This project is part of the PRIMA programme supported by the European Union

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Report on innovative agroforestry systems and models across the Mediterranean

Project Acronym: COSMOS

Project name: Coordinated Optimization for Sustainable Mediterranean Agroforestry with Truffles and High-Value Species

Call: Multi-Topics. Thematic Area 2-Farming Systems in the Nexus

Work Package: WP1. Agricultural diversification: economic and socio-ecological innovation, resilience and sustainability of agroforestry systems

Task Number: Task 1.1. Studies on agroforestry systems: Innovation, socio-environmental resilience and sustainability

Lead beneficiary: University of Çukurova (Ç.Ü)

Contributing beneficiary: All partners

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List of Abbreviations

Agrotecnio: Center of Research in Agrotechnology.

Ç.Ü: Çukurova University.

CFRI: Croatian Forest Research Institute.

CNRS: Centre National de la Recherche Scientifique.

COSMOS: Coordinated Optimization for Sustainable Mediterranean Agroforestry with Truffles and High-Value Species.

CTFC: Forest Science and Technology Centre of Catalonia.

Demirsoy Tarim: Demirsoy Tarim company

DS: Demonstration site

IDForest: Biotecnología Forestal Aplicada S.L.

LL: Living Lab

MAPs: Medicinal and Aromatic Plants

RBI: Ruđer Bošković Institute.

SFI: Slovenian Forestry Institute.

UNISI: University of Siena.

Dissemination Level

[X] PU- Public: must be available on the COSMOS's website

[ ] CO- Confidential: Only for members of the Consortium and the Commission Services

[ ] CI – Classified. As referred into Commission Decision 2001/844/EC

Document History

Edition	Date	Status	Author
Version 3	24-07-2026	Final version	Ç.Ü

Abstract

This report first explains the factors influencing the emergence of agroforestry. Then, the definition of agroforestry is examined, its scope is discussed, and different agroforestry systems in practice are introduced and examined with examples. The report continues by comprehensively explaining new trends in agroforestry in the Mediterranean. The challenges that Mediterranean agroforestry will face in front of climate change and global warming scenarios, and the critical importance of the region in this context, are emphasized. However, the report does not limit itself to the Mediterranean in its examples and applications; it also presents examples and applications from different parts of the world. In this context, the use, benefits, and applications of innovative systems such as precision agriculture, precision agroforestry, remote sensing, Geographic Information Systems (GIS), artificial intelligence, sensors, agricultural ecosystem monitoring, plant genetics technology, Internet of Things (IoT), cloud computing, machine learning (ML), and unmanned aerial vehicles (UAVs) in agroforestry are explained with examples. Innovative agroforestry systems such as climate-friendly agroforestry practices, urban agroforestry, and vertical farming integration are defined. The final section of the report provides some examples of applications and presents examples of recent projects on the use of new technologies in Mediterranean agroforestry.

1. Introduction

1.1. The Growing Relevance of Agroforestry in the Global Agenda

The world is currently experiencing significant environmental crises due to climate change, deforestation, soil erosion, and desertification (Barnosky et al. 2011; IPCC, 2021; Le et al., 2025). These crises, largely caused by human activities, are leading to a rapid decline in ecosystem functions such as water regulation, pollination, and soil fertility (IPBES, 2019; Le et al., 2025). As a result of this situation, biodiversity loss is occurring, and this is becoming increasingly alarming (IPBES, 2019; Le et al., 2025). Furthermore, land abandonment (Zerbe, 2022) threatens the sustainability of agroforestry (Le et al., 2025). In recent years, the gradual abandonment of agricultural land has led to the spontaneous regeneration of forests, particularly in Mediterranean Europe (Valladares et al., 2014), with forests in the Mediterranean increasing by 2% between 2010 and 2015, covering 10% of the total area of Mediterranean countries (Bou Dagher-Kharrat et al., 2022). However, this rate varies between countries, and the very high pressure on forested areas in southern Mediterranean countries may be due to population growth, expansion of agricultural land, livestock pressure, and overuse of water resources (Peñuelas and Sardans, 2021; Bou Dagher-Kharrat et al., 2022). The Mediterranean Forest Research Agenda 2030 (MFRA 2030) identifies four priority areas to be addressed over the next decade: forest resilience in the context of forest degradation related to global change, conservation and management of biodiversity and forest genetic resources, forest management addressing trade-offs and synergies among multiple ecosystem services, and social and business innovations and policy tools supporting a bioeconomy based on Mediterranean forests (Bou Dagher-Kharrat et al., 2022).

Agroforestry has attracted particular attention in recent years due to its potential to enhance climate resilience and the sustainability of agricultural systems (Scordia et al., 2023). Agroforestry contributes to the implementation of nine of the seventeen Sustainable Development Goals, including Smart Agriculture, Food Security, and Rural Employment (Andersson, 2018), and is included in several strategies of the European Green Deal (Scordia et al., 2023). In the new common agricultural policy, agroforestry is identified as a potential agricultural practice supporting the transition to a sustainable food system and the achievement of the EU's climate goals in the ecological schemes outlined (DG Agriculture, 2021; Scordia et al., 2023). The establishment of the International Council for Agroforestry Research (ICRAF) in 1977 formalized agroforestry (Dagar et al., 2024). The International Institute of Tropical Agriculture (IITA) has expanded its field of activity by integrating trees and shrubs into agricultural production (Kang et al., 1981; Dagar et al., 2024). Initially, the African Information Council, ICRAF joined CGIAR in 1991 for global agroforestry research and later changed its name to the World Centre for Agroforestry in 2002 (www.icraf.cgiar.org) (Dagar et al., 2024). The concept of agroforestry also evolute and originally it was shaped around the integration of trees and other crops at the individual plot level, subsequently focusing on the interactions between trees, soil, and crops, and the microclimatic effects of trees (Dagar et al., 2024). A significant European agroforestry research project, “AGFORWARD,” co-funded under the European Commission’s seventh Framework Programme in 2016 and involving partners from across Europe, has changed the understanding of European agroforestry practices and farmers’ perceptions (Dagar et al., 2024). Indeed, over 1.2 billion people in rural and urban areas interact with agroforestry practices, products, and services, and these practices cover more than one billion hectares globally (Dagar et al., 2024).

Agroforestry systems keep atmospheric carbon dioxide in above-ground and underground tissues, acting as carbon reservoirs (Raveendra et al., 2017; Nuwarapaksha et al., 2025). Therefore, they play a significant role in mitigating climate change and facilitate climate change preparedness and adaptation in agriculture through soil improvement, water retention, and distribution (Nuwarapaksha et al., 2025). In terms of biodiversity, habitat provision and ecological connectivity are continued in agroforestry through efforts to support habitats for advantageous species and connect smaller ecosystems in degraded geographic areas (Dissanayaka et al., 2024; Nuwarapaksha et al., 2025). Given the high rate of global species loss, agroforestry is important in addressing the conflict between conservation and agricultural goals (Nuwarapaksha et al., 2025). Trees, by supporting to increase soil fertility, can help to struggle with erosion and desertification and offer a useful way to rehabilitate degraded lands (Nuwarapaksha et al., 2025). Agroforestry systems support water management in water-scarce regions by reducing evaporation (Atapattu et al., 2017a; Nuwarapaksha et al., 2025). Additionally, and from a socioeconomic perspective, agroforestry offers a significant solution for poverty alleviation, promoting the development of rural areas (Nuwarapaksha et al., 2025). From the ecological point of view, the crops are protected from direct sunlight by trees (preventing the physiological damage of sunburn), while ensuring that sufficient photosynthetically active radiation (PAR), the spectral range of solar radiation between 400-700 nanometers used by plants for photosynthesis, reaches the sub-layer products (Udumann et al., 2024; Nuwarapaksha et al., 2025).

The Mediterranean region is known to be a climate change hotspot. Due to the increased frequency and intensity of summer heat waves, prolonged droughts can be expected. Due to the high evaporation rates typical from the Mediterranean region, and the increasing effect of climate change in the area, yield reductions are expected in many crops (Giannakopoulos et al., 2009; Scordia et al., 2023). In this context, agroforestry practices, through the shade provided by trees, can act as crop protectors from abiotic stress factors, including strong winds as well as other extreme weather conditions (Kanzler et al., 2019; Markwitz et al., 2020; Scordia et al., 2023).

1.2. Classifications of Agroforestry systems. European and Mediterranean models

Agroforestry systems have a long tradition in Mediterranean-type ecosystems. Specialists on this subject classify agroforestry systems into various categories: agroforestry, agroforestry-grassland, or forest-grassland systems (Dagar et al., 2024). Another classification includes silvoarable systems, silvopastoral systems, forest farming, riparian buffer strips, and windbreaks/fences (Mosquera-Losada et al., 202; Santos et al., 2023). In other words, agroforestry practices include corridor planting, which involves growing crops between rows of trees; silvopastoral production, where trees coexist with pastures for livestock; forest gardening, known as growing specific high-value crops in a forest-like environment; and water conservation, which involves using trees to protect waterways (Nuwarapaksha et al., 2024; Nuwarapaksha et al., 2025). Systems such as silvopastoral farming, forest farming, corridor planting, and riparian buffer strips increase biodiversity, conserve soil, improve nutrient dynamics and water quality, increase carbon (C) sequestration, and thus combine productivity with ecological benefits (Garrett et al., 2021; Terasaki et al., 2023; Pippi et al., 2025). In silvopastoral and forest farming, trees provide shade and shelter, reducing heat stress and thereby improving the health and productivity of animals and crops (Broom et al., 2013; Pippi et al., 2025). Deep root systems access water and nutrients from deeper soil layers, sharing them with surface vegetation (Jose, 2009; Nair, 2012; Bayala and Prieto, 2020; Pippi et al., 2025). In corridor planting and coastal buffer zones, surface runoff and nutrient losses are controlled, surface pollutants are filtered, and a more favorable environment for wildlife is supported (Udawatta et al., 2019, 2021; Pippi et al., 2025). Agroforestry can also act as a restorer of the complex and natural network, positively supporting biodiversity, improving soil texture, and increasing carbon sequestration, making the world more livable (Nuwarapaksha et al., 2023a; Nuwarapaksha et al., 2025). Modern temperate climate agroforestry is the reorganization of traditional agricultural practices, applied by farmers in many parts of the world to improve land efficiency, in a more systematic and conscious way (Pacey, 2008; Scordia et al., 2023). In Southern Europe, agroforestry systems such as grazed open woodlands (Dehesa in Spain, Montado in Portugal, Bocage in France, and Coltura promisqua in Italy) still cover a large area (den Herder et al., 2017; Casagrande et al., 2017; Paris et al., 2019; Scordia et al., 2023), while in North African countries (Tunisia, Algeria, Morocco, Egypt, Libya), agroforestry continues a long history and tradition, making a significant contribution to the well-being and livelihoods of local communities (Santoro, 2022; Scordia et al., 2023). Le et al. (2025) analyzed 232 research papers on agroforestry conducted between 1992 and 2024 reporting that the wooded pasture systems still largely present in Romania are among the oldest in Europe, dating back to the Neolithic period. They were originated in southeastern and central Europe and subsequently adapted to Britain, northwestern Germany and Denmark approximately 6,000 years ago, and to the Baltic and Scandinavian regions approximately 4,000 years ago (Rackham, 2008; Bergmeier et al., 2010; Mosquera Losada et al., 2012). The same study reported different examples and adaptative uses of the agroforestry systems across Europe, namely:

- In Central Europe (e.g., Germany, Czech Republic), orchard systems included both crop-growing and grazing orchards, with trees such as walnut (*Juglans regia*), apple *Malus domestica*, and pear (*Pyrus communis*) combined with livestock grazing and crop cultivation;
- Crops such as wheat, maize, and barley were integrated with trees such as walnut (*Juglans regia*), poplar (*Populus* spp.), and wild cherry (*Prunus avium*) in silvoarable systems such as row planting and hedges in Central Europe;
- Corridor planting was used in Belgium, Germany, and Italy to optimize land use, preserve soil fertility, and provide crop protection;
- In Atlantic and Central Europe, hedges acted as living barriers preventing wind erosion and providing fresh wood and timber.

Current agricultural, livestock, and forestry systems mostly offer monoculture models with highly specialized production methods, that are subject to economic pressures and cause numerous local and regional environmental impacts (Tilman, 1999; Santos et al., 2023). Considering their future ecological and economic importance, investments in the agroforestry practices and conservation and sustainability of this them require an understanding of their capacity to withstand and be less affected by degradations imposed by natural and human-induced factors (e.g., climate change) (Viñals et al., 2023; Santos et al., 2023).

