competition. Nevertheless, forages are less competitive as they are harvested earlier (typically at flowering) than grain crops. In addition to annual or poly-annual short-cycle crops, associations with perennial species compatible with olive grove management can be considered. One such species, selvatic asparagus (*Asparagus acutifolius* L.), has been recently studied and proposed for intercropping in olive groves (Rosati et al., 2011; 2012a; 2012b; 2014a; 2021b). Being perennial, it eliminates the need for annual tillage and allows the olive grove to remain grassy, providing advantages such as erosion control, organic soil accumulation, carbon sequestration, and improved fertility and diversity of the olive grove.

Regarding fodder crops, within the PF7 AGFORWARD Project, a research and development protocol was established between 2015 and 2018 at the private farm of Sebastiano and Martino Mu (Monti, SS). The objective was to investigate the effect of cork oak shade on the establishment and persistence of annual legume-based fodder mixtures (Franca et al. 2015). This farm spans approximately 100 hectares and operates as a silvopastoral farm, with tree densities ranging from 10 to 40 cork oaks per hectare and tree canopy covering less than 10 % of the total area. Dairy sheep are reared for the dairy industry. With the aim of transitioning from temporary pasture-grazing (cereal cultivation/forestry) to permanent pasture, an experimental trial was conducted comparing three types of pasture: pasture sown with a commercial mixture, pasture sown with a mixture developed by the CNR - ISPAAM based on native leguminous plants, and unseeded pasture. The trial was conducted both under and outside the tree canopy. For three years, observations were made on the composition of the transient and persistent seed bank (Franca et al., 2018).

The adaptive response of the different legume species tested in the mixtures varied greatly, showing contrasting morphological traits, productivity levels, and seed hardness. Three years after sowing, it was observed that the perennial seed bank under the canopy of trees was significantly richer in legumes compared to areas outside the canopy, regardless of the mixture used. Complex and **biodiverse legume** mixtures appeared to be more conservative in terms of persistence of legume species than simple native mixtures. In the Tuscan Maremma region, the production of alfalfa in association with olive trees planted at a spacing of 5 by 10 metres was evaluated in 2014 and 2015. It was found that alfalfa yield in the understorey area decreased with the presence of trees, with a significant correlation between biomass production and light availability. However, researchers noted the substantial absence of an effect of tree presence on the nutritional quality of the biomass (Mantino et al., 2021). These findings highlight the importance of selecting shade-tolerant species to be sown in agroforestry settings in order to improve the persistence of legume-rich permanent pastures.

6.3 INTERACTIONS BETWEEN TREES AND ANIMALS IN *silvopastoral* systems AND *agroforestry*

Permanent crops cover approximately 150 million hectares worldwide and are typically not intercropped. They are often associated with temporary or permanent grassland, yet the fodder potential of these grasslands remains largely untapped. Grassing permanent crops is one of the most effective practices for sequestering atmospheric carbon and storing it in the soil as organic matter. This practice enhances soil fertility, permeability, and water retention while reducing erosion and nutrient leaching. Fruits that naturally fall to the ground, either through natural dropping or thinning out, represent another potential but unused resource. Additionally, leaves that fall to the ground in autumn or through green pruning or winter pruning for evergreen species can serve as additional fodder sources. By-products generated from fruit processing also offer another resource for animal husbandry, which is not always fully utilised.

In the case of the olive tree, an evergreen species, pruning typically removes one to three tonnes of material per hectare per year, predominantly consisting of leaves and twigs. These materials can be consumed by various livestock species. In the olive grove, therefore, there are numerous fodder resources available, largely untapped. These resources include pruning material, green grass, fallen fruit before and during the harvest, and olive pomace. Animals could potentially consume these resources either in the barn or by grazing directly in the olive grove, where such grazing is feasible and compatible with the farming practices in place. Direct grazing by animals not only enhances fodder resources but also provides other ecosystem services to the olive grove itself or other permanent crop. For instance, through grazing, activities such as sward chopping, fodder harvesting, and fertilisation can be partially or entirely avoided.

Animals can effectively manage weeds not only within the fruit orchard but also within associated permanent crops. This is particularly beneficial as weed control is challenging due to the spatial heterogeneity of the tree and crop association. Additionally, in certain cases, animals can assist in controlling pathogens and pests, providing further benefits to the agrosystem.

Hence, intercropping permanent crops with grazing animals can enhance overall productivity within the same surface area while concurrently reducing the environmental impact of both crop and livestock farming. For further details, please refer to the following articles: Dal Bosco et al. (2014; 2016), Palliotti et al. (2020), Paolotti et al. (2016), Rocchi et al. (2019), Rosati et al. (2012a; b; 2014a; b; c; 2015a; b; 2019; 2021b; 2023).

In 2021, the animal science research group of the University of Pisa's Department of Agricultural, Food and Agro-Environmental Sciences conducted an experiment at the Tenuta di Paganico (GR) (refer to case study), aiming to assess the effect of herd management systems (pastoral vs. silvopastoral) on the growth and welfare of Maremmana cattle. During a six-week period in spring, the animals were divided into two groups, and the following parameters were measured: feed intake, total intake, body weight, and cortisol content in blood and hair. The silvopastoral group had access to 3.31 hectares of turkey oak (*Quercus cerris* L.) forest, while both groups had approximately 7000 square metres of grazing land available to them in a one-week rotation. No significant differences in total dry matter ingestion were observed between the two groups; however, the average daily weight gain was higher in the pastoral system (1.20 vs. 1.02 kg per day). This difference could potentially be attributed to the higher energy requirements of the animals due to varying activity levels, which were higher in the silvopastoral group. Furthermore, the management system did not influence the animal welfare indicators. Specifically, the serum cortisol concentration remained consistent between the management and sampling times, while the hair cortisol concentration decreased significantly during the experiment in both groups (Ripamonti et al., *in press*).

In the context of the LIFE Regenerate project (www.regenerate.eu), which concluded in June 2022, two grazing systems were compared across various silvopastoral study areas in Sardinia, the Extremadura region of Spain, and in the Alentejo region of Portugal. These grazing systems included continuous grazing and the adaptive multi-paddock system (AMP). The AMP system represents a regenerative grazing strategy, similar to rotational grazing. It involves dividing grazing areas into small paddocks with short grazing periods and high animal loads. This approach ensures optimal recovery times between successive grazing shifts and facilitates vegetation recovery. The AMP technique is dynamic, employing light and mobile fencing systems to adjust the size of the paddocks and, consequently, the animal load, based on grass availability. Given its adaptive nature, there is no universal management strategy applicable to all situations.

Management strategies vary depending on the area of interest and the pedo-climatic and production conditions specific to each location. In Sardinia, the three-year experimentation was conducted on a private farm situated in the central-western part of the island. This area is characterised by a downstream region (at 500 metres above Sea level) and an upstream region (at 950 metres above sea level). The primary breeding system in this area involves the cow-calf line with Sardo-Modicana breed bovines. The biomass production of the pastures was evaluated using the mobile exclusion cage method and indirect measurements based on grassland height. Additionally, vegetation analysis was conducted by categorising functional groups, including grasses, legumes, other edible species, and non-edible species or weeds. The study revealed that AMP grazing had a generally positive impact on total production and all functional groups in the mountain area, attributed to higher utilisation rates. However, these benefits were primarily observed in areas with permanent pasture, with less pronounced effects noted in arboreal pastures. In the downstream area, higher utilisation rates were observed for all functional groups and overall biomass, although no significant benefits were found from a production point of view.

6.4 TREE SPECIES IN SILVOARABLE SYSTEMS: *adaptability of species* AND ACCRETIONS

In order to optimise silvicultural models, it is necessary to identify the most suitable tree species for the planting site, as well as the most suitable varieties or clones for intercropping with herbaceous crops, in terms of growth speed, trunk quality, and foliage phenolics. Genotypes with rapid growth, marked apical dominance with little lateral branching, and late foliation to reduce shading from crops below are preferable. In the last few decades, research has focused on two groups of species for wood arboriculture: walnuts and poplars. The walnut tree is suitable for the production of saw logs, but above all, veneer logs, which are the production category with the highest sales value. In addition to the common walnut (*Juglans regia* L.) there are also interspecific hybrids between common walnut and black American walnut (*Juglans nigra* L.). Research was conducted by the CNR - IRET with agroforestry plots of common walnut and French hybrid NG23 x RA, from 1992 to 2010. The latter was found to be superior in terms of growth speed in both diameter and height, quality of the trunk for slicing, and later foliation (Perali, 2012). However, the hybrid walnut does not produce edible fruits. In case there is interest in the dual production of valuable timber and fruits, a number of traditional varieties/populations are available for the common walnut, which are widespread in different parts of Europe. In Italy, we point out the Sorrento (southern Italy), the Feltrina (central Italy) and the Bleggiana (northern Italy). Genotypes with late leafing and apical dominance should be used. In walnut, late leafing is essential to avoid late frost damage in spring (Fady et al., 2003, Paris et al., 2001).

As for poplar, at the pilot and demonstrative farm of Sasse Rami di Veneto Agricoltura in Ceregnano (Rovigo), a clonal comparison field was implemented in 2018 with 14 poplar clones of type MSA (Greater Environmental Sustainability), selected by CREA - Foreste e Legno di Casale Monferrato. The poplars were planted both in a specialised system with a square planting layout with a spacing of 6 × 6 m, and in a silvoarable planting system with rows (*alley-cropping*) oriented North-South, adjacent

to the drains, with a 40 m row spacing and a distance of 6 m between trees. Starting from the year of planting, the Territorio e Sistemi Agro-Forestali (TESAF) and DAFNAE Departments of the University of Padua monitor the growth and phenology of the different clones under the two conditions. At about halfway through the poplar shift, the greater availability of radiation and less intraspecific competition in the silvoarable system compared to the specialised poplar grove resulted, for example, in the Moncalvo clone, in a significantly greater stem diameter at breast height (23.8 vs. 20.5 cm, +16 %) and a lower plant height (14.3 vs. 15.5 m, -8 %) than in the specialised poplar grove (Piotto et al., 2023). In the silvoarable system, moreover, the phenology of the trees is delayed by approximately two weeks compared to the specialised poplar grove, presumably due to the lower water availability in the soil of the silvoarable system. In these systems with a low population density, reaching the commercial diameter (30-33 cm) is expected 1-2 years earlier than in the specialised poplar grove, i.e. at the end of the seventh to eighth year of growth.

