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Small woody features in agricultural areas: Agroforestry systems of overlooked significance in Europe

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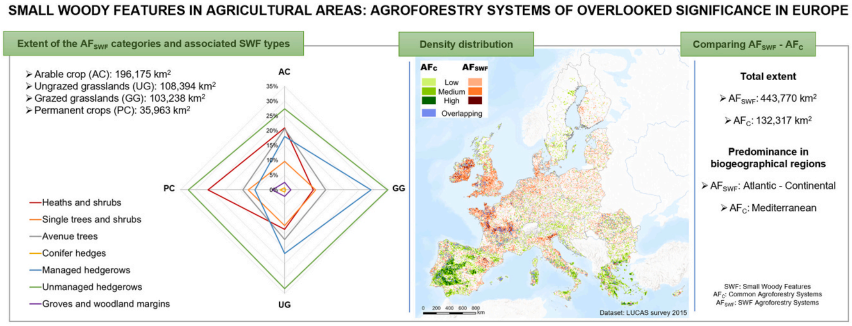
HIGHLIGHTS

- LUCAS data provide valuable insights into the typology and spatial distribution of SWF in agricultural areas.
- SWF agroforestry systems cover 3.3 times more land area than common agroforestry systems in the European Union.
- Arable crops associated with SWF were the most extensive agroforestry systems.
- Hedgerows are the most frequent type of SWF within agricultural areas.
- SWF have the potential to enhance ecosystem services in common agroforestry systems.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Small woody features (SWF), as field boundaries, hedgerows, or riparian buffers, are crucial for agricultural landscapes and, frequently, disregarded. In combination with agricultural land uses they are considered agroforestry systems (AF_{SWF}), but their spatial distribution and detailed location of SWF types are insufficiently known in the EU as to support agricultural policies or enhance the development of farming practices for biodiversity conservation or productivity management.
OBJECTIVE: In addressing this, the LUCAS 2015 dataset was analysed across EU member states to identify, characterise, and determine the extent and distribution of AF_{SWF} classes and the variety of SWF types in agricultural lands. Additionally, a comparison between AF_{SWF} and common agroforestry systems (AF_C), such as silvopastoral, silvoarable, grazed or intercropped permanent crops, and kitchen gardens was conducted.
METHODS: To achieve this, four categories of AF_{SWF} were established based on the classes of land cover within agricultural areas where SWF are present: arable crops AF_{SWF}, grazed grasslands AF_{SWF}, ungrazed grasslands AF_{SWF}, and permanent crops AF_{SWF}. The typology and relevance of the AF_{SWF} categories and the SWF types were analysed and mapped at country level and by biogeographical regions. The spatial distribution of AF_{SWF} and the different types of SWF were analysed using density maps.
RESULTS AND CONCLUSIONS: Results reveal that AF_{SWF} cover 443,770 km^2 (10% of the EU-28 and 25% of the utilised agricultural area). This area encompasses arable crops (44%), ungrazed grasslands (24%), grazed grasslands (23%), and permanent crops (8%). The extent of AF_{SWF} is 3.3 times larger than AF_C (132,317 km^2), being mainly concentrated in Ireland, United Kingdom, France, Denmark, and Germany, while AF_C prevail in the

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Mediterranean. As regards to SWF types, both managed and unmanaged hedgerows were dominant in France, Great Britain, and Ireland. Heaths and shrubs in Spain and Germany. Grove and woodlands margins in Spain, while avenue trees were dominant in Germany. Single trees and conifer hedges, the less prevalent SWF types, were broadly distributed.

SIGNIFICANCE: This pioneering research addresses a knowledge gap, thoroughly documenting AF_{SWF}, revealing both its types and spatial distribution. The findings highlight substantial disparities in AF_{SWF} prevalence among member states of the EU. The study compares AF_{SWF} with AF_C in relevance and distribution, significantly contributing to better understanding agroforestry systems and offering baselines for future monitoring and management. Findings advocate for policy incentives and increased awareness among farmers to foster the understanding of the impacts of SWF on productivity and biodiversity.