2. Innovative Tools for Mediterranean Agroforestry

Despite the importance, benefits, and returns of agroforestry, and the efforts of policymakers and researchers to promote it (Plieninger et al., 2020; Pippi et al., 2025), several challenges hinder the widespread adoption of agroforestry systems (Tranchina et al., 2024; Pippi et al., 2025): the long time it takes for agroforestry investments to yield returns (Valdivia et al., 2012); the fact that timber and non-timber products generally require niche markets, thus limiting market access for small farmers (Dissanayaka et al., 2023); the uncertainty of policy support, often supporting monoculture cultivation (Fahad et al., 2022); the difficulties that farmers face in managing multiple plant and animal species (Gonçalves et al., 2021); limited technical knowledge, species selection, and the need for training (Dissanayaka et al., 2025) are among the plausible explanations that agroforestry is facing (See also Deliverable 1.2). The integration of advanced digital technologies can facilitate the management of the complexity of agroforestry systems (Pippi et al., 2025). The digital agriculture, also called smart agriculture, aims to ensure efficiency and sustainability through the integration of advanced technologies such as sensors, the Internet of Things (IoT), cloud computing, machine learning (ML), artificial intelligence (AI), and unmanned aerial vehicles (UAVs) (Martos et al., 2021; Paul et al., 2022) that can also be applied to agroforestry systems.

2.1. Precision Agriculture, Remote Sensing, and GIS

Precision agriculture is a management strategy aimed at improving resource efficiency, productivity, quality, profitability, and the sustainability of agricultural production (Brick et al., 2022, https://www.ispag.org/about/definition). Precision agriculture utilizes technologies such as GPS, remote sensing, and artificial intelligence for data-driven agricultural production (Zhang et al., 2002; Ikram and Moni, 2026). In terms of forestry, precision forestry is defined by Taylor et al. (2006) as “site-specific forest management to increase wood quality, yield, and profit, and reduce waste and damage”, and by Kovacsova and Antalova (2010) as “the use of modern tools and techniques to improve decision-making processes and ensure the achievement of forest management objectives” (Vatandaslar et al., 2025). Remote sensing platforms and sensors, global navigation satellite systems (GNSS), wireless systems, mobile mapping using smartphones and tablets, geographic information systems (GIS) and computer-aided design (CAD), real-time process control scanners, visualization tools, robotics, and comprehensive knowledge bases are some of the technologies used for this purpose (Vatandaslar et al., 2025). In fact, it is assumed that the term "precision forestry" is similar to "precision agriculture," which is thought to be its origin, and common practices such as reforestation for weed control are listed (Vatandaslar et al., 2025).

The most fundamental differences between them are the spatial and temporal scales of precision forestry [from millimeter scale (such as soil organic matter analysis) to thousands of kilometers scale (such as global C stock maps), from short time periods (such as stomatal opening analysis) to long periods (monitoring C retention rates under future climate scenarios)] and the heterogeneity and high variability in forested areas (Ferreira et al., 2023; Vatandaslar et al., 2025). This last author examined precision forestry in six categories:

1. Forest management and planning: Aims to collect site-specific performance indicators in the timber area and use this information to develop site-specific management plans. Some examples are the use of LiDAR to identify tree and stand characteristics, forest cover mapping, plant production modeling such as tree growth and yield, harvest planning or evaluation of the spatial accuracy of GNSS in changing forest conditions.

2. Forestry operations: Use of GNSS and control systems and field computers for the effectiveness of herbicide and fertilizer application, monitoring the conditions under which tree seedlings are kept before planting with radio frequency identification (RFID) tags, gene mapping and genetic improvements, and automated nurseries.

3. Harvesting and transportation: Utilizing information technology to optimize transportation routes for wood products from the forest to the most suitable processing site, enabling wireless communication between harvesting machines, transport dispatch services, and production facilities, evaluating road surface deformation with UAV imaging or mobile laser scanners, and planning the forest road network using virtual reality (VR) or other visualization tools.

4. Technologies to meet forest industry demand: Using sensors to assess tree or log quality during harvesting, determine the most suitable use, and direct shipments to the most appropriate production facility; evaluating wood quality and internal characteristics using computed tomography or ultrasound; using RFID and other tagging systems in establishing an integrated wood supply (logistics) chain.

5. Forest protection: Assessing soil compaction that may occur during harvesting, detecting root damage caused using heavy machinery, identifying damage to tree trunks, habitat mapping for important wildlife species, and monitoring ecological integrity.

6. Other: Applications that do not fit into one of the above categories. Some applications fall into more than one category.

In addition, Vatandaslar et al. (2025) identified eight components of precision forestry:

1. Remote sensing platforms and sensors: Optical cameras, LiDAR, terrestrial laser scanning (TLS), radar, UAVs and other mobile scanning devices have gained popularity as near-range remote sensing tools (Fassnacht et al., 2024). The use of mobile laser scanners with simultaneous positioning and mapping (SLAM) technology (Wu et al., 2025), spatial data collection in a local coordinate system with SLAM-based scanners, and the use of UAVs in the detection and prevention of forest fires (John et al., 2024) has increasingly been adopted in natural systems. Lee et al. (2022) tested a hybrid LiDAR strategy combining terrestrial-based mobile scanning with ALS systems in a *Pinus koraiensis* plantation in South Korea. To collect ALS data, a Matrice M300 UAV (DJI, Shenzhen, China) equipped with a GeoSLAM Horizon LiDAR sensor (GeoSLAM Ltd., Ruddington, UK) was used, and the same sensor was designed in backpack mode for mobile laser scanning. The aim was to improve the estimation of tree trunk diameter and tree height in high-density forested areas. In a second application, Görgens et al. (2020) proposed a spatially open multi-criteria optimization approach to develop automated harvesting plans by integrating ALS data with GIS methods (Vatandaslar et al., 2025). Hyppä et al. (2024) demonstrated that Aerial Laser Scanning (ALS) could be used to estimate the height, diameter, volume, and biomass of 100 million trees, and presented a plan for its application to the whole of Finland (Perry et al., 2026). It is predicted that combining Terrestrial Laser Scanning (TLS) and Aerial Laser Scanning (ALS) can provide complete information by collecting data from both the ground and the air (Dobre et al., 2021) (Perry et al., 2026).

2. GNSS and wireless systems: GPS and UAV imaging systems such as FieldMap (IFER, Jílové u Prahy, Czech Republic) are included in this category.

3. GIS and CAD software: GIS and CAD packages are used for road design tools and/or property databases.

4. Real-Time Process Control Scanners: Soil sensors are used to collect data remotely for drainage and fertilization (Choudhry and O’Kelly, 2018), while X-ray CT is used to measure tree ring width, wood density, and other anatomical features (De Mil and Van den Bulcke, 2023). RFID tags can be attached to trees to store relevant data such as location, species, diameter, and health (Kovacsova and Antalova, 2010).

5. Robotic technologies: Oliveira et al. (2021) reported that robots are used in forestry for inventory operations (32%), environmental protection and monitoring (27%), forest planting, pruning, and harvesting (22%), and forest fire fighting (19%). Chirici et al. (2023) introduced a robot called SPOT (Boston Dynamics, Waltham, MA, USA) equipped with optical cameras and a LiDAR sensor, capable of navigating and avoiding obstacles in forested areas. Its functions included trunk mapping, individual tree detection, and diameter measurement. While it could detect the diameters of large trees (>20 cm) with acceptable accuracy, it struggled to identify smaller trees. The rugged, rocky, fallen dead trees and dense undergrowth of forests make robot use in precision forestry difficult, and the visual homogeneity of trees appearing similar limits the robots' navigation capabilities (Vatandaslar et al., 2025).

6. Visualization tools: This includes technologies ranging from e-boards to forestry simulators, such as creating synthetic point clouds from 3D forest scenes using software like virtual laser scanning, Blender v4.x, and HELIOS++. It has been shown that deep learning models can be trained using virtual laser scanning data and achieve accuracies comparable to models trained on real data (Esmorís et al., 2024).

7. Comprehensive knowledge bases: Decision support and integrated data systems are used. eYield, which provides biophysical and financial information on the outcomes of a forest management scenario, can be given as an example of a forest decision support system (Bettinger et al., 2024) (Source: eYield Web page, https://eyield.sref.info/).

8. Other: Precision agriculture technology enables the control of fluctuations in light and water demands of crops under tree canopies in agroforestry and allows for the measurement of carbon sequestration and biodiversity for ecosystem services and, where necessary, carbon support (Jiangyi et al., 2020; Nuwarapaksha et al., 2025). Since agroforestry requires long-term investments and planning, the use of precision agriculture in this field provides more successful optimization in future research to increase efficiency, reduce costs, and improve sustainability (Nuwarapaksha et al., 2025). Remote sensing and geographic information systems (GIS) with photographic interpretation, satellite imagery, aerial photographs, and LiDAR provide information on vegetation vitality, profile, and land use (Varga et al., 2014; Nuwarapaksha et al., 2025). GIS can create an effective agroforestry suitability map by combining soil quality maps, topography, and remote sensing data (Elsheikh et al., 2013; Dagar et al., 2024). Using such applications, ecological and economic factors such as altitude, soil type, climatic conditions, and market access can be made more apparent, and carbon stock can be assessed, leading to the development of more effective agroforestry designs (Kakamoukas et al., 2021; Nuwarapaksha et al., 2025). In satellite imaging, optical images can be used for basic land cover mapping,

infrared images for vegetation analysis due to their sensitivity to chlorophyll (Thenkabail et al., 2012), and radar images for surface structure analysis as they are less affected by cloud cover (Ulaby et al., 2014; Dagar et al., 2024). The combination of GIS with satellite imagery also facilitates the mapping and monitoring of agroforestry areas (Elsheikh et al. 2013; Dagar et al., 2024). Global positioning systems (GPS) provide precise location information for verifying data collected through remote sensing and GIS, and online mapping technologies such as Google Earth and WebGIS platforms complement GIS and remote sensing by facilitating data sharing and collaborative use, offering access to a wide audience (Dagar et al., 2024).

The significant benefits of high-resolution satellite imagery, along with its high cost and limited geographical coverage, mean it is not always accessible (Pettorelli et al., 2014). The need for ground-based observation to verify remote sensing data, and the challenges this presents due to accessibility and resource availability, make pixel cover interpretation difficult because a single pixel can contain information from multiple land cover types (Mountrakis et al., 2011). The difficulty and time required to process the volume of data (Wulder et al., 2019), the need for expertise in applying algorithms for image classification (Blaschke, 2010), sustainability issues such as policy constraints and the lack of user-friendly interfaces, and limitations on the use of certain data in geopolitically sensitive areas (DeVries et al., 2015), limitations in adoption among local stakeholders and policymakers due to the lack of understanding outside of experts (Elwood, 2010), and environmental factors (such as the presence of clouds and seasonal changes in vegetation) can be identified as obstacles to the widespread adoption of this system (Dagar et al., 2024). Access to technology is particularly hindered in some regions, with small-scale farmers in areas such as South Asia and sub-Saharan Africa lacking the necessary infrastructure, capital, or technical support to use Internet of Things devices, GPS, or machine learning techniques (Hellin and Fisher, 2019; Rose et al., 2016; Schimmelpfennig, 2016; Ikram and Moni, 2026). Public-private partnerships can broaden access to technology to address these issues (Ikram and Moni, 2026). In Kenya, subsidies for soil sensors and satellite imaging systems for small-scale agroforestry systems, implemented through collaborations between companies and local governments, have reduced costs by 40% (Klerkx et al., 2019; Ikram and Moni, 2026). In India, low-cost solutions that do not require technical expertise and are suitable for low literacy levels (e.g., smartphone applications with voice alerts) offer easy access to precision agriculture technology for those engaged in agroforestry (Rose et al., 2016; Ikram and Moni, 2026). Policy changes should promote integrated systems such as carbon credit programs that encourage farmers to use trees for carbon sequestration, and subsidies for precision agriculture tools (Ikram and Moni, 2026). Through digital extension services, farmers in Bangladesh have been successfully trained in interpreting UAV images for tree health monitoring (Ikram and Moni, 2026).

A survey conducted in the US revealed that only a small percentage of firms were able to integrate robots into their production systems, indicating a very low level of expertise in robotics technologies and limiting the use of robotics in manufacturing (Vatandaslar et al., 2025). GIS technology became widely available in the 1990s, but its inclusion in the forestry curriculum took almost 20 years (Vatandaslar et al., 2025). A Google Trends analysis by the same authors found that "precision forestry" was rarely used as a search term, while "precision agriculture" showed an increasing trend since 2010. The first study on precision forestry was published in 2001 and only a few studies were published annually until 2011, after which the annual number of publications generally increased, with a significant increase in 2019, and the upward trend continues (Vatandaslar et al., 2025). In the same analysis, Italy ranked first in publications on precision forestry when considering the countries of origin of the first authors, followed by China, Finland, and the USA: 12.4% of the studies were conducted in Italy, 9.5% in China, and 8.1% in Finland. Italy's prominence is attributed to its active participation in EU projects, strong academic expertise, and its leading role in addressing Mediterranean-specific challenges such as fire risk and forest fragmentation (Vatandaslar et al., 2025). China has increased its precision agriculture studies with government support, prioritizing precision forestry to support large-scale reforestation programs, ecological restoration, and sustainable timber production whilst Finland's strong forestry research stems from the country's national reliance on traditional forestry (Vatandaslar et al., 2025). National funding influences countries' focus on the subject. The Natural Sciences and Engineering Research Council of Canada (NSERC) provides greater flexibility in selecting research topics than the National Science Foundation (NSF) in the US, and Horizon Europe's expected contribution per forestry research project is approximately €6 million in 2025 (Citizens et al., 2025). Almost half of the studies analyzed were from Europe, followed by Asia (23.9%), North America (14.1%), South America (8.2%), and Oceania (4.9%) (Citizens et al., 2025). The "forest management and planning" category had the most studies in precision forestry, followed by "harvesting and transportation" (19.5%), "other" (12.9%), "forest maintenance operations" (8.6%), "forest conservation" (6.6%), and "technologies to meet forest industry demand" (2.9%) (Citizens et al., 2025). In precision forestry, “remote sensing platforms and sensors” have been the most commonly used tool, followed by “others” (18.6%), “GNSS and wireless systems” (10.0%), “comprehensive knowledge bases” (7.1%), “GIS and CAD software” (5.7%), “real-time process control scanners” (3.3%), and “robotic technologies” (1.4%) (Vatandaslar et al., 2025).