6.5 TREE SPECIES IN AGROFORESTRY SYSTEMS: MULTIFUNCTIONALITY *and ecosystem services*

Since 2009, the Istituto per le Produzioni Animali in Ambiente Mediterraneo (ISPAAM) of the Consiglio Nazionale delle Ricerche (CNR) has been conducting intensive research at the State Forest of Monte Pisanu to evaluate the effect of excluding grazing on the agro-ecological characteristics of the forest grass layer. This state-owned forest, protected since 1886 by royal decree, is managed by the Forestry Agency of the Autonomous Region of Sardinia (FORESTAS), and designated as a Site of Community Importance (SCI ITB001102). It spans over the Goceano mountains, covering central-northern Sardinia, between the villages of Bono and Bottidda, over an area of 2,500 hectares. The impact of grazing exclusion was evaluated by **monitoring indicators related to silvopastoral productivity (dry matter yield), quality (pastoral value), and biodiversity (Shannon index) at 23 grazed sites**. Furthermore, the role of grazing in reducing fire risk within the Monte Pisanu Forest (refer to case study) was assessed by estimating fire probability and severity using the FARSITE simulator (Franca et al., 2016). Concerning multifunctionality, conservation objectives in the Monte Pisanu forest are combined with wood and animal production. Cork production was estimated at around 120 tons per year during the observed years, in addition to firewood produced from conifers (approximately 100 m³ per year) and broadleaf trees (30 m³ per year). Animal production relies on extensive grazing of sheep and cattle from private herds in the mountain area. Dairy sheep of the Sarda breed prefer to graze in arboreal pastures with low tree density, clearings, and deforested areas. Conversely, cattle of the Sarda breed graze under denser tree canopies. Grazing is seasonal for dairy sheep and continuous for cattle.

The silvopastoral system of Monte Pisanu, based on short seasonal transhumance, is an integral part of the livestock feeding calendar and serves as an example of the coexistence of livestock farming and forestry in Sardinia, aimed at preserving biodiversity. Pastoral and ecological values, as measured by the Shannon index, are affected to varying degrees by grazing activity.

Pastoral values (VP) are significantly higher in non-grazed areas (VPs between 12.5 and 52.3), with high variability between years and sites, attributed to the selective grazing behaviour of livestock towards desirable species (*Lolium perenne* L., *Dactylis glomerata* L., *Trifolium subterraneum* L. and *Medicago* sp.pl.). Grazing loads ranged from 0.2 to 1.1 adult cattle units per hectare in the most marginal or fertile areas, respectively. Approximately 200 plant species were identified, including a high proportion of endemic species, and the Shannon Index was significantly higher (3.1) in grazed areas than in exclusion cages (2.7). Among the various ecological services provided by such systems, simulated FARSITE results demonstrated that grazing significantly reduced (-77%) the potential area covered by fire and the rate of fire front progression. In grazed areas, approximately 90 % of the potentially affected area by fire would still experience a fire intensity of less than 1700 kW m⁻², a critical threshold at which the effectiveness of fire extinguishing methods is maximised.

Politics, *market*, supply chains

7.1 IMPORTANCE OF '*out of forest*' TREES IN EUROPE AND ITALY

There are billions of trees in the world that are not included in the official definitions of forest and other wooded areas. **Trees outside the forests (TOF)** include those found in cities, on farms, along roads, and in many other places that, by definition, do not qualify as forests; typically classified as **agricultural** or **urban areas** (UNFCCC COP21). In Italy, this category is also referred to as "**off-forest**".

In some countries, such as India, 80 percent of the industrial wood requirements of pulp mills and plywood/panelling industries are met by wood from these off-forest areas, such as agroforestry plantations and agricultural forests. In Europe, according to estimates reported by den Herder et al., (2017), "*the total agroforestry area in the EU-27 is about 15.4 million hectares, which accounts for about 3.6 percent of the land area and 8.8 per cent of the utilised agricultural area.*" Additionally, the article specifies the area broken down by countries with the highest EU-wide values of the area under agroforestry systems, such as Spain (5.6 million hectares), France (1.6 million hectares), Greece (1.6 million hectares), Italy (1.4 million hectares), Portugal (1.2 million hectares), Romania (0.9 million hectares) and Bulgaria (0.9 million hectares).

Italy, therefore, plays an important role in the incidence and history of agroforestry on a European scale, which has already been discussed in previous chapters.

7.2 *Ecosystem* SERVICES PROVIDED BY 'OUT OF FOREST' TREES

All trees contribute to preserving the environment and to maintaining and/or enhancing the social and economic well-being of mankind. Agroforestry systems have local value in promoting national agricultural products and thus in international landscape and culinary promotion.

The presence of trees is always important, but it becomes even more relevant

In areas lacking forests, such as highly anthropized environments (like the Po Valley or many rural areas transformed for mechanised agricultural production), where **off-forest areas** could have a positive impact on providing ecosystem services, including:

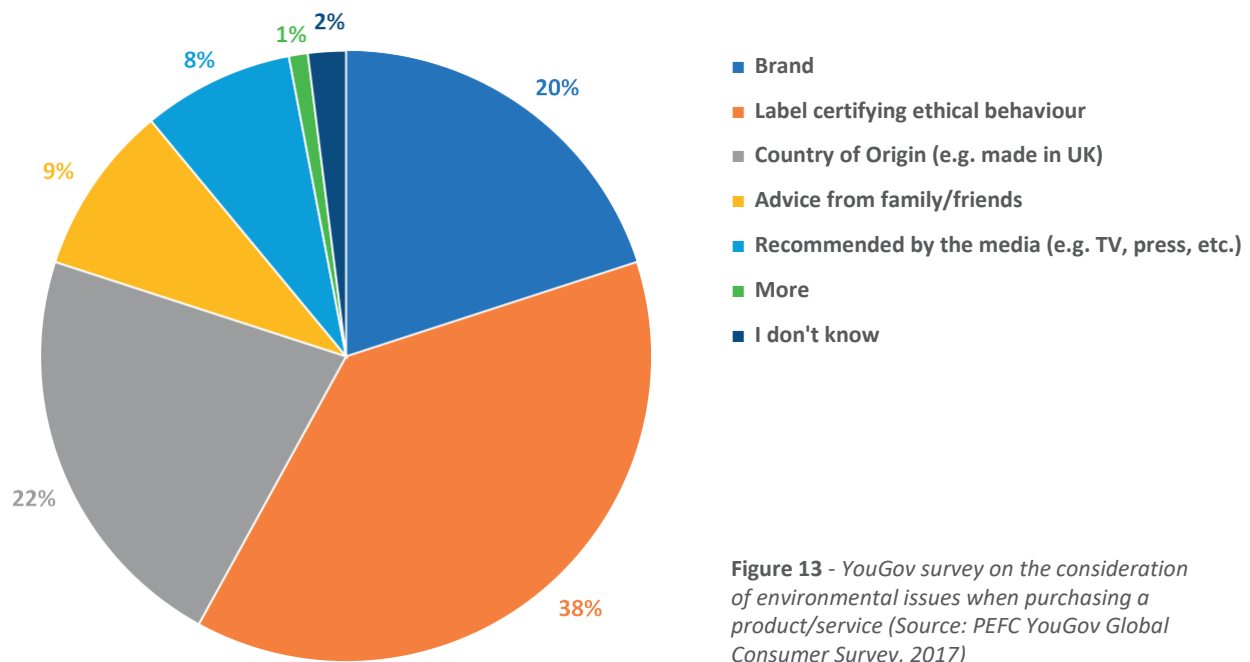
- landscape;
- habitat differentiation for biodiversity;
- climate mitigation;
- maintenance/increase of positive pedological characteristics;
- Production diversification for the market or as self-supply also for energy purposes;
- increased production of wood raw material and supply to local (in Italy) and international (Asia and South America) markets;
- further access to the market for wood products and non-wood Forest Products;
- culture of tree heritage towards the population.

7.3 VALORISATION OF ECOSYSTEM SERVICES AND NON-WOODY *forest products*

The services provided by trees, both within forests and outside of them, must be understood, promoted, and communicated, ultimately, valorised. Just as awareness has been raised in the forestry sector over the last twenty years, similar attention must be given to the agroforestry sector. In a mixed context like agroforestry, it's crucial to recognise that beyond its primary products, the world of trees outside forests (TOF) provides direct or indirect services to producers and the environment. In the Mediterranean area, goods produced in the agroforestry sector, known as non-wood forest products in economic terms, often hold a higher value than wood. Examples include honey production, which simultaneously sustains habitat crucial for many species' survival; cork production and its associated socio-economic chain; mushroom and truffle production, which can foster significant tourism; the maintenance of habitats for wildlife, particularly those subject to hunting activities; and the cultivation and utilisation of berries. Recognising and promoting these values is essential for fostering sustainable practices and preserving ecosystems in agroforestry landscapes.