Creating a digital repository of spectral signatures for different tree species using remote sensing data (Thenkabail et al. 2012) would be beneficial for assessing the expansion of tree species and their impact on carbon capture (Goetz et al. 2009; Dagar et al., 2024). Receiving updates to this system would be important for monitoring changes in land use, tracking the spread of invasive species, and assessing the impacts of climate change on agroforestry systems (Hansen et al. 2013; Dagar et al., 2024). In Bangladesh, mango-based agroforestry was integrated with soil moisture sensors and satellite-based NDVI (Normalized Difference Vegetation Index) mapping, resulting in a 32% reduction in system efficiency and a 20% reduction in water use (Ikram and Moni, 2026). Pilot applications in Bangladesh have demonstrated that drone-based real-time pest alerts have resulted in biodiversity conservation and a 25% reduction in pesticide use (Zhang and Kovacs, 2012; Ikram and Moni, 2026). Drones equipped with multi-spectral, hyperspectral, and thermal sensors provide high-resolution images. These images can help to determine tree density, tree canopy architecture, gaps in tree canopy, and boundary changes (Vaishnav et al., 2025). They are also useful in the early detection of stress signs, nutrient deficiencies, pest and disease infestations, and water stress in trees and crops (Vaishnav et al., 2025). Similarly, these engines equipped with spraying apparatus facilitate the application of nutrients, insecticides, and herbicides in situations where manual spraying is difficult due to height and density (Vaishnav et al., 2025). Drones support long-term plantation management in afforestation, agroforestry expansion, and carbon farming projects by rapidly assessing survival rates, monitoring height, canopy spread, and overall vitality (Vaishnav et al., 2025). Table 1 shows a summary of the section.

Table 1. Summary of main precision agriculture, remote sensing and GIS tools and their uses

Tool / Technology	Description	Key Applications in Agriculture & Forestry	Examples / Notes
Remote Sensing Platforms & Sensors	Use of satellite, aerial, and ground-based sensors to collect spatial data	Vegetation monitoring, biomass estimation, land cover mapping, tree height/diameter measurement, fire detection	Optical, infrared, radar imagery; LiDAR (ALS, TLS); UAV/drone imaging
GNSS (GPS) & Wireless Systems	Satellite-based positioning and communication systems	Precise geolocation, field mapping, machinery navigation, validation of remote sensing data	GPS, FieldMap, UAV-based positioning systems
GIS & CAD Software	Tools for spatial data analysis, mapping, and	Agroforestry suitability mapping, land use planning,	Combines soil, climate, and satellite data; used

	design	forest road design, spatial decision-making	with WebGIS platforms
Real-Time Process Control Scanners	Sensors and devices for continuous monitoring and measurement	Soil condition monitoring, fertilization control, wood property analysis, data collection on trees	Soil sensors, X-ray CT, RFID tags storing tree data
Robotic Technologies	Automated systems performing physical or monitoring tasks	Forest inventory, planting, pruning, harvesting, fire control, ecological monitoring	SPOT robot (with LiDAR/cameras); limited by terrain complexity
Visualization Tools	Software and platforms for data representation and simulation	3D forest modeling, planning, training AI models, decision support	Virtual laser scanning, simulators, Blender, HELIOS++
Comprehensive Knowledge Bases / Decision Support Systems	Integrated databases and analytical tools for management decisions	Scenario analysis, yield prediction, financial and ecological planning	eYield system; integrates biophysical and economic data
Drones (UAVs)	Aerial platforms equipped with sensors for high-resolution monitoring	Pest detection, stress monitoring, canopy analysis, spraying inputs, plantation monitoring	Multispectral, hyperspectral, thermal sensors; real-time alerts
Mobile Mapping & Smart Devices	Use of smartphones/tablets for field data collection	On-site data entry, mapping, communication, farmer accessibility	Useful in low-cost precision agriculture solutions
Integrated Data Systems & IoT	Networks connecting sensors and data platforms for real-time analysis	Monitoring water, nutrients, biodiversity, carbon sequestration	Used in agroforestry and smart farming systems

2.2. Sensors

In the digitalization of agroforestry, numerous sensors can be used for various purposes within the scope of precision agriculture. Comprehensive installations including air temperature, soil moisture, soil temperature, nutrients, greenhouse gases (GHG), photosynthetically active radiation (PAR), infrared thermography, network radiometers, and wind speed sensors provide actionable information to protect and maintain soil health and reduce environmental impacts

(Svoma et al., 2016; Pippi et al., 2025). As an example, the use of sensors mounted on UAVs can reduce downstream sediment yield and support stream rehabilitation strategies (Alfonso-Torreño et al., 2022; Pippi et al., 2025). Advantages can be achieved in integrated systems with sensor-based monitoring such as soil probes and automated weather stations. In Bangladesh, the use of IoT-enabled meteorological data and organic fertilizer application according to tree root growth cycles resulted in a 15% increase in nutrient uptake (Ikram and Moni, 2026).

Soil sensors can measure soil moisture, temperature, pH, electrical conductivity, and NPK, thus supporting precise irrigation planning, nutrient management, and soil fertility improvement (Vaishnav et al., 2025). Both resistive and capacitive sensors are used for soil moisture (Brick et al., 2022). The resistive sensors FC-286 and SEN133227 use two probes to quantitatively determine moisture by sending current into the soil (Barapatre and Patel, 2019; Brick et al., 2022). Another resistive soil moisture sensor, WATERMARK, uses gypsum boards surrounded by a porous granular filler material where the electrodes are placed (Kashyap and Kumar, 2021; Brick et al., 2022). Resistive sensors are easy and inexpensive to manufacture, but the probes can corrode, leading to inaccurate measurements and errors ranging from 10% to 25% (Barapatre and Patel, 2019; Brick et al., 2022). Capacitive sensors such as EC-59, SEN019310, and 10HS11 measure the dielectric constant of soil and are made of corrosion-resistant materials (Barapatre and Patel, 2019; Brick et al., 2022). The DS18B20 is a digital thermometer that operates without an external power supply and measures temperatures between -55°C and 125°C (Brick et al., 2022).

In-situ soil nutrient measurement sensors employ either optical or electrochemical methods. Optical sensors identify soil nutrients based on the amount of energy absorbed and reflected by nutrient ions, while electrochemical sensors utilize ion-selective electrodes that reflect the concentration of target ions (Burton et al., 2020; Brick et al., 2022). The ISL29125 light sensor was used to measure the reflectance of N, P, and K minerals in the soil (Grimblatt et al., 2019), but the accuracy rate was not specified (Brick et al., 2022). In various studies on this topic, nitrate and phosphate-sensitive test strips have been used to successfully read nitrate on smartphones, but not phosphate (Golicz et al., 2019). Some of the successful applications include: nitrate reading with disposable IoT garden soil sheets (Burton et al., 2018), developing a device containing a mobile chip to measure nutrients (Smolka et al., 2017), using optical diffuse reflection spectroscopy to measure soil properties such as soil organic carbon, total nitrogen, moisture, soil texture, cation exchange capacity, calcium, magnesium, potassium and pH in the field (Pei et al., 2019), and using handheld portable X-ray fluorescence spectrometers and near-infrared spectrometers for the detection of soil organic matter (SOM) and soil organic carbon (SOC) (Brick et al., 2022).

Weather sensors can measure air temperature, relative humidity, solar radiation, wind speed, and precipitation, thus enabling the assessment of how tree shading affects undergrowth plants, the selection of optimal species, and the creation of climate-adapted planting plans (Vaishnav et al., 2025). Plant stress sensors, including optical, thermal, and chlorophyll sensors, can measure leaf temperature, chlorophyll fluorescence, and photosynthetic activity, providing early warning of stress conditions caused by drought, nutrient deficiencies, or diseases (Vaishnav et al., 2025). The Negative Temperature Coefficient (NTC) thermistor (https://www.ametherm.com/blog/thermistors/temperature-sensortypes) correlates resistance with temperature (Brick et al., 2022). Both, the DHT1119 and DHT2220 consist of an NCT measurement component and a resistive type of humidity sensor. The Si7021 I2C is a monolithic CMOS integrated circuit combining humidity and temperature sensors. The C10-M53R is a resistive humidity sensor (http://c1170156.r56.cf3.rackcdn.com/UK_SHN_C10-M53R_DS.pdf) (Brick et al., 2022). The pressure sensor is an air pressure sensor (https://www.nxp.com/docs/en/data-sheet/MPXAZ4115A.pdf) (Brick et al., 2022). The BH175FVI light sensor is a digital ambient light sensor (https://www.mouser.com/datasheet/2/348/bh1750fvi-e-186247.pdf) (Brick et al., 2022).

Animal wearable devices monitor animal movement, grazing behavior, health, and body temperature, thereby better integrating animals into tree-based systems, improving grazing management, and preventing overgrazing (Vaishnav et al., 2025). GPS, accelerometers, inertial measurement units (IMUs), pressure sensors, and acoustic sensors are among the sensors used to detect animal behavior (Aquilani et al., 2022; Brick et al., 2022). Virtual fences are used for controlled grazing; when animals approach a designated boundary, their GPS-equipped collars emit an audible warning to stop them, and if the animal continues, an electric shock is administered (Aquilani et al., 2022; Brick et al., 2022). PLF can also be used for breeding tracking by notifying the farmer when an animal is ready to breed or has begun giving birth (Aquilani et al., 2022; Brick et al., 2022).

IoT platforms can support real-time monitoring of agroforestry systems, early warning of insect outbreaks or soil moisture deficiencies, and understanding trends across large areas for forest management by integrating sensors, drones, and weather stations into a single data network. IoT irrigation systems utilize soil moisture data to adjust irrigation, ensuring effective water use by applying water only where and when needed. Internet of Things (IoT)-based monitoring technologies enable the traceability of non-timber crops such as fruits, medicinal plants, and resins. IoT-enabled carbon sensors can estimate carbon sequestration rates and monitor greenhouse gas emissions (Vaishnav et al., 2025).

A Wireless Sensor Network (WSN) is a network of wireless sensors that transmit data to a base station or coordinator node (Jawad et al., 2017; Brick et al., 2022). Among those designed for this purpose, ZigBee is inexpensive, has low power consumption, but has a short communication range (Jawad et al., 2017; Brick et al., 2022). Bluetooth is widespread, easy to use, and has low power consumption, but also a short communication range (Jawad et al., 2017; Brick et al., 2022). Wi-Fi backs up data but requires a high amount of power, long communication time, and large data payload (Jawad et al., 2017; Brick et al., 2022). In GPRS technology, data transfer speed is variable, and performance depends on the number of consumers (Ojha et al., 2015; Brick et al., 2022). LoRa has low power consumption and a long communication range, making it suitable for agricultural areas, but its message capacity is limited and requires hardware implementation, making it complex (Jawad et al., 2017; Gresl et al., 2021; Brick et al., 2022). SigFox has low power consumption and a long range, but low and slow data and transmission speeds (Jawad et al., 2017; Brick et al., 2022). Narrowband IoT, along with SigFox and LoRa, is low power consumption and supports wide area networks (LPWAN), but NB-IoT deployment is limited to LTE base stations (Mekki et al., 2019; Brick et al., 2022). 5G networks offer high speed, wide coverage, low energy consumption, low-cost devices, and low latency, but have a short range due to the low frequency band (Tang et al., 2021; Brick et al., 2022). Among all these, LoRa appears to be the best option in agriculture due to its low power consumption and long communication range (Brick et al., 2022). Table 2 shows a summary of this section.

Table 2. Summary of sensors in agroforestry systems

Tools/Technologies	Main uses
Wearable sensors attached to animals	By monitoring animals' movements, grazing behavior, health status, and body temperature, they can enable better integration of animals into tree-based systems, improve grazing management, and prevent overgrazing.
Virtual fences	Used for controlled grazing using GPS-based collars; support livestock management and breeding monitoring (alerts for breeding or birthing)
Weather sensors	They can measure air temperature, relative humidity, solar radiation, wind speed, and precipitation. Support species selection and climate-adapted planting strategies
Plant stress sensors,	Detect early stress from drought, nutrient deficiencies, or diseases by

including optical, thermal, and chlorophyll sensors	measuring leaf temperature, chlorophyll fluorescence, and photosynthetic activity.
Soil nutrient measurement sensors	Measure soil properties such as soil organic carbon, nitrogen, moisture, texture, cation exchange capacity, mineral content
Soil sensors	Measure soil moisture, temperature, pH, electrical conductivity, and NPK. Supports precise irrigation planning, and soil fertility management.
Environmental sensor systems	Monitor parameters such as GHG emissions, PAR, infrared radiation, and wind speed to maintain soil health and reduce environmental impacts
Sensors mounted on UAVs	Support landscape monitoring, reduce sediment yield downstream, and support stream rehabilitation strategies.
Internet of Things (IoT)	By integrating sensors, drones, and weather stations into a single data network; enable real-time monitoring, early warning of insect outbreaks or soil moisture deficiencies, and large-scale trends analysis.
Wireless Sensor Networks (WSN)	Transmit sensor data to central systems for monitoring and decision-making across large areas
Communication technologies (LoRa, ZigBee, Wi-Fi, NB-IoT, etc.)	Enable data transfer between sensors and systems; LoRa is especially suitable due to low power consumption and long range

2.3 Agro-Ecosystem Monitoring

In agro-ecosystem monitoring, multi-source satellite imagery, including data from Sentinel-2, MODIS, GEDI, and SMOS, offers a broad-scale perspective to characterize the multiple ecosystem services provided by agroforestry systems (Leroux et al., 2022; Pippi et al., 2025). This remotely sensed data is crucial for the accurate and effective characterization of these complex environments, enabling detailed land cover classification (Ndao et al., 2021) and large-scale above-ground biomass estimates to assess forest recovery (Aragón et al., 2021; Pippi et al., 2025). For example, the Sentinel-1 (radar) and Sentinel-2 (optical) Earth Watch satellites, high-spatial-resolution optical satellite imagery such as WorldView-3, the Landsat-5 Thematic Mapper, and Sentinel 2A can assist in targeted land management interventions (Pippi et al., 2025).

In animal monitoring, especially in silvopastoral systems where trees and grazing animals coexist, the integration of multiple sensors, such as Global Positioning System (GPS) units and accelerometers, enables comprehensive monitoring of animal behavior and physiological responses (Pippi et al., 2025). Wearable biometric sensors measuring heart rate, body temperature, and rumination patterns facilitate early detection of heat stress, disease, or nutritional deficiencies in silvopastoral systems where tree canopy alters microclimate conditions (Li and Rak, 2025; Pippi et al., 2025). Remote sensing technologies, such as thermal imaging cameras mounted on drones or fixed towers, allow for the assessment of herd distribution and the identification of individuals under stress or injury by detecting the heat signatures of animals (Mufford, 2020; Pippi et al., 2025). The development of virtual fence systems (using GPS collars and audible cues or electric shocks to control animal movement and grazing patterns) is also an important issue for improving grazing management in livestock systems (Aquilani et al., 2022; Pippi et al., 2025). This technology helps create virtual boundaries, optimize resource use such as vegetation, prevent overgrazing, protect biodiversity and water quality by restricting animal access to areas that need protection or restoration, such as riparian zones, wetlands, or areas with young trees, and prevent soil erosion (Pippi et al., 2025).

In soil monitoring, various sensors provide measurements of volumetric water content (Pippi et al., 2025). Capacitive sensors, Time Domain Reflectivity, and Frequency Domain Reflectivity sensors are used to reveal different moisture regimes under tree canopies and in crop aisles (Zhu et al., 2019; Jackson and Wallace, 1999; Pippi et al., 2025). This real-time data is crucial for optimizing irrigation schedules, conserving water, and preventing water stress, resulting in higher crop yields and sustainability (de Carvalho et al., 2021; Kashyap and Kumar, 2021; Pippi et al., 2025). Electrical resistivity tomography can map soil moisture dynamics (Coussement et al., 2018), and sap flow sensors, in conjunction with micro-lysimeters, can enable precise assessment of water use efficiency (Padovan et al., 2022; Pippi et al., 2025). Ion-selective electrodes and portable X-ray fluorescence spectrometers provide rapid field analysis of essential macro and micronutrients (Jefferies et al., 2014; Pippi et al., 2025). This optimizes fertilizer use efficiency, reduces environmental impacts, and supports site-specific nutrient management (Mugunga et al., 2017; Taugourdeau et al., 2014). This benefit is significant, as the negative impact of unnecessary fertilization on the environment, soil, and living organisms has been well understood since the green revolution in agriculture. Furthermore, less fertilizer use means lower costs for the producer. The VISNIR hyperspectral imager offers accurate, mobile, and cost-effective estimation of soil organic carbon and nitrogen (Pellikka et al., 2023; Pippi et al., 2025). A combination of VNIR spectrometry, a dry combustion analyzer, and other data sources can accurately estimate and map soil organic carbon (Kinoshita et al., 2016; Pippi et al., 2025). Advanced sensing techniques are providing farmers with tools to monitor greenhouse gas emissions from their soils, with systems such as ventilated chambers being used to measure greenhouse gas flows from the soil surface (Oertel et al., 2018; Mandal et al., 2022; Pippi et al., 2025). Micrometeorological methods, such as eddy covariance, provide information on gas exchange between soil and atmosphere by measuring vertical turbulent flows of greenhouse gases (Franzluebbers et al., 2017; Pippi et al., 2025). Advances in biosensors are enabling the measurement of soil biological activity, including microbial respiration and enzymatic activity, which are critical indicators of soil health and the carbon cycle (Semenov et al., 2025; Pippi et al., 2025). Table 3 shows a summary of this section.

Table 3. Summary of Agro Ecosystem Monitoring Tools

Tools / Technologies	Main uses
Various sensors in soil monitoring	Measure volumetric water content, revealing different moisture regimes under tree canopies and in crop rows, mapping soil moisture dynamics, precise assessment of water use efficiency, rapid field analysis of essential macro and micronutrients, accurate, portable and cost-effective estimation of soil organic carbon and nitrogen, measuring greenhouse gas flows from the soil surface, measuring soil biological activity.
Multi-source satellite imagery (Sentinel-2, MODIS, GEDI and SMOS)	Enable detailed land cover classification and large-scale above-ground biomass estimates to assess forest recovery.
High-resolution satellite imagery (Sentinel-1, Sentinel-2, Landsat, WorldView-3)	Support detailed monitoring and targeted land management interventions
Integrated animal monitoring sensors (GPS, accelerometers)	Enable comprehensive monitoring of animal movement, behavior and physiological responses in silvopastoral systems
Wearable biometric sensors (heart rate, temperature, rumination)	Detect early signs of heat stress, disease, and nutritional deficiencies in livestock
Thermal imaging systems (UAVs or fixed towers)	Assess herd distribution and detect stressed or injured animals through heat signatures
Virtual fencing systems (GPS collars and audible alerts or electric shocks)	Help create virtual boundaries, optimize resource use such as vegetation, control grazing patterns, prevent overgrazing, protect biodiversity and water quality by restricting animal access to areas in need of protection or restoration, such as riverbanks, wetlands or areas with young trees, and prevent soil erosion
Soil moisture sensors	Measure volumetric water content and identify moisture variability

(capacitive, TDR, FDR)	under tree canopies and crops
Electrical resistivity tomography	Map soil moisture dynamics across landscapes
Sap flow sensors and micro-lysimeters	Assess plant water use and water use efficiency
Nutrient sensors (ion-selective electrodes, XRF spectrometers)	Provide rapid field analysis of macro- and micronutrients to support targeted fertilization
Hyperspectral imaging (VIS–NIR)	Estimate soil organic carbon and nitrogen accurately and cost-effectively
Spectrometry and combustion analysis (VNIR, dry combustion)	Map soil organic carbon and improve soil quality assessment
Greenhouse gas monitoring systems (ventilated chambers)	Measure soil emissions of greenhouse gases
Micrometeorological methods (eddy covariance)	Analyze gas exchange between soil and atmosphere
Soil biosensors	Measure microbial activity and enzymatic processes to assess soil health and carbon cycling

2.4. Artificial Intelligence (AI)

In the discipline of agroforestry, which aims to create more diverse, efficient, sustainable, and resource-efficient land-use systems by combining agricultural and forestry processes, artificial intelligence is becoming an indispensable tool day by day, just as in other branches of agriculture (Mporas et al., 2020; Daniel, 2025). When artificial intelligence is properly integrated into agroforestry systems, it provides benefits such as increasing production, improving crop health, minimizing environmental impact, and optimizing resource management (Daniel, 2025). In AI-assisted agroforestry, benefits are achieved through data collection, processing, evaluation, interpretation, information acquisition, and increasing overall efficiency and productivity (Wang et al., 2021; Daniel, 2025). Artificial intelligence is a broad and versatile technology developed by computer and engineering sciences and can be transferred to different disciplines. The goal of artificial intelligence is to develop machines and systems that can perform tasks requiring human intelligence (Daniel, 2025). Early applications of AI in forest research included tree species identification, diagnosis of tree disorders, and application of rule-based reasoning in forestry decision-making processes (Gadow, 1988; Daniel, 2025). The vast majority of current AI applications in agroforestry focus on assisting data analysis to monitor agroforestry productivity and health, detect changes in land cover and land use, and assess tree density and species distribution (Daniel, 2025). Machine learning and deep learning have been used to process large amounts of remote sensing imagery (e.g., Landsat) and textual data (e.g., LiDAR) to map global forest cover (Hansen et al., 2013; Daniel, 2025). High-resolution, full-area global maps offer significant opportunities to understand the current state of forests and identify areas requiring intervention. Since the conscious adoption of agroforestry, efforts have been made to create sustainable growth and yield models to predict the productivity and future state of forested areas, and an impressive array of forest growth and yield models has been developed, ranging from early yield tables to today's computer-based forest growth simulators. However, creating forest growth and yield models is quite costly (Daniel, 2025). Recent advancements, namely the development of machine learning techniques (Ma et al., 2020) and self-learning systems (Pukkala et al., 2021) aimed at making forest growth and yield models more economically feasible, have facilitated the creation of these models (Daniel, 2025). However, these improved models still require human supervision, which limits their applicability. To overcome this challenge, Purdue University's Advanced Forest Computing and Artificial Intelligence Laboratory (FACAI), in collaboration with the World Resources Institute and the Food and Agriculture Organization of the United Nations (FAO), is developing MATRIX, an AI-based forest growth model. AI-powered equipment can perform precise cuttings to reduce waste and environmental impact, increase resource efficiency, and promote sustainable forestry practices. In addition, AI systems can facilitate inventory management by automating or supporting forest inventory surveys. Little is known about how much of local forest carbon sequestration rates are due to upstream growth, regeneration, and death, and how sensitive these key components of forest growth are to changes in climate and land-use patterns. Artificial intelligence has great potential to help monitor and predict carbon stocks in forests and assist researchers in understanding the role of forests in the global carbon cycle. Recently, advances have been made in green agriculture such as Smart Agriculture, Robotic Agriculture, Precision Agriculture, Regenerative Agriculture, Satellite-Based Agriculture, AI-Assisted Agriculture, etc., to ensure and support productivity and sustainability (Daniel, 2025). AI enables automated agricultural operations and systems requiring minimal supervision and control with unmanned aerial vehicles or ground-based autonomous vehicles, and the use of robotics in agriculture and agroforestry (Eli-Chukwu, 2019; Daniel, 2025). An AI-powered weather forecasting system can make predictions for future rainfall, temperature, humidity, etc., by analyzing annual data and weather conditions. Based on predicted weather conditions, farmers can select suitable crops, forestry products, and livestock, and also determine the optimal time for sowing seeds. AI-powered technologies can detect nutrient deficiencies and provide information on the appropriate amount of fertilizer to use. AI-powered techniques are used to detect and control insect pest infestations and can be managed using drones or autonomous tractors, allowing farmers to receive real-time alerts and pest control measures on their smartphones. An AI-based irrigation system uses sensor data (e.g., soil moisture levels and weather conditions), and algorithms can determine and prove how much water is needed for irrigation in a crop with a real-time solution. By combining machines and robots, crop yields can be predicted for a specific crop. Data is collected in multiple drone flights in the field, and by increasing the level of precision analysis through the use of various algorithms, very accurate yield predictions can be made. When artificial intelligence and machine learning are combined, computer software analyzes all data related to leaf size, shape, and color to distinguish weeds and invasive plant species from crops and can provide solutions that can be used to program a robot performing robotic process automation (RPA) tasks (Daniel, 2025). In Bangladesh, machine learning algorithms based on local data for pruning mango trees have been used to predict the optimal timing to maximize light for substrate crops (Liakos et al., 2018; Ikram and Moni, 2026). Table 4 shows a summary of this section.