7.4 CERTIFICATION *and the market*

When discussing production, products, promotion, and valorisation of agroforestry supply chains, it's essential to keep the ultimate and indispensable business objective in focus: the market. According to a YouGov survey conducted on behalf of PEFC International (PEFC YouGov Global Consumer Survey, 2017), the market is increasingly attentive to production/management system or product certifications (Figure 13).



For this reason, in addition to compulsory certifications necessary for compliance with legal requirements, there are also voluntary certifications. These certifications enable producers to communicate their commitment to environmental and social sustainability in their business management. Simultaneously, they allow consumers to consciously choose products that, besides their inherent qualities, also contribute positively to the environment. As illustrated in figure 13, depicting a consumer survey on factors influencing their purchasing decisions, 38 % of consumers prioritise labels certifying the ethical behaviour of the producing company. This is followed by 22 % considering the country of origin, and 20 % considering the product brand. This general perception, supported by this and similar studies, reflects consumers' increasing attention not only to the products they purchase but also to the ethical, sustainable, and social behaviour of companies. Consequently, certifications play a crucial role as communication and marketing tools.

These certifications therefore allow:

- **Differentiation:** by branding or declaring a product as certified, one distinguishes it from other products with similar characteristics on the market. The competitive advantage lies in offering something more and different than one's competitors, something ethical, environmentally friendly, and respectful of the tree components of agroforestry;
- **competition:** the real advantage of certification lies in differentiating oneself from another supplier or manufacturer by offering something more reliable, ethical, and preferable. A certified company is perceived as more trustworthy compared to another that does not provide the same guarantees;
- **image:** a certified product and implemented certification convey a positive image and a message of trust about one's own company.

Agroforestry certification serves as an environmental and territorial communication and *marketing* tool towards civil society, materialised with a logo. PEFC Italy, one of the two internationally recognised schemes, has contributed to the development of an Italian-wide applicable standard on the Sustainable Management of an Agroforestry System. This document delineates elements of sustainable management for the tree component of agroforestry systems, as well as the technical preparation, health, and safety of the operators responsible for managing certified areas. In all cases, the management of agroforestry and animal components must adhere to recognised good management practices and relevant standards. Sustainable management of an agroforestry system involves managing agrosilvopastoral, silvoarable and silvopastoral systems in a manner that maintains capacity, to provide ecosystem services, biodiversity, regenerative capacity, vitality, and their potential. This ensures the continuity of vital ecological, economic, and social functions at local, national, and global levels, without causing harm to other ecosystems (PEFC Definition Adaptation ST 1003:2018; PEFC, 2008).

Economic *sustainability*

In economic evaluation, there are two analysing investment returns that also apply when comparing returns **from conventional agriculture**

(CA) and agriculture combined with forestry (agroforestry) (AF):

- **Financial analysis**, which takes into account the cost of production factors (such as land, capital, and labour) and the revenue generated from the sale of products at their market values,
- **Proper economic analysis**, which goes beyond financial analysis by also examining non-monetary costs and benefits, in addition to market costs and benefits. When market prices do not accurately reflect the real value of goods and services, proper economic analysis corrects them using **shadow prices**.

When comparing the performance of CA versus AF, the results of the financial and economic analysis often diverge significantly: the economic ones tend to be more positive for AF than the financial ones for CA. In other words, agriculture combined with forestry (AF) tends to have a higher capacity to meet social needs compared to conventional agriculture (CA), primarily due to the more pronounced presence of non-market benefits. These include soil conservation, carbon fixation, protection of landscape quality, regulation of the water cycle, slope stability, microclimate improvement, biodiversity conservation, among others (Mercer et al., 2014). According to the FAO (2022), AF can achieve 50-80 % of the biodiversity levels of natural forests. What's particularly intriguing is that the types of protected species in AF systems often differ from those in forests located nearby. In AF systems, taxa richness can be 60 % higher than in forests (Udawatta et al., 2019). Additionally, cultural ecosystem services can be enumerated, benefiting local communities through better care and protection of the landscape, thereby enhancing recreational and cultural settings. These non-market ecosystem services, which are the focus of established valuation methodologies (Cai et al., 2021), drive public support for AF (Paris et al., 2019). Recently, AF has also become a central theme in agricultural policies in countries with advanced economies, starting with the European Union.

In the countries of the Global South, the economic rationale for implementing agroforestry (AF) policies have been augmented by additional motivations for several decades. These motivations are closely linked to the opportunity to attain conditions of food sovereignty, specifically to meet the needs of food self-production. Furthermore, AF policies aim to diversify crops and stabilise incomes. Generally, prices of locally consumed food products are less volatile than prices of raw materials traded on international markets. These functions are associated with enhancing the resilience of agricultural socio-ecological systems against climatic stresses (Buttoud et al., 2012).

Directly comparing AF and CA is not the only appropriate evaluation to make. AF can also be economically assessed in relation to the costs associated with maintaining land in a state of neglect and degradation. From this perspective, AF, much more than CA, can play a crucial role in achieving the morally binding goals outlined in the UN Decade of Land Recovery and the legally binding goals set out in the European Commission's draft Regulation on land recovery. Of the 2.2 billion hectares of degraded land identified as potentially available for restoration worldwide, AF is considered the optimal solution for 1.5 billion hectares (Minnemeyer et al., 2011). An evaluation conducted from a purely financial perspective in 42 African countries demonstrated that the benefits of restoration and land conservation for agricultural productivity outweigh the cost of inaction by a factor of 3 to 26 (Oberle et al., 2019 cited in FAO, 2022). From an economic perspective, taking market-free ecosystem services into account, the effects are even more significant. A meta-analysis of 89 studies (Benayas et al, 2009) on a wide range of ecosystems internationally found that restoration through AF interventions increased biodiversity protection (particularly in terms of species abundance and richness, diversity, growth, and biomass of organisms present) and led to improvements in other ecosystem services by an average of 44 % and 25 %, respectively, compared to previous levels. These significant increases have also been recently confirmed in various European countries for other regulating ecosystem services, such as the reduction of soil erosion (increased by 25-51 %) (Crous-Duran et al., 2020).

When comparing the strictly financial advantage of AF over CA conducted under the same environmental conditions, the challenges of economic evaluation become more complex. One method of comparison is the land-equivalent ratio, which is defined as the ratio between the area under CA and the area under AF required to yield the same output in physical or economic terms. In a study of five agroforestry systems in five European countries (Lehmann et al., 2020), it was found that the adoption of AF results in a land-equivalent ratio ranging from 1.36 to 2.00 (i.e., agronomic production increased by 36 to 100 percent), depending on the type of crop and different local conditions. However, the results of the soil-equivalent ratio in financial terms are more complex to generalise. Higher levels of productivity (particularly agricultural biomass produced per unit of cultivated area) are often achieved with an intensification of labour and capital factors in AF systems.

These factors can be influenced by cost and availability constraints. Another challenging aspect when comparing the economic performance of AF with that of CA is related to product prices. While CA typically involves explicit market prices for products, in AF, even in the EU context, some products may have non-explicit prices. This is because they are used for self-consumption (e.g., firewood), internal re-use (e.g., foliage used as fodder or litter), or serve as substitutes for inputs with explicit prices typically used in CA (e.g., fertilisers replaced by the effects of nitrogen-fixing tree species).

These economic considerations comparing CA and AF are influenced by the fact that CA analyses typically refer to highly standardised investments. For example, maize cultivation in the Po Valley, apple production in South Tyrol, or strawberry production in Basilicata are all examples of standardised CA practices. In contrast, standardisation is low in AF. In Italy, for instance, AF traditionally encompasses various agroforestry systems with differing tree cover densities, ranging from a few scattered trees to actual forests or olive grove grazing. Additionally, AF involves various crop combinations (intercropping) and forms of animal husbandry (Paris et al., 2019). Agricultural control systems often do not effectively account for these diverse agricultural activities, making it challenging to conduct a generalised comparison of yields, let alone economic returns.

Furthermore, there are other factors that contribute to the complexity of economic analysis in AF and comparison with CA. These include the structure of costs and revenues over time, as well as the structure and distribution of risks associated with both systems.

Regarding the time dimension, CA typically involves constant annual production, whereas investment in AF comes into full swing after several years, primarily due to the presence of the tree component with multi-year production cycles (FAO, 2022). Farmers thus face challenges in prioritising the upfront costs associated with AF systems. In comparing costs (which are usually incurred upfront) and revenues (often delayed, sometimes by several years in the case of AF), the discount rate plays a decisive role. This rate could be calculated as the cost of borrowed capital or as the expected rate of return by the farmer. However, especially for small to medium-sized entrepreneurs commonly interested in AF, these rates tend to be relatively high, thereby reducing the attractiveness of the investment.

On the other hand, the presence of diversified income streams from annual agricultural crops and forestry activities in AF systems, operating at different timescales (e.g., short-term biomass production and long-term quality timber), tends to mitigate risks associated with income stabilisation. Additional differentiating elements between CA and AF with economic relevance include economies of scale, which are typically lower in specialised crop management, and marketing costs. Mechanisation in CA often leads to lower costs, as does the distribution of fertilisers and cultural care.

Finally, there exists a significant disparity in the availability of information-related components between CA and AF, especially when it comes to privately-initiated efforts. This disparity is governed by mechanisms such as patentability and the privatisation of profits from the sale of certain innovations. There tends to be more investment in research related to industrialised agriculture, greater capacity for technology transfer, and more information on markets in CA compared to AF.

However, it's worth noting that AF, unlike CA, can benefit from the rediscovery and improved application of *indigenous traditional* or *local knowledge*, which is a fundamental aspect of agricultural policies in many countries of the global South. This rediscovery has also been reevaluated in Western economies. Additionally, AF benefits from various incremental system innovations that do not require large investments (Paris et al., 2019). This rediscovery is intertwined with the growing appreciation of traditional varieties, agro-ecological, organic, and biodynamic farming products, as well as agricultural activities with low environmental impact, which are increasingly valued by consumers in advanced economies, typified by the segment defined as 'LOHAS' (Lifestyles Of Health and Sustainability).