Table 4. Summary of Artificial Intelligence Applications in Agroforestry

Tool / Technology	Main Uses
Machine learning (ML) and deep learning (DL)	Analyze large datasets (remote sensing, LiDAR, field data) for land cover mapping, tree species identification, and productivity assessment
AI-based forest growth models	Predict forest growth, yield, and future ecosystem dynamics; support long-term planning and management
AI-assisted remote sensing analysis	Detect land-use and land-cover changes, assess tree density and species distribution, and monitor agroforestry systems
AI-powered decision support systems	Support data-driven decision-making in crop selection, forest management, and resource allocation
AI-driven inventory and monitoring systems	Automate forest inventory processes and improve accuracy and efficiency of field surveys
Autonomous systems and robotics (UAVs, ground vehicles)	Enable automated operations such as monitoring, spraying, harvesting, and precision interventions
AI-based weather prediction systems	Forecast climate variables (rainfall, temperature, humidity) to support planning and risk management
Smart irrigation systems	Use sensor data and AI algorithms to optimize water use and

	irrigation scheduling in real time
AI-based nutrient management systems	Detect nutrient deficiencies and recommend optimal fertilizer application rates
AI-powered pest and disease detection systems	Identify and control pest infestations using image analysis and real-time alerts
Yield prediction models	Estimate crop productivity using drone data, sensors, and predictive algorithms
Computer vision systems	Identify weeds, invasive species, and crop characteristics based on visual data (leaf size, shape, color)
Robotic process automation (RPA)	Enable automated field operations such as weeding, pruning, and crop management

2.5. Plant Gene Science Technology

The breeding of trees and crops compatible with specific purposes, and the use of biotechnology in plant breeding, are among the recent changes in agroforestry. While classical methods in plant breeding are preserved, the rapid developments in plant biotechnology in recent years have led to the combination of biotechnological techniques with classical methods. In this way, the duration of plant breeding can be shortened, its efficiency can be increased, and previously impossible goals can be achieved. For example, interspecies or intergenera hybridization where fertile individuals cannot be obtained with classical hybridization can be made possible with in vitro pollination and fertilization technique or protoplast fusion.

In agroforestry, the genetic aspects of compatibility between trees and crops are important: root system in terms of competitiveness for nutrient uptake, canopy cover in terms of light access, and phenology to avoid competition (Tscharntke et al., 2011; Nuwarapaksha et al., 2025). In tree breeding, factors such as growth vigor, timber quality, yield, and nitrogen fixation are highly important (Nuwarapaksha et al., 2025). Marker-assisted selection and genome editing have enabled breeders to easily select ideal genes, aiding in genetic improvements in plants and animals (Nuwarapaksha et al., 2025). Thus, significant advancements in plant and animal breeding, particularly in biotechnological methods, have been made, yielding high returns for agroforestry. In agroforestry investments, which require long-term planning, implementing regulations with more compatible species will provide significant advantages in every aspect.

3. Innovative Agroforestry Systems

Innovation can be also applied to the definition of agroforestry systems. Three new models have been identified:

Climate-friendly agroforestry model: This model includes applications such as the selection of drought-tolerant species, the implementation of effective water regimes, and soil conservation measures. In this way, solutions are offered for protecting ecosystems, supporting multi-crop systems, and addressing climate change. For example, the integration of fast-growing and nutrient-rich species such as *Tithonia diversifolia* and *Gliricidia sepium* as hedge rows or corridor plants into agroforestry systems can be given (Atapattu et al., 2017b; Nuwarapaksha et al., 2023b; 2025), and in this way, multiple advantages such as erosion control and increased organic matter content can be achieved (Atapattu et al., 2017b; Dissanayaka et al., 2022).

Urban agroforestry: Urban agroforestry is a synthesis of urban forestry and urban agriculture, supporting the management of urban ecosystems and offering significant advantages such as increasing food production, improving air quality or mitigating the urban heat island effect (Singh et al., 2024; Nuwarapaksha et al., 2025). Such applications offer advantages in terms of water control through rainwater management, greenhouse gas reduction through carbon stock regulation, and the creation of natural habitats in urban areas (Jose, 2019). Urban agroforestry also offers a solution for bringing people who have become distanced from nature back to nature. Recently, there have been waves of migration from rural areas to cities worldwide, and over time, people have become distanced from nature. Urban agroforestry offers advantages in this respect by bringing nature to cities, while simultaneously cultivating crops.

Vertical farming integration: Recently, interest in vertical farming systems in agriculture has increased. Vertical farming systems enable the production of high-value products under controlled environmental conditions within the scope of agroforestry using innovative vertical farming technologies such as hydroponics, aquaponics, and aeroponics (Sharma et al., 2024; Nuwarapaksha et al., 2025). The system can range from simple structures containing trees and products stacked on the floors of a building to complex structures that blend indoor vertical farming systems with outdoor systems such as trees and products, providing benefits such as increased production, the use of water-saving closed-loop systems, improved control of pests and diseases, carbon sequestration, and microclimate management (Nuwarapaksha et al., 2025).

4. Benefits of Agroforestry Systems based on successful initiatives

Initiatives and projects related to innovative approaches in agroforestry have been put into practice and have produced beneficial results. These initiatives and projects have particularly emphasized women-positive approaches. For example, in India, the "Digital Sahelis" program trained women in using precision agriculture tools in agroforestry (Hellin and Fisher, 2019). Again, in India, the "e-Agroforestry" dissemination program taught women how to analyze sensor data (World Bank, 2021). Nigeria's "SheFarms Digital" program demonstrated that empowering women increased the adoption rate of digital advancements. Another objective of such initiatives is irrigation optimization. Considering future climate change scenarios, irrigation optimization is a crucial issue. In Bangladesh, the "Digital Bari" project enabled 15,000 farmers to receive mobile alerts along with humidity sensors, leading to a 22% increase in yield and a reduction in water use. In West Africa, LoRaWAN networks and low-cost IoT sensors have been used to optimize cocoa irrigation in agroforestry in Ivory Coast. One of the limiting factors in agroforestry applications is the initial investment costs and the ongoing management of the system. Innovation systems are seen to provide advantages in this area as well. In East Africa, FarmDrive's machine learning algorithms increased the income of more than 50,000 small farmers by 15-30% by evaluating satellite and SMS data and suggesting tree-product combinations (Liakos et al., 2018). In Rwanda, agricultural technology companies developing solutions for agroforestry were granted a three-year tax exemption through climate-friendly loans. In the European Union, the AGROMIX initiative has established living laboratories to evaluate policy combinations in seven bioclimatic regions (Agroforestry and Mixed Farming Systems Consortium, 2022). In Bangladesh, CV4 Agroforestry has reduced yield losses by 22% by detecting mango pests using artificial intelligence and smartphone cameras (BAU, 2023). In Vietnam, the 2023 National Agroforestry Policy states that updated agricultural input subsidies cover 40% of the cost of precision agriculture equipment for certified agroforestry systems (Vietnam Ministry of Agriculture and Rural Development, 2023). Indonesia's "AIFOREST" program has reported a 3:1 increase in return on investment for integrated systems (Ikram and Moni, 2026). One of the significant advantages of agroforestry is carbon sequestration and its monitoring. Innovative approaches offer great advantages in this area as well. In Costa Rica, verified carbon data from drones has begun to be used in agroforestry (FAO, 2017). One of the biggest concerns in agroforestry is the possibility of trees shading undergrowth and the resulting disadvantages. Studies have also been conducted in this area using innovative approaches. In

Vietnam, coffee grown in the shade in agricultural forests using IBM's AgriBlock system was traced to EU markets and sold at 20% higher prices (Tripoli and Schmidhuber, 2018). Another service needed in innovative agricultural forestry is the difficulty for small farmers in understanding and implementing these systems. It is quite clear that they will need support in this area. As an example, in Brazil, EMBRAPA's national agricultural forestry decision platform integrated more than 15 datasets to provide consultancy services to small-scale farmers (EMBRAPA, 2021).

5. Benchmark of Large Cooperative Innovative Projects on agroforestry and related disciplines funded by European Union

The European Union has been very active in the promotion of agroforestry projects through different funding schemes. A total of forty cooperative innovative projects has been identified under the frame of EU Horizon2020, EU Horizon Europe Program PRIMA Program and other European initiatives. Al them are providing interesting learnt lessons that are summarized in the next subsections.

5.1. Projects supported under the EU Horizon2020 program on agroforestry

(https://digitaf.eu/tools-data-and-projects-catalogue/projects/project/agromix)

“AFINET - Agroforestry Innovation Networks” was a project funded by the EU Horizon2020 program, carried out between 2017 and 2019, with 13 partners from 9 European countries. The project aimed to create an interregional European network in 9 strategic regions of Europe (Spain, UK, Belgium, Portugal, Italy, Hungary, Poland, France and Finland) and an European agroforestry scientific and practical knowledge pool ("Knowledge Cloud") where all collected information and materials would be published (https://agroforestrynet.eu/afinet/). The project established the Regional Innovation Network (RAIN), bringing together more than 800 stakeholders across Europe. It bridged the knowledge gap between researchers and farmers by pooling innovative practices, experiences, and literature; established working groups in nine countries, bringing together more than 300 stakeholders every six months to foster applied innovation; identified challenges and innovations hindering the adoption of agroforestry under technical, economic, educational, and policy headings; and produced brochures, technical articles, instructional videos, and a handbook for transitioning to agroforestry. The project has produced 15 reports, 3 websites, 14 conference proceedings, and 2 non-peer-reviewed articles (https://cordis.europa.eu/project/id/727872).

“INCREDIBLE-Innovation Networks of Cork, Resins and Edibles in the Mediterranean basin” was a project funded by the EU Horizon2020 program, carried out between 2017 and 2021. The INCREdible project focused on best practices related to the production, processing, and trading channels of key NWFPs such as mushrooms, resins, aromatics, and edible products (https://www.incredibleforest.net/). The INCREDIBLE thematic network established five international innovation networks (iNets) in the field of non-timber forest products (NWFP): mushrooms, resins, aromatic and medicinal plants, wild nuts and fruits, and wild mushrooms and truffles. Each iNet encompassed 300 to 500 stakeholders in seven Mediterranean countries: Portugal, Spain, France, Italy, Croatia, Greece, and Tunisia. The project has developed a narrative for each sector; mapped each value chain and compiled a list of priority issues and topics to be addressed. To facilitate the exchange of information, INCREDIBLE organized free events in different locations for all relevant stakeholders. A policy forum has been organized to generate policy recommendations at both EU and national levels on improved management of non-timber forest products. Nine entrepreneurs from five startups that were winners of the INCREDIBLE Open Innovation competition have been supported with a ten-day business and social innovation acceleration service to help them develop and commercialize their businesses. The "Information Repository for Non-Timber Forest Products" (https://repository.incredibleforest.net) has been developed. INCREDIBLE has published 35 blog posts on its website, over 250 articles across other communication channels, 13 electronic newsletters, and five videos. Also, 8 reports, 6 websites, patent fillings, videos, 2 book chapters, 3 peer reviewed articles, 1 conference proceedings, 1 non-peer reviewed articles were produced from the project (https://cordis.europa.eu/project/id/774632).

“DiverIMPACTS-Diversification through Rotation, Intercropping, Multiple Cropping, Promoted with Actors and Value-Chains towards Sustainability” was a project funded by the EU Horizon 2020 program, carried out between 2017 and 2022 with 34 partners. The aim of the project was to explore the potential of diversifying cropping systems to create efficient and sustainable value chains (https://www.diverimpacts.net/about.html). In 25 case studies, 46 obstacles to crop diversification from farm to table were identified, and a catalog of solutions were developed. To disseminate their findings to both academic and non-academic audiences, DiverIMPACTS partners provided the following services: collaboration within the European Crop Diversification Cluster (https://www.cropdiversification.eu/); 54 implementation briefs to disseminate practical solutions; 21 online seminars and 29 videos; a video of the entire project final conference in Brussels presenting a comprehensive summary of the project findings and practical recommendations; and 5 policy briefs offering key recommendations for overcoming obstacles to crop diversification at farm and value chain levels, generating applicable knowledge, teaching, training, and learning. During the project 7 reports, 6 websites, patent fillings, videos, 1 open research data pilot, 17 peer reviewed articles, 20 conference proceedings, 2 monographic boxing, 1 thesis, 1 non-peer reviewed articles were produced (https://cordis.europa.eu/project/id/727482).