In summary, the greater social benefits linked to AF advocate for a stronger commitment from agricultural and rural development policies towards a complete conditionality of public support to agriculture. This entails aggregating and systematising support actions, which have thus far been dispersed over various measures and therefore less effective (Paris et al., 2019). By doing so, AF could and should be rewarded for its advanced integration conditions between financial (or commercial) productivity and the provision of market-less ecosystem services.

Environmental sustainability and ecosystem services

The contribution of agroforestry to environmental sustainability is significant due to its multifaceted environmental, social, and economic functions. The complexity of agroforestry systems leads to efficiency gains in the utilisation of nutrients, light and water (Plieninger et al., 2020). As a result, impacts on natural resources are minimised, while simultaneously increasing in the productive capacity of soils and conserving biodiversity. Agroforestry also plays a crucial role in environmental protection, adaptation, and mitigation to climate change, which are fundamental aspects of land environmental sustainability and sustainable development programmes (Sobola et al., 2015).

Ecosystem services, as defined by the Millennium Ecosystem Assessment (2005), can be organised into four macro-categories:

- I) **supply services**: these includes the goods or products obtained from ecosystems, such as timber and agricultural production;
- II) **regulating services**: these encompass the benefits gained from controlling natural ecosystem processes, including reducing soil erosion, protecting against flooding, and filtering pollutants in soil and surface water. Regulating services also contribute to reducing greenhouse gases;
- III) **supporting services**: these are natural processes that maintain other ecosystem services, such as the creation of buffer zones between forest and agricultural environments and the establishment of ecological connection elements;
- IV) **cultural services**: These are non-material benefits obtained from ecosystems, such as the preservation of rural landscapes and biodiversity, as well as the use of these resources by the community for recreational activities.

These ecosystem services can be considered on different spatial and temporal scales (Jose, 2009), directly or indirectly contributing to human well-being. Conversely, in ecosystems where negative effects on human

well-being are predominant, these are referred to as disservices. Ecosystem processes and functions, which precede ecosystem services, describe biophysical relationships that exist irrespective of whether humans benefit from them or not (Costanza et al., 2017). Fast-growing species such as poplar can be of considerable interest for agroforestry, as they can provide numerous ecosystem services. These include the production of valuable wood, biomass for energy, carbon sequestration, water purification, regulation of the hydrological cycle, landscape connectivity (ecological corridors), biodiversity conservation, and reduction of soil erosion processes (Kanninen et al., 2010).

Agroforestry has been demonstrated to be more productive than traditional agricultural systems with the same *land* area as indicated by the *land equivalent ratio*. Studies conducted in European countries have shown that agroforestry can increase overall yields. This characteristic of agroforestry systems is particularly relevant given the projected increase in global demand for food crops by 70-85 % from 2000 to 2050. Moreover, in industrialised countries, agricultural areas are decreasing, making the productivity of each hectare of land even more critical (Millennium Ecosystem Assessment, 2005).

Simultaneously cultivating cereals and fast-growing tree species in agroforestry systems can yield considerable quantities of wood for industry within a 10-year rotation, averaging approximately 10-20 m³ ha⁻¹ year. Utilising species belonging to the *Populus* genus, enables the production of wood suitable for plywood, wood fibre boards, packaging, lumber, and to a lesser extent, energy production. This practice helps alleviate pressure on natural forests. Numerous studies have highlighted the benefits of natural forests and poplar plantations in mitigating flooding and soil erosion. Following the extreme flood events in the Po Valley in 1994 and 2000, Chiarabaglio et al. (2014) reported that poplar and other woody arboriculture in floodplains reduce soil erosion, debris deposition, and hydrogeological instability more effectively than conventional agricultural systems. These benefits were found to be comparable to those provided by natural forests. The presence of trees, such as poplars, helps prevent leaching of mobile nutrients like nitrogen into the groundwater, resulting in numerous groundwater benefits (Mbow et al. 2014). Poplars are also recognised for their potential in decontaminating polluted soils due to their rapid growth, extensive root system, and high water uptake. Various experiments have been conducted on different types of pollutants, including heavy metals, polycyclic aromatic hydrocarbons, hydrocarbons, and nitrogen compounds. Given the growing concern over the climatic consequences of greenhouse gas emissions, efforts are underway worldwide to increase carbon sequestration and reduce CO₂ emissions. Utilising trees or shrubs in agroforestry systems can enhance carbon sequestration compared to using only arable land or pastures, thus contributing to the carbon stock in the atmosphere, which is primarily composed of carbon dioxide. Carbon can be stored in the soil through the root system of trees via physical and biological processes, primarily in the surface horizons (30-50 cm). This stored carbon can then be utilised in biomass production for durable products in the building and construction sector, aligning with objectives such as climate change mitigation and environmental improvement. The estimated global potential for greenhouse gas sequestration by agriculture ranges from 1,500 to 4,300 megatons of CO₂ per year, with developing countries contributing to 70% of the total.

Agroforestry systems exhibit biomass three to four times greater than traditional agricultural systems lacking a tree component (Mbow et al., 2014). Considering a total agroforestry area of 1,023 million hectares worldwide and assuming a potential sequestration of 94 tons of carbon per hectare, it's estimated that a total of 2.2 petagrams of carbon could be accumulated over 50 years (Torralba et al., 2016). Studies analysing organic carbon and soil aggregates in agroforestry systems, particularly those consisting of poplar, have demonstrated significant carbon concentration in the soil. This accumulation appears to be closely related to the age of the plants (Jose 2009). Furthermore, the carbon sequestered in agroforestry systems holds the potential to be traded in voluntary carbon credit markets (Jose 2009).

In environmentally sensitive areas adjacent to watercourses, traditional cultivation practices may lead to numerous negative impacts. However, adopting a sustainable cultivation model such as agroforestry in riparian areas offers several environmental benefits. The incorporation of tree species diversifies the landscape, introducing new elements into the ecological network, which is often characterised by low biodiversity in traditional agricultural regions. Additionally, the presence of tree species creates ecological niches that provide favourable conditions for the survival of various animal and plant organisms, while also serving as windbreaks (Corona et al., 2018). Implementing agroforestry systems helps preserve the distinctive rural landscape of floodplains. Recent standards and management guidelines for sustainable poplar cultivation suggest that integrating tree species with seed crops can positively impact biodiversity compared to traditional agricultural systems (Corona et al., 2018).

Agroforestry, considered as a possible tool for sustainable land management, increases agricultural productivity and ecological stability while promoting environmental development. Beyond providing timber, food, and/or animal products, the integration of trees into agricultural systems can play a vital role in addressing critical environmental concerns. Agroforestry practices foster the creation of microclimates conducive to the growth of agricultural species, enhance mineral recycling, and provide increased soil cover, thereby safeguarding against erosion and extreme temperatures (Sobola et al., 2015). Moreover, agroforestry improves gas exchange and water use efficiency (Mbow et al., 2014), while also creating habitats for wildlife.

In conclusion, it can be asserted that agroforestry systems provide different possibilities for food production, thereby diversifying the income streams of agricultural entrepreneurs, while simultaneously playing a role in mitigating climate change. Agroforestry can significantly contribute to the supply of wood for industry and energy, aligning with multifunctional and environmentally suitable cultivation models. Research conducted both in Italy and abroad demonstrates the feasibility of utilising wood production to achieve environmental benefits and positive effects on biodiversity, landscape preservation, the carbon cycle, and soil protection (Facciotto et al., 2014).

Incentives and issues arising from previous rural development programmes

The reintroduction of woody vegetation into agricultural landscapes in our country has been fostered by EU agricultural policies since the early 1990s, particularly through measures such as the Accompanying Measures to the CAP of 1992 and Regulations (EEC) 2080/92 and 2078/92. Initially, this focus was driven by an acknowledgement of the environmental value of hedges, trees, and small woods, within the context of strategic reductions in agricultural exceptions. However, there was limited recognition of the biotic, abiotic, and economic relationships between the tree component and agricultural crops.

It wasn't until 2005 that the high ecological and social value of agroforestry was officially recognised at EU level. Council Regulation (EC) No 1698/2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) provided the first non-repayable support for the creation of agroforestry systems, acknowledging their 'high ecological and social value'. However, during the programming period of 2007-2013, agroforestry was included among the supported measures in the rural development plans of Member States, but it was categorised under forestry measures (Measure 222). This approach did not fully consider agroforestry as an integrated system of practices within agriculture. Instead, it treated agroforestry as a forestry-related addition in the agricultural context. As a result, only new plantations were financed, while traditional agroforestry systems that were already present across various territories of Member States remained largely overlooked.

In the recently concluded 2014-2020 Common Agricultural Policy (CAP) programme, agroforestry continued to receive support under the second pillar, which focuses on rural development policies. Specifically, Article 23 of Regulation 1305/2013 was dedicated to the creation of agroforestry systems. These systems were defined as **land-use systems in which trees are cultivated in combination with agriculture on the same land**. *Agroforestry means land use systems and practices in which woody perennial plants are deliberately integrated with crops and/or animals on the same parcel or land management unit without the intention of forming a forest stand. Trees can be arranged singly, in rows or in groups, while grazing can also take place within parcels (agroforestry, silvopastoral, mixed orchards) or on the boundaries between parcels (hedges, rows)"* (http://www.europeanagroforestry.eu/sites/default/files/pub/docs/08_measure_fiche_art_23_agroforestry_final.pdf). Under Measure 8.2, beneficiaries of the subsidy were eligible for 80 % coverage of the cost of installation and maintenance for the first five years. This measure was of interest to private owners, municipalities, and their associations. Details such as the minimum and maximum number of trees per hectare, technical design specifications, and limitations based on local soil, climate, and environmental conditions, as well as the list of allowable species, were defined at the Member State level. In the case of Italy, these details were determined by individual Regions that chose to activate the related measures.