"SHERPA - Sustainable Hub to Engage into Rural Policies with Actors" was a project funded by the EU Horizon 2020 program, implemented between 2019 and 2023 with 17 partners. The project aimed to develop recommendations for future policies related to EU rural areas by creating a science-society-policy interface. SHERPA utilized state-of-the-art multimedia tools across 40 multi-actor platforms covering 20 EU countries (https://rural-interfaces.eu/what-is-sherpa/). During the project opportunities and challenges for rural areas have been synthesized, a review of rural objectives in the Common Agricultural Policy Strategic Plans has been carried out, existing forecasting and scenario studies at EU and global levels have been examined, 41 regional and national MAPs have continued to operate effectively, and an implementation summary has been prepared for each MAP. The SHERPA online Repository has been updated to compile research outputs and findings from past and ongoing projects related to rural areas, Citizens, policymakers and researchers have been engaged in the issue of multi-level governance in rural areas through the implementation of the SHERPA approach (i.e., more than 80 MAP meetings with more than 610 actors from science (27%), society (42%) and policy (30%) in 2023), resulting in 31 MAP Position Notes and MAP Sheets, discussed at a hybrid Annual Conference with more than 100 participants from across Europe, and discussed at a face-to-face Final Conference with more than 160 participants from across Europe. On June 2, 2023, a second set of recommendations regarding future research agendas was discussed, and a second set of recommendations regarding the development of future rural policies was developed and presented. During the project; 23 reports, 4 websites, patent fillings, videos, 2 open research data pilot, 4 peer reviewed articles, 5 conference proceedings and 3 book chapters were produced (https://cordis.europa.eu/project/id/862448).

"Stargate-ResienT fARminG by Adaptive microclimaTe managEment" was a project funded by the EU Horizon 2020 program, performed between 2019 and 2024. STARGATE aimed to design a multi-scale, holistic Climate Smart Agriculture (CSA) methodology to help farmers and policymakers adapt to climate change in the short and long term. STARGATE identified the climate change-related vulnerabilities of existing agricultural systems, landscape management models, methods, and practices, and shaped the stakeholder community based on this analysis by conducting a requirements analysis for Climate Smart Agriculture (CSA) (https://www.stargate-h2020.eu/project/). The STARGATE project has developed a strong stakeholder community across six countries. Through their active participation, these stakeholders helped define pilot case studies encompassing diverse agricultural and climatic conditions. A detailed user requirements database has been created addressing the weather/climate information needs and challenges in adopting climate-friendly agricultural technologies. Furthermore, data management protocols based on pilot data requirements have been designed. The project has developed an atmospheric data integration system integrating satellite and ground-based observations for high-resolution weather forecasts. Climate risk scenarios and agricultural climate indicators have been formulated. A land/crop suitability methodology for efficient land-use planning under climate change has been developed. The project has provided advanced decision support tools (DSS), forecasting models, and data-sharing platforms enabling farmers to optimize their operations, increase productivity, and build resilience to climate change. Through extensive testing in pilot areas, STARGATE validated its methodologies and demonstrated their practical impact on real-world agricultural systems. Commercialization of key usable outcomes (KERs), development of business models suitable for market adoption, and collaborations with SMEs and policymakers have been undertaken. During the project; 38 reports,1 website, patent fillings, videos, 1 open research data pilot, 13 peer reviewed articles and 4 conference proceedings were produced (https://cordis.europa.eu/project/id/818187).

"NextLand-Next Generation Land Management services for Agriculture and Forestry" was a project funded by the EU Horizon2020 program, performed between 2020 and 2023. NextLand aimed to develop a set of remote sensing-based services for agriculture and forestry. The collaborative design approach aimed to break the cycle of service development, which is often tailored to the needs of a specific lower-tier service provider and developed only for a limited group of end-users from the same region. Including alpha and beta users in service design was crucial for increasing the feasibility and reliability of services for potential customers worldwide (https://nextland.services4eo.com/home/about). At the end of the project, the NextLand online store integrated 17 commercial agricultural and forestry intermediate services from 6 providers. These services were based on Copernicus and GEOSS data collections and were developed and improved with input from alpha and beta users. To ensure long-term sustainability, target markets and valuable services were identified, pricing strategies were developed, and sales forecasts were implemented. NextLand's efforts have led to significant sales activity, resulting in 600 sales leads, contact with 79 people from trade shows and sales events, 20 potential customers, 3 commercial deals, and past negotiations. During the project; 22 reports and 5 conference proceedings were produced (https://cordis.europa.eu/project/id/869520).

“AGROMIX -Agroforestry and MIXed farming systems - Participatory research to drive the transition to a resilient and efficient land use in Europe” was a project funded by the EU Horizon2020 program, carried out between 2020 and 2024. The AGROMIX project enabled a network of 83 sites with Mixed Farming (MF), Agroforestry (AF), or value chain stakeholder networks to drive the transition to resilient and efficient land use in Europe. An interwoven approach was applied to conduct 12 joint design pilot studies across Europe. Their objectives were: to uncover the potential synergies in MF/AF systems; to develop and promote value chains and infrastructure for MF/AF products; to develop the MIX-A toolkit for jointly designing and managing MF/AF systems in practice; to identify and model transition scenarios; to develop policy recommendations and action plans for a successful transition; and to maximize the impact and legacy of the project in creating low-carbon, climate-resilient agricultural systems. AGROMIX used an interdisciplinary multi-stakeholder research approach with 10 universities, 7 research institutes and 11 multi-stakeholder partners (https://agromixproject.eu/about/). AGROMIX involved creating a GIS (Geographic Information System) database to integrate land-use scenarios into modeling, complemented by the creation of a catalog of existing areas. AGROMIX was implemented across 6 different systems and locations, completed with a participatory design methodology, sustainability and resilience assessments, and a participatory GIS mapping handbook. AGROMIX completed collaborative design activities in 12 locations and published an accessible “Collaborative Design Handbook” for farmers. AGROMIX included a new methodology for modeling resilience, the addition of more tree species and climate and economic data to existing models, and agent-based land-use modeling, completing modeled scenarios. Policy publications were also available (https://zenodo.org/communities/agromixproject). During the project 32 reports, 1 demonstrator, pilots, prototypes, 1 website, patent fillings, videos, 14 peer reviewed articles, 31 conference proceedings, 4 monographic books, and 2 non-peer reviewed articles were produced (https://cordis.europa.eu/project/id/862993).

“Trees4Clima-Enabling carbon accounting of trees on farms for agroforestry-based climate action (Marie Curie Action)” was a project funded by the EU Horizon2020 program, performed between 2021 and 2025. The Trees4Clima project aimed to identify and classify agroforestry systems, facilitate carbon accounting, and develop cost-effective methods for climate finance based on agroforestry (https://cordis.europa.eu/project/id/896512). TREES4CLIMA enhanced its innovation capacity by offering open and accessible deep learning processes for agroforestry mapping, 3D reconstruction, and individual tree-level monitoring. TREES4CLIMA tools have enabled low-cost, scalable carbon accounting and structural monitoring at field, farm, and landscape scales, leveraging cutting-edge technology by integrating 2D/3D computer vision with field measurements and directly linking individual tree monitoring to finance and policy. Accessible monitoring processes for agroforestry unlocked market opportunities by reducing transaction costs for agroforestry projects, making nature-based solutions investable and auditable, and helping producers and cooperatives access climate finance revenue streams. Throughout the project, high-resolution PlanetScope imagery was downloaded via the NICFI program. Drone imagery and orthophotos were acquired across hedges, silvopastoral areas, multilayer systems, shaded systems, and fallow lands. Agroforestry detection, a dual-branch model that acquires satellite imagery and forest loss layers in parallel, learns high-level semantic features, and combines them for agroforestry classification, was developed. Agroforestry 3D models were created using a hybrid pipeline combining UAV-mounted RGB imagery and state-of-the-art neural network methods. Biomass was collected to train and evaluate machine learning models. 25 cm GSD orthophotos were downloaded from Spain's PNOA program and matched with aerial LiDAR. Matching_trees was developed to address the discrepancy between tree locations in NFI records and aerial photograph features (https://cordis.europa.eu/project/id/896512).

"Undertrees-Creating knowledge for UNDERs-Determining ecosystem services of agroforestry systems through a holistic methodological framework (Marie-Curie Action)" was a project funded by the EU Horizon 2020 program, carried out between 2020 and 2025. UNDERTREES aimed to create an international and inter-sectoral network of 15 organizations across 3 continents (Europe, Africa, and South America) working on a joint research program in the field of agroforestry (AF) and ecosystem services (ES). UNDERTREES planned research, training and activities in 16 study sites across 5 biogeographic areas in three thematic areas: agricultural and environmental sustainability, socio-economic sustainability and policy development (https://projectundertrees.wordpress.com/). In line with UNDERTREES' aim, new research pathways was designed with a cross-sectoral and multi-stakeholder approach to create a holistic methodological framework: moving beyond biophysical and monetary assessment towards a common method for evaluating ecosystem services at temporal and spatial scales; engaging stakeholders in the process to map and estimate ecosystem services; and adopting multi-scale approaches to inform regional, national and EU policymakers. During the project; 19 reports, 1 website, patent fillings, videos, 1 open research data pilot and 1 dataset were produced (https://cordis.europa.eu/project/id/872384).

"MIXED-Multi-actor and transdisciplinary development of efficient and resilient MIXED farming and agroforestry systems" was a project funded by the EU Horizon 2020 program, running from 2020 to 2025. MIXED has researched and supported the development of agroforestry systems (their benefits on climate, environment and society). The objectives are listed as: generating knowledge and innovations for improved Mixed Agriculture and Forestry Systems (MiFAS), climate change resilience and other ecosystem services, decision support systems for MiFAS to facilitate farmers' transition to MiFAS, and estimations of the consequences of MiFAS implementation at multiple scales for the development of supporting policies (https://projects.au.dk/mixed/about-mixed). Through combined qualitative and quantitative analysis, ecosystem services provided by MiFAS were assessed at the farm level, and field tests were conducted with real-world examples of how MiFAS can contribute to mitigation and adaptation. Improved ecosystem services through the adoption of MiFAS on individual farms and across farms were evaluated, modeled, and enabled. MIXED collaborated with the parallel AGROMIX and STARGATE EU H2020 projects to achieve the highest levels of reach and implementation. In particular, the MIXED project documented the multiple impacts of mixed farming systems on climate, environment, and biodiversity, and their benefits for more resilient and sustainable bio-based production, by showcasing lists of specific farm examples and relevant farm data across Europe. During the project; 24 reports, 1 open research data pilot, 2 websites, patent fillings, videos and 7 peer reviewed articles were produced (https://cordis.europa.eu/project/id/862357).

5.2. Projects supported under the EU Horizon Europe program in agroforestry

(https://digitaf.eu/tools-data-and-projects-catalogue/projects/project/agromix)

"ResAlliance- Landscape resilience knowledge alliance for agriculture and forestry in the Mediterranean basin" was a project funded by the EU Horizon Europe program, carried out between 2022 and 2025, with 16 partners. The project aimed to foster collaboration with farmers and foresters to facilitate knowledge sharing and enhance landscape resilience in the Mediterranean region (https://www.resalliance.eu/). ResAlliance has established a multi-stakeholder structure: LandNet and LandLabs. LandNet engaged stakeholders from the Mediterranean region, educating them and identifying new collaborations and networks to develop knowledge and practices. LandLabs was a regional subset of LandNet, supporting knowledge transfer and enabling regional landscape resilience solutions across five different Mediterranean countries (Northern Portugal, Catalonia (Spain), Sardinia (Italy), the

Peloponnese (Greece), and Cyprus). During the project; 1 website, patent fillings, videos, 2 reports, 4 conference papers, 3 peer reviewed articles and 1 monographic book were published (https://cordis.europa.eu/project/id/101086600).

"AF4EU-Agroforestry Business Model Innovation Network" was a project funded by the EU Horizon Europe program, running from 2023 to 2025, with 12 partners from 10 different countries. The project aimed to promote agroforestry in Europe by developing a multi-stakeholder, interactive, and innovative agroforestry network. During the project, 33 successful agroforestry farm models from across Europe have been analyzed in terms of sustainability (https://af4eu.eu). The AF4EU project established Regional Agroforestry Innovation Networks (RAINs) across Europe, facilitating knowledge sharing among stakeholders. Through RAIN meetings, 33 model agricultural forestry farms and the value chains connecting them were identified. During the project; 6 reports, 9 peer reviewed articles and 4 conference papers were produced (https://cordis.europa.eu/project/id/101086563).

"FOREST4EU-European innovation partnership network promoting operational groups dedicated to forestry and agroforestry" was a project funded by the EU Horizon Europe program, running from 2023 to 2025. During the project, stakeholders from nine countries (Portugal, Spain, France, Italy, Croatia, Germany, Latvia, Slovenia, and Finland) examined these innovations (https://medforest.net/2025/07/23/mediterranean-innovation-in-action-local-operational-groups-shaping-the-future-of-agroforestry-and-forestry/). The project presented new approaches and methods to ensure the sustainability of forest management, mitigate risks, and increase forest sustainability and resilience to climate change impacts such as drought, pests, and diseases. The Bioclimsol Decision Support System (DSS) provided a dual assessment by integrating GPS and climate models, supported by innovations such as "climate monitoring maps," enabling the identification of future ecological mismatches to measure the risk of drying out forests and identify species suitable for potential reforestation. The project produced 5 innovation topic hubs, 329 stakeholders from 25 countries, 86 connected OGs, 176 extended summaries, 175 practice abstracts, 173 factsheets, 219 multilingual capacity-building materials, 5 international study visits, 6 policy briefs and governance analysis tools. Also, 22 documents and reports, 2 peer reviewed articles and 62 others were published (https://cordis.europa.eu/project/id/101086216)

"DISTENDER-Developing Strategies by integrating mitigation, adaptation and participation to climate change risks" is a project funded by the EU Horizon Europe program, running from 2022 to 2026. The project aims to create a framework to guide the integration of climate change adaptation strategies in Europe (https://distender.eu/). The project co-design integrated climate adaptation and mitigation strategies for five CCSs through stakeholder workshops that develops transformative pathways based on climate projections and collaborative efforts. The design of a Decision Support System (DSS) with functionalities to examine local climate impacts and prioritize adaptation and mitigation strategies using a multi-criteria decision analysis framework has been completed. DISTENDER has produced high-resolution maps and GeoTIFF files detailing year-by-year climate impacts, risks, and vulnerabilities up to 2049. During the project; 38 reports, 2 demonstrators, pilots, prototypes, 12 conference papers, 2 book chapters and 6 peer reviewed articles were published so far (https://cordis.europa.eu/project/id/101056836).

"DigitAF-Digital Tools to help AgroForestry meet climate, biodiversity and farming sustainability goals: linking field and cloud" is a project with 26 partners, funded by the EU Horizon Europe program, carried out between 2022 and 2026. The project aims to help policy actors design more efficient support for agroforestry and carbon agriculture, provide farmers and foresters with tools to help them cope with the complexities of agroforestry systems, develop open-source modeling tools, and ensure their dissemination to target groups (https://digitaf.eu/). DigitAF identified needs through surveys in six Life Labs with the participation of over one hundred stakeholders across Europe, mapped value chains, and assessed the costs and benefits of key practices and agroforestry interventions. Policy analysis was conducted at the European level, and policy summaries on agroforestry were created. Outputs during the project included a database on agricultural environmental indices, methods for recording agroforestry areas and greenhouse gas emissions and the LPIS Sustainability Compass, contributions to carbon farming and certification, an online catalog integrating technical and financial assessment tools, certification and branding studies, and guides for viable business models. During the project; 18 reports, 3 websites, patent fillings, videos, 1 data set, 1 book chapter and 1 peer reviewed article were produced so far (https://cordis.europa.eu/project/id/101059794).

"Reforest-Agroforestry at the forefront of farming sustainability in multifunctional landscapes in Europe" is a project funded by the EU Horizon Europe program, running from 2022 to 2026, with 14 partners from 10 different countries. REFOREST aims to develop solutions to the main barriers preventing wider adoption of this type of land use by farmers in the EU and participating countries, and to increase the sustainability of agroforestry and food production (https://agroreforest.eu/). The agroforestry models used in the project are fully parameterized with data obtained from the Live Laboratories. Advances in dataset creation, neural network training, and remote sensing tool development have improved the estimation of carbon capture and biodiversity potential and have successfully deployed an agroforestry carbon and biodiversity estimation tool. The project has also developed a scheme for agroforestry financing in Europe and is testing various business models to support the establishment and scaling of agroforestry businesses. The FarmTree Tool has been successfully adapted to temperate European conditions, including tree species characteristics, management practices, and region-specific climate data. In the technology field, the project has enabled the development and field testing of automated workflows that recognize and define agroforestry characteristics such as trees, shrubs, and crop plots by creating comprehensive datasets combining remote sensing and land data. ReForest has developed a hybrid agroforestry financing model combining public funding, private investment, and results-oriented payments. In collaboration with DeepRoots, an agroforestry consultancy business model has been created that offers integrated technical, financial, and implementation support to landowners and businesses. During the project; 9 reports, 1 website, patent fillings, 1 demonstrator, pilots, prototypes, 2 data management plans, 4 peer reviewed article and 1 monographic book were produced so far (https://cordis.europa.eu/project/id/101060635).

"Grazing4AgroEcology-European Network to promote grazing and to support grazing-based farms on their economic and ecological performances as well as on animal welfare" is a project funded by the EU Horizon Europe program, performed between 2022 and 2026, with 18 partners from 8 different countries. The objective of G4AE is to empower farmers to optimize ruminant grazing through a multi-stakeholder approach. G4AE's Partner Farm Network, comprising 120 partner farms (15 per country), will facilitate the implementation of innovations (https://grazing4agroecology.eu/). The project has produced 120 videos and application summaries, which are being published through social media and the project website. A comprehensive online survey was conducted in the eight countries of the consortium to examine the perceived attitudes towards grazing among farmers and students under the age of 40, the barriers to grazing, and the factors that encourage grazing. Perceived barriers and encouraging factors showed significant differences between regions in relation to local contexts. During the project; 5 reports, 2 websites, patent fillings, videos, 22 conference papers, 2 book chapters and 1 peer reviewed article were produced so far (https://cordis.europa.eu/project/id/101059626).

"FIRE-ADAPT-The Role of Integrated Fire Management on Climate Change Adaptation for Ecosystem Services in Tropical and Subtropical Regions" is a project with 24 partners from 10 countries, funded by the EU Horizon Europe program, running from 2023 to 2026. The project aims to improve understanding of the role of integrated fire management (IFM) in preventing forest fires and improving natural and cultural ecosystem services (https://www.fireadapt.eu/). The project has created a broad international and interdisciplinary network of more than 160 scientists and practitioners working together to improve understanding of the role of Integrated Fire Management in socio-ecological systems. The TREX (Controlled Combustion Exchange Programme) implementation has been carried out. During the project; 1 data set, 2 reports, 1 data management plan and 3 peer reviewed articles were published so far (https://cordis.europa.eu/project/id/101086416).

"Wilde-Climate-smart rewilding: ecological restoration for climate change mitigation, adaptation and biodiversity support in Europe" is a project with 22 partners, funded by the EU Horizon Europe program, carried out between 2023 and 2026. The project aimed to develop a research and innovation program incorporating the climate-biodiversity link. For this, a team of experts from Europe worked to gather information on European rewilding trends and their consequences, explore alternative land-use options, develop state-of-the-art projections, and develop concrete and easily accessible decision support and management guidelines (https://www.wilde-project.eu/). The project is still ongoing and has produced a limited number of publicly available outputs. However, the preparation of research results is progressing. Activities have included establishing a formal quantitative framework for 'climate-friendly reforestation', as well as conducting various literature reviews and meta-analyses addressing different environmental, socio-economic and political aspects associated with reforestation and alternative land management options. Activities have been carried out through the organization of more than 15 meetings and workshops. During the project; 2 websites, patent fillings, videos, 1 reports, 18 peer reviewed articles and 1 thesis were produced so far (https://cordis.europa.eu/project/id/101081251).

"RhECAST-Rural landscape heritage and Carbon sequencing" is a project funded by the EU Horizon Europe program, running from 2024 to 2026. The project aims to develop a new interdisciplinary approach to examine the interactions between sustainability and rural landscape heritage, particularly CO2 sequestration (https://cordis.europa.eu/project/id/101105219). In the project, spatial datasets defining land use and landscape structure in selected study areas were collected and organized. Historical cartographic sources, remote sensing data, and other geographic-spatial information were integrated into a GIS environment to reconstruct the spatial configuration of past agricultural landscapes. In the second phase, analytical and modeling workflows aimed at assessing carbon sequestration in different land-use scenarios were developed. The integration between environmental reconstruction and socio-economic modelling approaches was also enhanced. During the project; 1 data management plan and 2 peer reviewed articles were produced so far (https://cordis.europa.eu/project/id/101105219).

“DRYAD-Demonstration and modelling of Nature-based solutions to enhance the resilience of Mediterranean agro-silvo-pastoral ecosystems and landscapes” is a project funded by the EU Horizon Europe program, which will be carried out between 2024 and 2028, with 27 partners from 6 different countries. DRYAD aims to provide climate-resilient, viable nature-based solutions (NBS). The project will focus on regions such as Andalusia, Alentejo, and Sardinia, testing innovative NBSs and then transferring successful solutions to other regions. Local authorities, stakeholders, and citizens will be actively involved in the process through living laboratories (https://dryad-project.eu/). One book chapter, one conference proceeding and one peer reviewed article has been produced from the project so far (https://cordis.europa.eu/project/id/101156076).

“GALILEO-Strengthening rural livelihoods and resilience to climate change in Africa: innovative agroforestry integrating people, trees, crops and livestock” is a project funded by the EU Horizon Europe program, performed between 2025 and 2028. The project aims to develop agroforestry innovations in agro-livestock, agro-forestry, and agro-forestry-livestock systems in Sub-Saharan Africa using multi-actor approaches. Eight living labs have been established in the semi-arid regions of Senegal and Kenya, and in the humid but drought-prone regions of Ghana and Cameroon (https://galileo-project.eu/).

“AfroGrow- Informed Decision - Making for Agroforestry Systems in Africa through a Network of Living Labs” is a project funded by the EU Horizon Europe program, running from 2025 to 2028, with 25 partners from 15 countries. The project promotes sustainable systems that enhance climate resilience, food security, biodiversity, and gender equality, blending traditional practices with modern tools to foster innovation, collaboration, and knowledge exchange (https://afrogrow-project.eu/).

“CAFAMORE - Carbon Farming Monitoring and Registry” is a project funded by the EU Horizon Europe programme, to be carried out between 2025 and 2029, with 23 partners from 10 countries. The project will conduct research, including market and policy making, to build the necessary trust in carbon markets across Europe (https://www.cafamore.eu/).

5.3. Projects supported under the EU PRIMA program in agroforestry

(https://digitaf.eu/tools-data-and-projects-catalogue/projects/project/agromix)

"FORECAST- Fostering Resilient Agroforestry Systems with climate-ready Tree and Herbaceous Germplasm" was a project funded by the PRIMA programme, carried out between 2017 and 2021, with nine partners and five countries (Algeria, France, Italy, Portugal, Tunisia). The project implemented an innovative strategy based on integrating highly resilient, locally adapted legumes and specialized seed technologies into existing agroforestry systems, addressing the diverse socioeconomic/pedoclimatic conditions of the Mediterranean region. A multi-actor approach met the needs of stakeholders/end-users, focusing on the empowerment of women in agroforestry. A multi-scale approach was used to drive policy and social change and support the adoption of FORECAST systems. Innovative food/non-food products and processing solutions developed to create new value chains and utilize by-products/best raw materials. Capacities necessary for broader communication and dissemination developed to support the community-driven process, knowledge transfer, and scaling of FORECAST systems (https://www.forecast-project.eu/).

"TRANSITION (InnovaTive Resilient fArmiNg Systems in MediTerranean EnvIrONments)", a completed PRIMA project, was carried out between 2021 and 2024 with 10 partners from six countries (Algeria, Egypt, France, Greece, Italy, Spain) (https://mel.cgiar.org/projects/transition#impact). The project aimed to understand the obstacles to the dissemination of new agricultural practices in agroforestry, develop a watershed-level roadmap, and develop evidence-based decision-making tools aligned with stakeholder priorities. During the project, the aim was to identify appropriate strategies to enhance the resilience of the agricultural sector, including the use of genetically adapted resources to local conditions, water recycling and soil conservation strategies; to identify environmental and socio-economic barriers to the implementation of resilient agriculture; to quantify the system efficiency and delivery of ecosystem services and their impact on farmers' livelihoods through existing systems and collaboratively designed and replicable case studies; to strengthen the expansion of agroforestry and mixed farming systems through practical innovation and knowledge exchange; and to provide useful robust information for administrations in terms of measurable impacts and potential transition scenarios that maximize the ecological service delivery and resilience of basic agricultural systems in the Mediterranean.

"MA4SURE- Mediterranean Agroecosystems for Sustainability and Resilience under Climate Change" was a project funded by the PRIMA programme, carried out between 2021 and 2024, with eight partners and five countries (Egypt, France, Italy, Slovenia, Spain). The project aimed to characterize sustainable and profitable, climate -resilient and adaptable agroforestry/mixed agriculture systems. It focused on examining the sustainability of agroforestry and mixed agriculture systems in the Mediterranean by reducing their dependence on external inputs (fertilizers, water, energy, pesticides), increasing natural resource use efficiency, and strengthening their resilience to climate change. The project also aimed to establish multi-sectoral partnerships to address the biophysical and socioeconomic assessment of multicultural systems and the services and benefits they provide to the community (https://ma4sure.institutmetropoli.cat/).

The EU-supported PRIMA project (2024-2027), TransformMed (Transforming the Mediterranean Region through Agroforestry), aimed to support and promote the large-scale adoption of successful agroforestry systems (AFS) in saline and degraded areas to improve soil health, increase biodiversity and the productivity of agricultural ecosystems, with the participation of seven different countries (Spain, France, Turkey, Morocco, Tunisia, Portugal and Germany) (https://www.transformed-prima.eu/). The project utilized more than 15 plant species/products in 11 newly restored areas: Windbreaks: cedar, almond, acacia and maple; trees producing high value-added products: carob, argan, cactus pear, rosehip, caper and sainfoin; drought-resistant shrubs and trees along with medicinal plants such as rosemary, lavender or thyme; and halophytes in saline areas.