Only with the introduction of the Omnibus Regulation at the end of 2017 did it become possible to provide aid for the improvement of already established agroforestry systems, rather than solely for the creation of new ones. The revised Article 23 of the regulation allowed for the **creation, regeneration, or renewal of agroforestry systems**.

However, in the Italian context, the implementation of Measure 222 and of 8.2 presented a disappointing picture. Initially, only two Regions, Veneto and Marche, participated in Measure 222, with only two beneficiaries in Veneto, covering a total of 24 hectares of plants. Financial commitments under this measure represented a mere 0.8 % of available funds and 0.4 % of expected areas.

Measure 8.2, although more focused on agroforestry practices, also yielded dismal outcomes. There were no applications for aid in the five regions with allocated funds (Basilicata, Marche, Apulia, Umbria and Veneto). As of the end of 2021, Basilicata had not issued any calls for tenders, while Marche and Umbria had not yet spent anything. Veneto had spent only around 1%, and for Apulia had utilised just 13% of the agroforestry budget (Rivieccio et al., *in press*).

The reasons behind the lack of interest in measures supporting agroforestry are multifaceted. Some commonly cited factors include the absence of a clear connection between planted areas and direct payments under Pillar I, as well as the conditional access to Measure 8.2 under Pillar II. Another significant factor is the insufficient training and awareness among farmers regarding agroforestry models, which has been identified as a barrier to adoption (Mosquera M.R. et al., 2017).

Many farmers, as well as technicians and civil servants, maintained a certain prejudice that viewed agroforestry measures as merely a re-proposal of agro-environmental initiatives and support for creating hedges, rows, and forest. These existing initiatives were perceived as saturated in terms of demand. Moreover, the inclusion of agroforestry measures within the framework of the second pillar of agricultural policy effectively precludes the possibility of economically valorising the entire agroforestry system. This reaffirms the perception that the tree component serves primarily environmental purposes and does not contribute directly to income generation. Essentially, there is a fundamental challenge in grasping the essence and synthesis of the concept of agroforestry. Furthermore, the Italian translation of the term “agroforestry” exacerbates this difficulty, as it still conveys the idea of **replacing agricultural land with forest cover**.

Several key recommendations for addressing critical issues and facilitating the gradual adoption of agroforestry models as resilient and large-scale opportunities were outlined in *deliverable 8.24* of the EU-funded project AGFORWARD. This document includes a comprehensive analysis of current regulations and proposes 15 summary recommendations aimed at establishing a genuine European strategy for agroforestry. Such a strategy would provide the essential framework for harnessing the potential of agroforestry as one of the most effective solutions within the context of the climate crisis, empowering the agricultural sector to contribute significantly to mitigation efforts.

Agroforestry in the *new* rural development

Under the new European programming, a single **CAP National Strategic Plan (NSP) 2023- 2027** has been drafted, encompassing both direct payments in agriculture (Pillar I) and rural development (pillar 2).

The Italian NSP was approved by the European Commission on December 2, 2022, and will be implemented through 21 Regional Rural Development Complements (RDPs).

Within the Italian NSP, agroforestry systems are included in two specific measures, one focused on investment (SRD), and the other on environmental commitment (SRA):

- SRD05 - Forestation/afforestation and agroforestry systems on agricultural land;
- SRA28 - Support for the maintenance of forestation/afforestation and agroforestry systems.

11.1 INTERVENTION FOR INSTALLATIONS ON *agricultural land* (SRD05)

Three actions are envisaged: the first two relate to natural afforestation (permanent woodland) and open-field arboriculture, while the third **action** is **SRD05.3 - Establishment of agroforestry systems on agricultural land, which are** defined as follows: systems in which the following are present on the same area

- Intercropping and agricultural production (3.1 - silvoarable systems) and
- animal husbandry (3.2 -silvopastoral systems)

with forest species with **a density ranging from no less than 50 to no more than 150 trees per hectare**, arranged in scattered order, rows, groups, or regular planting patterns.

These areas can be used for agricultural and fodder production, for direct grazing and/or mowing and for an ancillary production of wood assortments (construction wood and/or biomass for energy use), and/or non-wood forest products, as well as for windbreaks and environmental diversification. Additionally, it's important to note that the systems created are reversible at the end of the specified period of permanence outlined in the concession deed by the competent Managing Authority.

Eligibility criteria under the SPP (Support for Permanent Pastures) include: native tree and shrub forest species, including those of ancient origin or adapted to the local environmental and climatic conditions of the area, **including poplar clones and/or mycorrhizal clones and plants**. The agroforestry system must be maintained **for a period of more than 8 years**; the minimum eligible area is 1 hectare per application. The maximum eligible expenditure per hectare is set at 5,000 euro for silvopastoral systems and 4,000 euro, with the following contribution rates:

- 80 % in Piedmont, Umbria, Veneto;
- 100 % in Apulia, Sicily, Tuscany.

The implementation of action SRD05.3 is currently only planned in these six regions.

11.2 SUPPORT INTERVENTION FOR *environmental commitments* (SRA28)

Within the plant maintenance sheet, action SRA28.3 provides for an annual premium per hectare to cover the costs of maintenance (cultivation care) of agroforestry systems, along with the following maximum amounts and premium payment periods:

- 1500 euros/ha/year for 5 years for Puglia;
- 600 euros/ha/year for 8 years in Umbria;
- 800 euros/ha/year for 5 years in Toscana;
- 600 euros/ha/year for 5 years in Piemonte;
- 300 (silvoarable systems) - 350 (silvopastoral systems) euros/ha/year for 5 years in Veneto.

Although Sicilia implements the action of planting agroforestry systems (SRD05.3), it does not offer premiums for their maintenance like some other administrations.

Additionally, it's worth noting that certain regions are currently in the process of redefining the size of the maintenance unit premiums compared to the maximum amounts specified in the PHP.

Possibility of *certification* of wood products from agroforestry

12.1 *wood* production in agroforestry systems

As discussed in Chapter 6, trees serve various roles, often associated with diversified production. In a silvopastoral system, trees serve a dual purpose of providing animal welfare and yielding a woody product over time. Grazing animals benefit from the mitigating effect of extreme weather events while diversifying their diet with additional food sources, including certain botanical species with medicinal properties not typically found in cultivated pastures.

In a forestry system, trees are primarily cultivated for timber production or energy purposes, allowing space for the cultivation of main agricultural species. These TOF can also provide some mitigation of thermal extremes for the main crop and offer a diversified income stream for the owner, who may even establish a self-production chain for thermal energy to meet internal farm needs.

In an agroforestry system, trees can serve a combination of these functions, adapting to the specific context and objectives of the agricultural operation.

Figure 14 - *Silvoarable system analysed by GO Newton - Alley cropping at CIRAA Pisa with 12-metre row spacing for arable crops interspersed with poplar rows in short rotation forestry*
(Photo: Francesco Marini)



12.2 IMPORTANCE OF CERTIFICATION IN THE *AGROFORESTRY* *wood products market*

In one of Italy's national projects dedicated to studying and implementing agroforestry, the Operational Group of the PS GO NEWTON project - NEtWork for agroforestry in Tuscany under Measure 16.2 of the RDP 2014-2020 Tuscany Region Call PS-GO 2017 focused on various study topics, including certification types for products derived from agroforestry systems and wood products (Figure 14). Wood products sourced from management within agroforestry systems can now be certified as of 2024 through the PEFC Italy agroforestry scheme outlined in chapter 7 of this publication. Wood products, encompassing not just timber but also derived materials, produced sustainably within agroforestry systems listed above, may undergo certification and enter the market with a system certification attesting to the sustainability of their management. Results from the study conducted within the GO-NEWTON project revealed that 61 products (both processed and semi-processed) potentially qualify for existing certifications in the market, including quality, product, ethical or sustainability certifications. These certifications are applicable on an international scale, with 35 certification schemes having relevance on Italian, European, or global levels. However, a scheme specifically focused on certifying agroforestry systems as an integrated entities was not identified, but rather certifications were specific to individual products. Nonetheless, the potential for sustainability certification is evident in valorising the various products associated with business practices committed to socially and environmentally conscious production. This differentiation on the market adds value to the marketed product and provides consumers with assurance regarding the production's social and environmental responsibility. Recognising the necessity for proposing sustainable management criteria in this sector, **PEFC developed a standard for sustainable management of 'out-of-forest' areas.** Coordinated by the technical secretariat of PEFC Italy, the project involved research institutes, universities, professional associations, and sector companies. Their active participation and fruitful discussion facilitated the creation of the first national and international standard for the certification of sustainable agroforestry management. The certification, effective in Italy from April 2024, enables wood and tree products from agroforestry systems to be certified for their sustainability and legality.



Figure 15 - Agroforestry system in Sardinia, a cork oak woodland sown with herbaceous species in annual rotation and grazed by sheep for dairy production. (Photo: Francesco Marini)

Linking scientific knowledge to *management practices* in agroforestry

Considerable knowledge on the ecophysiology and management of agroforestry systems has been accumulated through research projects conducted across Italian regions.

However, it is imperative that this knowledge be summarised and transferred to farm managers. University education, particularly at the master's degree level, plays a key role in equipping young forestry and agronomy professionals with scientific expertise to provide technical guidance to farms. Currently, university training opportunities on agroforestry are available at the University of Padua and the University of Pisa.

The Department of Land and Agroforestry Systems of the University of Padua has introduced a Study Plan in "Agroforestry Systems" as part of the Master's Degree Course in Forestry and Environmental Sciences, starting from the Academic Year 2020-2021. This Study Plan offers 26 University Educational Credits (CFU), distributed across five disciplines related to: 1) ecophysiology and management of agroforestry systems; 2) agroforestry systems for soil conservation and recuperation; 3) agroforestry systems and ecosystem services; 4) wood arboriculture; 5) European design for forests and the environment.

Students are encouraged to analyse agroforestry systems from an ecosystem perspective, considering the system's functionality, complexity, multiple interactions, and temporal dynamics. This approach is crucial for managing both natural or man-made systems that offer a variety of services and goods. Through a formal agreement between the Veneto Region and Veneto Agricoltura, students have access to experimental farms across various pedoclimatic zones of Veneto. These farms provide opportunities for educational outings, internships, and experimental activities for dissertations.

At the Department of Agricultural, Food and Agro-environmental Sciences of the University of Pisa, the Master's Degree Course in Sustainable Agricultural Systems was launched in the academic year 2022-2023. The course offers common courses covering various aspects of agricultural production, including plant and animal production, defence-related topics, and rural and environmental valuation. The curriculum is divided into five tracks: 1) agricultural production quality, 2) *precision farming*, 3) agroecology, 4) innovative agro-industrial systems, 5) *bioeconomics*, delivered in English.

These curricula include subjects focused on the study of sustainable and agroforestry systems, such as *Agroforestry* (taught in English), Ecosystem Services of the Agro-livestock Farm, and Tree and Forest Ecosystems. The objective is to educate professionals with a high level of cultural, scientific, and practical knowledge in various fields of agricultural production within the context of ecological transition. Additionally, a course titled '*Advances in Agroforestry Systems*' has been established as part of the PhD programme in Agricultural, Food, and Agro-environmental Sciences. This course aims to equip students with the latest knowledge on sustainability and resilience assessment methodologies in forestry, silvopastoral and agroforestry systems.

Italian *agroforestry* association

AIAF (Italian Agroforestry Association - <http://www.agroforestry.it/>) was founded in 2012 through the initiative of a group of agronomists, foresters, as well as passionate technicians in agroforestry, coordinated by Giustino Mezzalana, manager of Veneto Agricoltura, who served as chairman of the board until 2022.

The objectives outlined in Article 2 of the association's Statute include promoting the adoption of sustainable agroforestry practices throughout Italy. Additionally, the association aims to support initiatives and actions focused on increasing awareness, knowledge, research, and policy development to encourage the use, cultivation, and dissemination of wood species on Italian farms. It seeks inspiration from international experiences and utilises available financial and non-financial resources at local, national, and international level, especially within the European Union. Furthermore, AIAF is dedicated to promoting the conservation and restoration of traditional agroforestry systems in Italy. It also strives to foster the economic value of products and services, both direct and indirect, generated by agroforestry systems, with a particular focus on promoting certification systems.

AIAF intends to provide a platform for all stakeholders involved in agroforestry, including farmers, agricultural and forestry technicians, public officials, policymakers, and researchers.

Since its inception, AIAF has been actively engaged in promoting agroforestry by raising public awareness through various initiatives such as training and dissemination initiatives, conducting research projects, supporting operational groups, establishing a network of pilot and demonstration farms, and fostering relationships with other agroforestry organisations nationally and internationally.

Under the leadership of a new board chaired by Alberto Mantino, comprised of technicians, researchers, and farmers, AIAF has strengthened

its network of members and contacts. It has actively participated in events like EURAF2020 and EURAF2022, organised by the *European Agroforestry Federation*, where AIAF represents Italy. These conferences have not only facilitated international networking but also provided a platform for Italian researchers and agroforestry enthusiasts to come together.

AIAF's overarching goal is to contribute to the development of agroforestry in Italy as a comprehensive strategy in both rural and urban areas. This includes supporting sustainable food, wood, and energy production while ensuring environmental protection, fostering sustainable economic growth, enhancing the cultural value of rural landscapes, and promoting community cohesion.

Furthermore, AIAF aims to expand and coordinate its network at the local level by establishing regional networks. This approach allows for better interpretation of the technical and administrative needs of agroforestry within specific geographical contexts.



Figure 16 - The current logo of the Italian Agroforestry Association

Conclusions

Agroforestry systems encompass various forms of land use and management, integrating woody perennial plants with arable land (**silvoarable systems**, see § 4.1) and/or animal husbandry (**silvopastoral systems**, see § 4.2). These systems capitalise on the synergies between trees and agricultural/livestock crops, allowing for more efficient utilisation of resources compared to monoculture models (see § 8-9). By incorporating trees into farming practices, agroforestry can enhance soil and water quality, mitigate wind erosion and flood damage, enhance resilience to climate change, boost biodiversity, aid in pest control, facilitate pollination processes, and diversify farm products. Consequently, the **long-term profitability** of agroforestry activities often surpasses that of monoculture investments.

The implementation of agroforestry **measures** holds promise as a **long-term strategy for adapting to** global changes, a recognition explicitly acknowledged by the **UN Conventions on Climate Change** and **Biological Diversity**. However, achieving effective implementation on a large scale requires the full engagement of stakeholders, ideally within robust **knowledge and innovation systems** (<https://ec.europa.eu/eip/agriculture/en/tags/akis>). To this end, it is imperative to network expertise and convene key actors, including researchers, public institutions, agricultural entrepreneurs, professionals, agricultural representatives, and contractors.

In line with this approach, this monograph has endeavoured to consolidate both the **methodologies** and **interactions** associated with the primary technical and economic elements defining agroforestry systems, along with addressing **critical** aspects. These efforts serve as valuable references to foster greater **awareness** and support tailored **training** initiatives aimed at enhancing **interest** and **competencies** for the renewed **valorisation of production chains based on agroforestry**.

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Case *Studies*

Below are files detailing several Italian case studies that have contributed to the development of experience and the acquisition of valuable data in the field of agroforestry.

Poplar and paulownia forestry systems

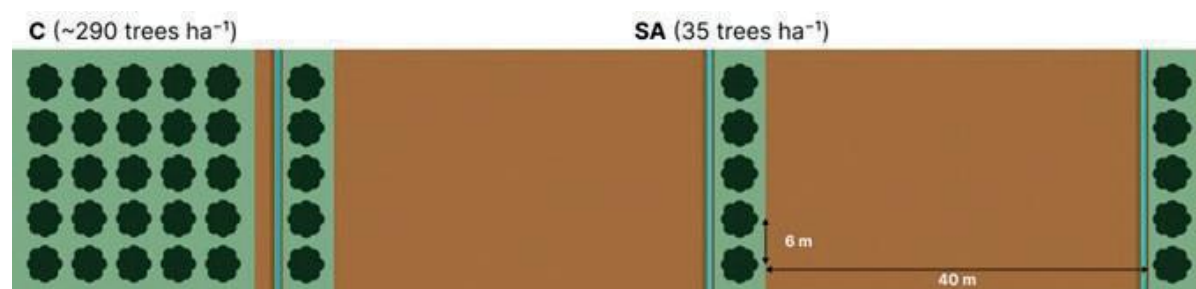
‘*Sasse Rami*’ pilot farm of Veneto Agricoltura

DESCRIPTION

The pilot and demonstration farm 'Sasse Rami', managed by Veneto Agricoltura, is located in Ceregnano (RO). In 2018, a clonal comparison field was established with 14 clones of poplar (*Populus × canadensis*) selected for Greater Environmental Sustainability (MSA) by CREA - Forestry and Wood Research Centre of Casale Monferrato. These clones were planted in both a specialised system (C: 6 x 6 m) and an *alley-cropping* silvo-arable (SA) system. In 2020, a clonal comparison field was conducted with 6 paulownia clones (*Paulownia tomentosa* Steud), 4 of which originated from China, in collaboration with the CNR - Istituto per la BioEconomia in Sesto Fiorentino. These clones were planted in a specialised plantation (5 x 4 m), and in 2023, were introduced in a new silvo-arable scheme. For both tree species, the silvo-arable design involves N-S oriented rows planted along 40-metre spaced drainage ditches, adapting to the arrangement of the plots in the plain of Ferrara.



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Planting scheme of poplar and paulownia in a specialised system (C: 6 x 6 m for poplar; 5 x 4 m for paulownia) and in an alley-cropping system (SA).



Threshing the different varieties of soft wheat in the silvo-arable system with poplar in the fourth growing season.



Paulownia plants in their second growing season

SILVICULTURAL MANAGEMENT

Poplar clones are cultivated in agroforestry mainly for the production of veneers for plywood and multilayers industry. For this purpose, they require training pruning during their development in order to obtain a stem free of branches for a height of at least 6 to 8 metres. Pruning is carried out during vegetative restand is repeated between July and August to eliminate the shoots along the stem. Paulownia is cultivated in agroforestry to produce timber utilised for products such as furniture, window frames, wall and floor coverings and stairs. The plants need to be pruned after the first year and before vegetative growth, the herbaceous shoots in the upper axil of the leaves need to be removed and pruned to obtain a stem free of branches for at least 5 metres in height.

SYLVOARABLE MANAGEMENT

Agronomic practices

The application of holistic flexible conservative (ACFO) is characterised by:

- I) continuous crop rotation wheat - (rapeseed) - soya - maize;
- II) constant soil cover utilising cover crops operation, including bulation;

- III) no inversion of the soil horizons (sowing on tillage or minimum tillage depending on conditions);
- IV) frequent use of the decompactor;
- V) precision agriculture (semi-automated guidance, variable rate dosing of seed, fertiliser, water);
- VI) Advanced Integrated Protection according to the Herbaceous Crops Bulletin;
- VII) inputs of quality organic matter;
- VIII) varietal choices that reduce the risks of soil compaction (e.g. early hybrids).