The PRIMA project "RevAgroForMed (REVitalization of AGROFORestry systems through agroecological transition for increasing farm productivity in the MEDiterranean)", to be carried out between 2025 and 2028, supported by the European Union and involving six countries (Algeria, France, Italy, Jordan, Slovenia, Spain), aims to contribute to the revitalization of agroforestry systems in the Mediterranean region, increase productivity, improve soil quality, and enhance climate resilience through the application of precision agriculture techniques to agroecology, organic farming, and agroforestry systems (https://www.era-learn.eu/network-information/networks/prima/section-2-multi-topic-2024/revitalization-of-agroforestry-systems-through-agroecological-transition-for-increasing-farm-productivity-in-the-mediterranean). Two strategies have been identified in the project: (i) updating traditional agroforestry systems with revitalizing practices such as cover crops, mulching, diversified rotations, genetic improvement methods, animal integration, and the implementation of advanced certification systems specific to agroforestry; (ii) promoting the adoption of agroforestry practices that will accelerate the ecological transition in agriculture by integrating agroforestry practices with ecologically intensive organic, microorganic, and precision farming techniques. The project envisions a 'light beacon' farm as a living laboratory and a network of target farms at the end of the project that will manage and implement the innovation. The impact of innovative agroforestry systems and technologies will be assessed in terms of their effects on land, energy, water, productivity, biodiversity, soil quality and environmental pollution, response to fluctuations in climate and macroeconomic conditions, and soil biodiversity in terms of microbiome and microarthropods. Multivariate statistical methods will be used to identify and characterize local farm types and to assess the extent to which the sustainability impacts of field and farm-scale practices and innovations are reflected at the landscape level.

"SCALARE - SCaling Agroforestry by living LAbs for Resilient Mediterranean agro-Ecosystems" is a project funded by the EU PRIMA program, to be carried out between 2025 and 2028. The SCALARE project aims to create a comprehensive innovation ecosystem to improve agroforestry land management systems in the Mediterranean. Living laboratories will be established in Egypt, Italy, Morocco, Spain, and Tunisia (https://www.scalare-project.eu/).

"TAIE - Truffle Agroforestry Innovate & Empower", is a project funded by the EU PRIMA program, to be carried out between 2025 and 2028 with eight partners from five countries (Germany, Italy, Morocco, Spain, Türkiye). TAIE aims to innovate in truffle cultivation through the implementation of agroforestry practices, while empowering communities through the development of techniques, learning activities and materials, and with an unwavering commitment to gender equality. Agroforestry practices such as cover crops and/or grazing, beekeeping, etc., combined with the cultivation of valuable truffles, have the potential to improve soil quality by promoting organic carbon sequestration and thus reduce losses, particularly in regions like the Mediterranean where erosion is a significant problem. In addition, grazing can provide natural weed control and soil fertilization, ultimately leading to increased nutrient content in the soil. It encourages crop diversification to improve soil structure, reduce pest and disease pressure, and increase ecosystem resilience. Furthermore, TAIE aims to develop research technical solutions and promote high-value cultivation to sustain biodiversity and landscape diversity, especially in areas of high ecological value such as mountainous regions. By analyzing truffle value chains in selected partner countries, the project aims to comprehensively understand their organizations, strengths and weaknesses, regulatory and institutional frameworks, and the characteristics of truffle producers, processors, and retailers. It also aims to promote greater adoption of agroforestry practices by exploring various strategies, including certification schemes, branding, and new business models, to enhance value chain development for agroforestry products. Finally, it seeks to innovate in existing agroforestry practices through the use of precision farming techniques (https://www.era-learn.eu/network-information/networks/prima/section-2-multi-topic-2024/truffle-agroforestry-innovate-empower).

"AGROFIG- Fostering Agroforestry Benefits Through Fig Tree Cultivation in the Mediterranean" is a project funded by the PRIMA programme, to be carried out between 2025 and 2028, with 4 countries. AGROFIG aims to promote agroforestry through fig cultivation in the Mediterranean basin, identify and remove barriers to the more widespread adoption of agroforestry systems, and establish strong ties with regulatory bodies and market actors to support the revitalization of agroforestry practices in the region. The project will test the performance of fig trees within agroforestry systems in demonstration areas. By gathering socioeconomic data and stakeholder perspectives, the project will inform policies and protect biodiversity, particularly undervalued crops like figs, by examining 130 genotypes. Economically, it supports farmers with low-input, adaptable fig varieties, increasing income and market opportunities, especially in degraded areas. Socially, it plans to collaborate with at least 100 stakeholders annually to promote the adoption of agroforestry solutions, resilient and inclusive rural communities, and gender-sensitive training by establishing living laboratories and fostering innovation and knowledge exchange (https://www.agrofig.eu/en/home).

"AGROFORESTEAM- AGROFORESTry for TErritorial sustAinable Management" is a project funded by the PRIMA programme, to be carried out between 2025 and 2028, with 7 countries. AGROFORESTEAM will support the adoption of agricultural forestry systems (AF) in the Mediterranean region by establishing regionalized multi-actor platforms to overcome technical, political, and socio-economic barriers to agricultural forestry practices. AGROFORESTEAM will establish 7 Multi-Actor Platforms (MAPs) in 7 different countries: Morocco, Algeria, Tunisia, Portugal, Spain, France, and Italy. Experts and training programs focusing on gender perspectives and effective stakeholder participation will be programmed to ensure better relationships and robust decision-making processes during and after project implementation. AGROFORESTEAM will include case studies (CS) of both silvo-pastoral and silvo-arable agricultural forestry systems known and/or monitored by partners in the 7 working regions. CSs will be selected from systems adapted to the local context (e.g., oases), representing alternative/innovative practices (e.g., successor agricultural forestry systems), or requiring urgent action to conserve the systems (e.g., Montado) (https://www.era-learn.eu/network-information/networks/prima/section-2-multi-topic-2024/agroforestry-for-territorial-sustainable-management).

"ASPmed- Agroforestry practices for Agroecological transition towards sustainable Sheep and Poultry farming in the Mediterranean region" is a project funded by the PRIMA programme, to be carried out between 2025 and 2028, with 11 partners. ASPmed develops innovative agroforestry tools and tests novel feeding and management strategies. Monitoring technologies and pilot applications validate best practices in real agricultural settings, creating practical and scalable solutions adapted to Mediterranean contexts. By integrating trees, crops, and animals, ASPmed contributes to climate resilience, carbon sequestration, and sustainable protein production. The project supports inclusive rural development and promotes long-term environmental and socio-economic sustainability (https://www.aspmed.eu/home).

"Cork-Med-Cork Quality Yield Provision Monitoring for Revitalising Sustainable Agroforestry in the Mediterranean Basin" is a project funded by the PRIMA programme, to be carried out between 2025 and 2028, with five partners and four countries (Algeria, Portugal, Spain, Tunisia). The CorkMED project will focus on assessing mushroom quality and yield in cork oak agroforestry systems. Within CorkMED, mushroom quality and yield indicators will be identified based on baseline data, their spatial and temporal variation will be mapped, and monitoring of mushroom quality and yield will be established on an open-access web platform. This framework can be combined with remotely sensed data and integrated with other institutional frameworks in essential mapping tools for policymakers, the mushroom industry, researchers and academics, and small-scale producers (https://www.era-learn.eu/network-information/networks/prima/section-2-multi-topic-2024/cork-quality-yield-provision-monitoring-for-revitalising-sustainable-agroforestry-in-the-mediterranean-basin).

"SustAgri-Promote sustainable agroforestry systems" is a project funded by the PRIMA programme, to be carried out between 2025 and 2028, with six partners and five countries (Algeria, Germany, Italy, Morocco, Tunisia). The project aims to provide training on traditional and innovative agroforestry systems, develop a digital and open agroforestry decision support tool, provide new business models and financing opportunities, and empower local (women) farmers. Sustainable agroforestry systems will be promoted by improving agroforestry structures and considering dimensions such as soil and water management, crop diversity, climate adaptation and mitigation, technology integration, and social benefits. The web application will suggest suitable business models by enabling site-specific, environmental, and socio-economic optimization and planning of smart agroforestry systems. Emphasis will be placed on the training of local (women) farmers and the consideration of gender dimensions (https://www.era-learn.eu/network-information/networks/prima/section-2-multi-topic-2024/promote-sustainable-agroforestry-systems).

5.4. Projects funded by other EU programs

In addition to previous projects, several agroforestry initiatives have been supported by other EU programmes, including ENI CBC, FP7, LIFE, and Interreg.

LIVINGAGRO (Cross Border Living Laboratories for Agroforestry) project, carried out between 2019 and 2023, funded by the European Union (ENI CBC Medprogram) aimed to share innovations related to agroforestry with stakeholders working with olive and grassland forests in Mediterranean countries, with the participation of six partners and four countries (Italy, Jordan, Lebanon, Greece) (https://www.livingagrolab.eu/about-livingagro/). LIVINGAGRO addressed these issues with an innovative approach and established two Living Laboratories [olive multifunctional system (Living Laboratory 1) and grazed woodlands (Living Laboratory 2)] to facilitate interaction between innovators and stakeholders. Olive cultivation is iconic of many Mediterranean rural areas and has traditionally been, and often still is, managed as agroforestry systems alongside olive groves, cereals, fodder legumes and/or pastures. After conducting surveys and interviews to understand stakeholder needs, the LIVINGAGRO team presented technological developments, practical research results, and other types of innovation to stakeholders that can benefit both financially and environmentally.

AGFORWARD (Agroforestry that Will Advance Rural Development) project, funded under the Seventh Framework Programme (FP7) from 2014 to 2017, aimed to promote agroforestry practices across Europe by involving over 800 stakeholders and evaluating innovative systems to enhance ecosystem services and farm profitability.

In the LIFE programme, the AFaktive project (2023–2027) focuses on improving water retention, climate adaptation, and soil protection through the implementation of agroforestry systems in agricultural landscapes. Earlier LIFE projects, such as LIFE Montado (2016–2019), also addressed sustainable management of traditional agroforestry systems, particularly in Mediterranean regions.

The CAMBIUM project (2024–2027), funded under Interreg program, aims to accelerate agroforestry adoption in Flanders and the Netherlands by improving advisory services, strengthening knowledge exchange, and facilitating cross-border collaboration.

These projects collectively contribute to strengthening innovation, promoting sustainable land management, and supporting the wider adoption of agroforestry practices across Europe.

6. Conclusion

In the introduction, it was mentioned that the Mediterranean Forest Research Agenda 2030 (MFRA 2030) meeting identified four priority areas to be addressed in the next decade.

Regarding the first thematic area (forest resilience in the context of forest degradation related to global change), the following research areas were proposed: fire simulation exercises, high-tech training modules to assess the impacts of degradation on forest structure, on-site studies to measure forest resilience under drought conditions, examining the socioeconomic impacts on soil fertility and forest products and services, and the costs of post-degradation infrastructure restoration, investigating the costs of risk mitigation measures, identifying best practices in fire management approaches, modeling to predict future forest conditions in climate change scenarios, experiments to investigate the intensity of animal grazing in Mediterranean forest ecosystems, predicting specific conditions for forest rehabilitation, knowledge sharing and capacity building among Mediterranean institutions.

The second thematic area (conservation and management of biodiversity and forest genetic resources) proposes developing niche modeling techniques based on the adaptive and functional characteristics and distribution patterns of trees, applying population genomics to assess and monitor species interactions in reference and restored forests, creating living laboratories for forest sustainable development, and collecting a dataset for use in statistical tools such as machine learning to predict future scenarios.

The third thematic area (forest management addressing trade-offs and synergies among multiple ecosystem services) proposes designing innovative multi-purpose forest management models, adopting a general approach to vegetation/fuel load management at the landscape level, developing management approaches that support bioeconomic policies and strategies, and developing management alternatives and multi-stakeholder engagement strategies to ensure the sustainability of multiple ecosystem services.

For the fourth thematic area (social and business innovations and policy tools supporting the bioeconomy based on Mediterranean forests), it is proposed to design systems thinking/systems dynamics frameworks to adopt interdisciplinary research approaches and tools, strengthen policy effectiveness and social innovation processes, and focus on needs-based research (Bou Dagher-Kharrat et al., 2022).

The thematic areas identified at the meeting and the proposed research approaches for them are listed above. Recent projects in agroforestry also show that they are continuing with projects consistent with these research approaches. A large portion of these projects incorporate precision agroforestry approaches and tools. Completed and ongoing projects demonstrate that significant progress has been made in this area. It is anticipated that proposed projects will also be developed in this direction.

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This project is part of the PRIMA programme supported by the European Union