ECONOMIC OPPORTUNITIES

The plywood industry currently imports over 20% of its poplar wood requirements. Consequently, trochus with good technological qualities find ready buyers in the market. It's noteworthy that prices are currently experiencing an upward trend.

In contrast, the supply chain for paulownia wood in Italy remains underdeveloped. However, considering the wood's favourable technological characteristics, gradual development can be assumed in the coming years.



Installation of dendrometers to measure the radial growth of poplars, and sensors to monitor microclimatic parameters and soil water availability at different distances from the poplar row in the silvoarable system. The research activities are coordinated by the DAFNAE and TESAF Departments of the University of Padua.



Strengths

- Agroforestry contributes to the increase of organic matter in agricultural soils through the deposition of litter, incorporation of wood from shredding pruning residues, growth of tree roots, and fostering the development of beneficial soil fauna.



Challenges

- The interactions with agricultural crops are still to be investigated.
- There is a need to gain better experience with training pruning in silvo-arable systems.

Alley Cropping with poplar and English oak in the Po Valley-Venetian Plain, *Azienda Casaria*

DESCRIPTION

The Po Valley is renowned for its intensive and profitable agricultural cultivation, including crops such as wheat, maize and rice. Hybrid poplars (*Populus xeuroamericana*) are the predominant timber tree crop in the region, particularly in monoclonal plantations aimed at industrial timber production. Historically, intercropping of herbaceous crops with poplars was widely practised in Italy until the 1970s, but gradually fell out of practice. However, there is a renewed interest in intercropping poplars for timber alongside herbaceous crops, known as tree alley cropping, due to its environmental and productive benefits in mitigating climate change and addressing environmental challenges associated with modern monoculture agriculture. Public institutions in Italy and Europe offer funding to support alley cropping initiatives through Rural Development measures or actions. For instance, in 2014, 10 hectares of *alley cropping* were established on the Casaria farm with funding from the Veneto Rural Development Plan.



Contact details: Casaria Società Agricola Semplice via Frattesina 8, Masi (PD). www.aziendacasaria.it



SILVICULTURAL MANAGEMENT

Poplars of the hybrid clone 'I-214' were planted along the existing drainage ditches, spaced 30-35 metres apart. These poplars were alternated with oak trees, with a row spacing of 5 metres, resulting in a total density of approximately 60 plants per hectare. The poplars typically have a utilisation period of approximately 10 years, while the oak trees have a longer rotation cycle, lasting between 30 and 40 years.

AGRICULTURAL PRODUCTION

The agricultural land between the rows of trees was managed according to current cultivation practices, with standard machinery, without any additional costs and time due to the presence of the trees along the drainage channels. The productivity of the associated crops was monitored from 2015 to 2022, showing no significant reductions.



ECONOMIC OPPORTUNITIES

The CNR-IRET conducted a study on the agroforestry system in collaboration with the Casaria and Veneto Agricoltura company. In 2014, these entities worked together with farm owners to plan the trial. The study involved recording data on the production of poplars and associated crops, as well as on-farm cultivation costs. Financial and experimental simulations suggest that agroforestry trees with low planting density are expected to yield higher individual volumes compared to plantation trees. The production of industrial timber (for plywood, packaging and chips) within cultivated fields facilitates the diversification of farm products, thereby increasing profitability per unit area. By 2022, nine years after planting, the poplars are ready to be harvested, with valuations ranging from 100 to 120 euros per standing plant for the farm property. Such an *alley cropping* model is easily replicable in fertile alluvial soils, with drainage ditches being essential for maintaining proper water balance in the soil. For future poplar rotations, the use of new hybrid clones with Greater Environmental Sustainability is recommended.



Strengths

- The trees on the side of the gully allow productive use of the non-cultivated land;
- Trees increase the absorption of carbon in both wood and soil, contributing to *carbon farming*;
- Empirical observations suggest that it is not necessary to use pesticides on poplars, as is the case with denser, single-specification plantations.



Challenges

- Trees in low-density plantations require specific and timely pruning to maintain the technological quality of the plywood;
- The price of poplar wood on the domestic market may fluctuate over time due to foreign imports.

“Paganico Estate” agosilvopastoral farm

DESCRIPTION

The Tenuta di Paganico is an organic agro-livestock farm spanning 1,500 hectares, specialising in the rearing of Maremman cattle, Cinta Senese pigs, and crossbreeds, as well as Maremmani horses in the wild. It follows silvopastoral management for all production phases. Within its 400 hectares of arable land, it cultivates fodder and grain for livestock and human consumption. Additionally, the farm offers hospitality, catering and educational services. It boasts a farm shop with butcher's counter, delicatessen, grocery store, and restaurant. Furthermore, it produces oil, wine, grappa, and beer. The Tenuta di Paganico actively participates in various projects and collaborations, including those at the European level, thanks to a territorial network of companies and research bodies. It continually shapes new ideas with innovative techniques.

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www.tenutadipaganico.it, e-mail: azienda@tenutadipaganico.it



TENUTA DI PAGANICO
ALLEVAMENTO BRADO - AGRIMACELLERIA - AGRITURISMO



SILVICULTURAL MANAGEMENT

Until the mid-1950s, the 1,100 ha of woodland consisted mainly of coppice of *Quercus cerris* L. used for the production of charcoal, firewood, heather logs, with 14/15 year shifts. With the onset of the 'coppice crisis', the farm pursued a project to create 40-50 m wide firebreaks by clearing and planting pasture grassland and converting the coppice to pastureland, creating several sections with watering points and barbed-wire fences to contain livestock. The planting of tall trees has generally been successful: today the stands have good development and vegetative vigour, with an average plant height of over 20 m and an average diameter of around 30 cm. The transitional coppices have already been largely affected by intermittent cuts that have regulated their density, stimulating individual trees' diameter growth and the formation of denser crowns. As a result, the amount of penetrating light has increased, favouring the development of herbaceous species and the regrowth of the still viable coppices, sources of food for cattle and wild animals.

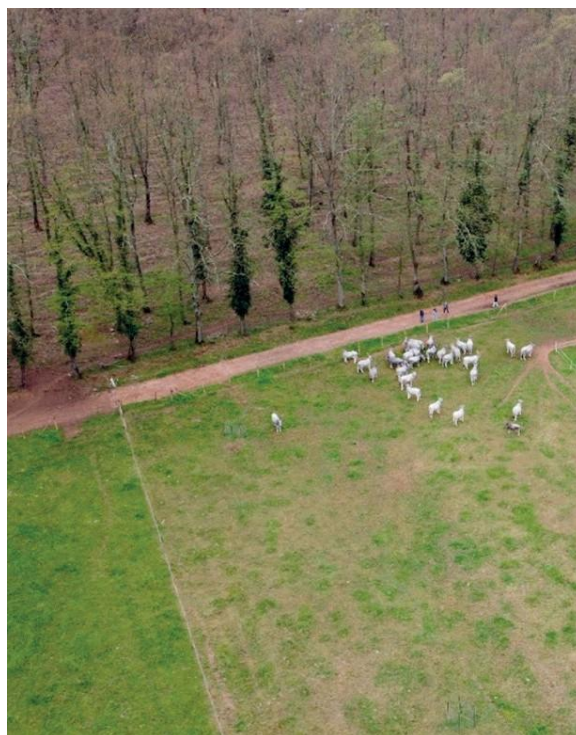
ANIMAL WELFARE

The choice of the Maremmana breed, which has co-evolved with the woods of the Maremma for thousands of years, was made precisely to emphasise the adaptation that these animals demonstrate in their environment. Grazing, browsing, *self-medication*, shelter and defence form the foundation of

their life in the woods, under the daily supervision of the operator. The operator is adept at interpreting the behavioural signals of the animals and supplements their food with farm products if necessary.

ECONOMIC OPPORTUNITIES

- Meat production with 'high environmental value';
- valorisation of timber from sustainable forest management;
- experiential tourism and training activities.



Strengths

- Agroecological agricultural image in a tourist area;
- demand for *pasture-based* meat is rising;
- business management in line with EU development strategies;
- circular economy and multifunctionality;
- strong prospects for technical and economic improvement;
- identity production of food, with provision of ecosystem services;
- consistent ethical management.



Challenges

- Income linked to EU subsidies;
- difficulties in finding professionals for extensive livestock breeding and meat valorisation;
- company located far from major cities;
- vast fragmented territory;
- high running costs;
- low productivity per unit of area;
- visionary approach vs. economic goals.

Monte Pisanu State Forest

DESCRIPTION

Monte Pisanu is a State forest initially protected by Royal Decree in 1886. It spans between the mountains of the municipalities of Bono and Bottidda, in Goceano, within the province of Sassari, covering a total surface area of 1994 hectares. The geology of the area comprises volcanic soils and clastic deposits. Additionally, there are soils derived from crystalline schists, characterised by high potassium levels, moderate phosphoric anhydride content, and low calcium and clay content. Within the site, the CNR ISPAAM has conducted studies on the effect of grazing on vegetation dynamics of the pasture and seed bank, and on fire risk.

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Panoramic view of the area with Monte Rasu (1259 m a.s.l.) in the background.



Grazed area within the forest.



Fenced area for monitoring the vegetation dynamics of the pasture.

SILVICULTURAL MANAGEMENT

The vegetation in the area is predominantly characterised by the presence of downy oak (*Quercus pubescens* Willd), which extends to altitudes exceeding 1000 metres above sea level. These downy oaks often exhibit a bushy habit and are interspersed with small mountain meadows. On the summit of Monte Rasu, the highest peak in the area, vegetation is limited to thyme, helichrysum, and rockrose. Areas of oak, accompanied by holly, are found on the eastern slope, which has been less affected by fires and deforestation. At lower altitudes, the vegetation mainly consists of cork oaks and holm oaks. Notably, at Pedra Rujas, there is a significant monumental cork oak. A distinctive feature of the forest in the Sos Nibberos area is a biotope containing thousand-year-old European yews (*Taxus baccata* L.), declared a natural monument in 1994. These yews boast a trunk diameter of approximately 1 metre and a crown height exceeding 10 metres. In recent years, efforts have been made to restore the habitat of some oak coppice forests through the partial or total removal of conifers.

Grazing typically occurs in areas where tree density is lower or in clearings.

The grazing intensity is highest for dairy sheep (rotational grazing) and lowest for beef cattle (cow-calf line), totaling approximately 650 LU per year across a total area of 2000 hectares. The abundance of perennial grasses and annual legumes significantly enhances the overall pastoral value. Grazed areas facilitate the preservation of a higher biodiversity of herbaceous species compared to areas that are closed to grazing.

ECONOMIC OPPORTUNITIES

High-quality animal productions are notable, exemplified by daily milk production ranging from 700 to 1500 litres, entirely sold to the dairy industry. Additionally, significant production of cork (approximately 120 tons) is sold at public auction for approximately EUR 1000 per ton, along with firewood sourced from conifers (110 m³) and broadleaf trees (30 m³). Further cuts of broadleaves, such as oaks, are undertaken in response to biotic and abiotic damage (60 m³). Lastly, recreational and educational activities targeting schools, as well as the welcoming of tourists and hikers, contribute to the farm's activities.



Strengths

- High animal and plant biodiversity; 200 plant species, primarily consisting of therophytes, hemicryptophytes, and geophytes, attributable to 34 families; at least five endemic species;
- Large area with low industrialisation.



Challenges

- Mediterranean rural landscapes are often susceptible to frequent fires. Regardless of the causes and structure of the landscape, grazing limits the risk of fires by reducing the presence of combustible biomass.

The Asprinio Alberata, *Alberata aversana* or vine married to the poplar

DESCRIPTION

The alberata d'Asprinio, also known as Alberata Aversana or Vite Maritata al Pioppo, is a vine cultivation system that has characterised and continues to define the landscape of the Aversa countryside for centuries. It is named 'married vine' because the vine rows grow tall and are supported by living supports; typically poplars or elms. The vine, which can reach heights of up to 15 metres, extends between the stakes with the assistance of taut galvanised iron wires. The arrangement of the trellises often follows the Roman centuriation which was the system used to organise agricultural territories. The tradition of marrying vines with poplars dates back to the Etruscans, who exploited the climbing characteristic of *Vitis vinifera* L. by placing it on trees, which acted as natural supports. This approach allows for cultivation to occur vertically, preserving land for other crops while maximizing space utilisation. Furthermore, the cultivation typically follows the classic north-south arrangement to optimise sun exposure.

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arch. Michele Autiero - Pro Loco Cesa.
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MANAGEMENT

These impressive green barriers have given rise to a unique wine-growing culture intricately tied to the farming method. The harvesting of Asprinia grapes has been dubbed 'La Vendemmia Eroica', or the heroic Harvest, as it is carried out by skilled grape-pickers who adeptly ascend heights of up to 15 metres using a custom-made ladder known as 'Scalillo'. This ladder allows climbers to utilise three techniques: 'A spalla' (on the shoulder), 'a Braccia' (by arm) and 'a Recchia' (using a hook). Once harvested, the grapes are placed in a conical-shaped basket called 'Fescina', which features a pointed end for stability when placed on the ground..

ECONOMIC OPPORTUNITIES

The cultivation of poplar vine and its breeding have historically been widespread in the Aversa countryside. Their peak occurred during the 1950s and 1960s, but experienced a drastic decline from the 1970s onwards. During this period, many farmers chose to uproot their trees and transitioned to planting specialised orchards. Simultaneously, urban development increased, partially due to population growth, further diminishing the available space for tree cultivation and consequently reducing Asprinio production. Data reveals a significant decrease in cultivation area, dropping from 16 thousand hectares in the 1960s to just under 200 hectares today. The few remaining producers either make wine for their own consumption or increasingly frequently sell the grapes, resulting in a decline in the value of this cultivation within the production sector. However, in recent years, there has been a

reversal of this trend, with the emergence of new farms operated by young entrepreneurs who have chosen to focus on Asprinio production.



Strengths

- The trellis training system enables optimal utilisation of small plots of land through a three-tiered cultivation approach: on the first level, cereals and vegetables are cultivated, on the second level, citrus fruits and orchards are grown, and finally, on the third level, vines are cultivated. The elevated structure promotes excellent ventilation and sunlight exposure, thereby reducing the necessity for phytosanitary treatments.



Challenges

The primary challenge lies in preserving this ancient native vine and its breeding. Furthermore, the objective is to attain UNESCO intangible heritage status for its uniqueness as the highest grape variety in the world. This recognition could result in heightened sales of Asprinio wine and the development of wine and food tourism in the area.

Agro-Environmental Research Centre *“Enrico Avanzi”* University of Pisa

DESCRIPTION

The E. Avanzi Research Centre is one of Europe's largest research facilities dedicated to the study of sustainable agricultural systems. Located within the Migliarino - San Rossore - Massaciuccoli Natural Park and the biosphere reserve 'Selve Costiere di Toscana', it covers an expansive area of 1400 hectares, stretching from the village of San Piero a Grado to the sea. Its history began in 1963, when the former Tombolo estate was entrusted to the University of Pisa to advance research and education in the fields of agricultural and veterinary sciences. The Centre bears the name of Professor Enrico Avanzi, a distinguished scholar, agronomist and former Rector of the University of Pisa, serving from 1947 to 1959.

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LONG TIME TRIAL, LTE ARNINO

The intercropping of woody perennial and herbaceous crops, whether annual or multiannual, is one of the potential strategies to reverse the progressive simplification of agricultural systems and enhance their environmental, economic and social sustainability, as well as their resilience to ongoing climate change. To deepen our understanding of the potential contribution of perennial crops within arable or mixed (agro-pastoral) systems, a special trial is currently underway at the Centro di Ricerche Agro-ambientali 'Enrico Avanzi',

conducted by researchers from the DISAA-a of the University of Pisa, and the Scuola Superiore Sant'Anna, with the support of researchers from CREA - Forestry and Wood. The open field experimentation, known as ARNINO LTE (long-term experiment), focuses on studying the ecosystem services generated by agroforestry systems and involves comparing two crop rotations (three-year arable and seven-year mixed) in two systems: agroforestry and conventional, as illustrated in the figure below.



Strengths

- Study of the behaviour of different herbaceous crops in the presence of trees;
- Study on the effect of the presence of trees in arable and mixed systems;
- Field trial conducted under conditions comparable to farms.



Challenges

- Maintaining the field trial for an extended period to gather data on wood production (45 years);
- Sustainably managing herbaceous, tree and animal resources within a reproducible farm system to facilitate the adoption of proven innovations.

Farm

“Una Garlanda”

DESCRIPTION

Una Garlanda is an agro-forestry rice farm and organic seed company. It covers an area of 140 hectares, 130 of which are arable land (clayey and constipated soils) while the remaining 10 hectares are woodland predominantly comprising oak (*Quercus robur* L.), white hornbeam (*Carpinus betulus* L.) and birch (*Betula pendula* Roth). The woodland area is enclosed in the 'Baragge di Rovasenda' (VC), which is a rare example of foothill moorland recognised as a 'Special Area of Conservation (SAC)' of the Natura 2000 Network. The degradation of this ecosystem, attributed to industrial settlements and intensive rice cultivation, prompted the owners to initiate, in the late 1990s, the pioneering conversion of management and production practices towards environmental protection models.

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Panoramic view of the rice fields in Agroforestry.



Examples of green mulching



Oasis Emys Orbicularis (marsh tortoise)

AGRICULTURAL PRODUCTION

Rice cultivation occupies approximately 50 percent of the cultivation area, with the utilisation of indigenous, non-hybrid cultivars and/or old conservation varieties that the farm is responsible for keeping in good condition. Further productions are reported, including: seed rice, other grains and legumes for sale, fruit, carps and poultry meat for self-consumption.

ECONOMIC OPPORTUNITIES

High-quality organic products

Annual productions of 2500 q of rice, millet (100 q), oats (60 q), rye (20 q), cowpeas (120 q) processed by hand in the farm, with re-use of by-products, and entirely sold to retailers and *e-commerce*.

Production and sale of Italy's only BIO seed paddy rice

Approximately 100 q per year.

Energy sustainability

Savings in expenditure on pesticides and seeds (100 %), diesel (75 %), and irrigation water (50 %). Self-production of the entire wood requirement for heating and 50 % of the electricity requirement (certified Green photovoltaic).

Ecosystem services produced by agroforestry

Carbon sequestration in woody biomass, fertility enhancement and reduction of wind and water erosion of soil, protection from extreme weather events, reduction of diseases/parasites.

Tourism and environmental education

The farm and its habitats of community importance such as the oasis of the marsh tortoise (*Emys orbicularis*) welcome farmers, researchers, hikers and organised guided tours for schools and universities.



Strengths

- High cultivated and natural biodiversity (flora and fauna) documented by research carried out by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) and the Universities of Turin, Milan and the Eastern Piedmont, with the presence of numerous protected species.



Challenges

- In the wetlands, where rice paddies reside, lives 40% of the world's biodiversity, which has been reduced over the last 60 years by intensive agricultural practices; sustainable rice farming gives back agriculture its fundamental role in preserving these ecosystems.

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