1. Introduction

Woody vegetation plays an important role in shaping agricultural landscapes. It can be observed as woodlands or shrublands, whether naturally occurring or intentionally planted. Additionally, it can also appear in the form of small woody features (SWF), which usually serve as field boundaries or to demarcate ownership (Scholefield et al., 2016; García de León et al., 2021), as well as riparian vegetation or small groups of trees.

Agroforestry systems have been defined as *"the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions"* (Burguess and Rosati, 2018). These systems are widespread worldwide, covering approximately 7% of the global land area (Zomer et al., 2014). Based on the location of the woody vegetation, agroforestry (AF) types are classified into two groups (Dupraz et al., 2018). The first group comprises systems where woody vegetation is within parcels, either arranged in rows or dispersed. Examples include silvopastoral, silvoarable, and agrosilvopastoral systems, which involves grazed and intercropped permanent crops. The second group encompasses AF systems where woody vegetation is situated between parcels, forming borders or boundaries, or along roads, tracks, and watercourses. This group includes linear agroforestry or SWF such as shelterbelt networks, hedgerows, riparian tree strips, avenue trees, conifer strips, or small groups of trees (Dupraz et al., 2018; Mosquera-Losada et al., 2018).

Various authors have presented information on the extent of the first group of AF systems in the European Union (EU). Den Herder et al. (2017), estimated a total of 154,000 km^2, while Mosquera-Losada et al. (2018) and Rubio-Delgado et al. (2023), who also included kitchen gardens, reported approximately 200,000 km^2. Regarding woody vegetation between parcels, Dupraz et al. (2018), Mosquera-Losada et al. (2018), and Plieninger (2011) have acknowledged the importance of the presence of SWF in agricultural lands due to the ecosystem services they provide. Mosquera-Losada et al. (2018) conducted an assessment to calculate the extent of riparian buffer strips and hedgerows in Europe, estimating a surface area of 18,000 km^2.

1.1. Benefits of SWF

The presence of SWF in agricultural areas contributes positively by enhancing ecosystem services and biodiversity. For example, hedgerows have been found to support diverse plant species, acting as habitats, movement corridors, and shelters against predation and harsh weather conditions for a wide array of wildlife such as birds, insects or small mammals, including those that are threatened or endangered (Jose, 2009; Plieninger, 2011; Mengistu and Asfaw, 2016; Moreno et al., 2018; Pantera et al., 2021). Additionally, hedges contribute to the maintenance of functional ecosystem properties by promoting populations of natural pest-control agents, benefiting arthropod pollinators, and favouring species that produce pollen that have often been depleted from fields due to agricultural intensification (Jahnová et al., 2016; Scholefield et al., 2016). Single trees and shrubs provide structural support to agricultural areas, which aids in reducing soil erosion and nutrient loss, and enhancing soil health (Nair, 2014; Palma et al., 2018; Castle et al., 2021; Gebirehiwot et al., 2022). Moreover, woody plants favour nutrient cycling by absorbing nutrients from deep soil layers and returning them through the decomposition of leaf litter and other organic matter (Jose, 2009). They also serve as a defence against leaf loss caused by pests and alter the water cycle in drylands (Lajos et al., 2020; Wilcox et al., 2022). Isolated trees or small groups of trees also offer other benefits such as the provision of wood products, shade, sheltered grazing areas, and fodder for livestock (Plieninger, 2011). The shade provided by these types of trees also helps in reducing heat stress of grazing animals, enhancing overall productivity, conserving soil moisture, and reducing water stress in crops (Jose, 2009; Nair, 2014). In general, SWF in agroforestry agricultural areas play a significant role in carbon sequestration, contributing to climate change mitigation by storing carbon in both aboveground biomass and soil (Palma et al., 2018; Castle et al., 2021). Studies by De Stefano and Jacobson (2018) and Chatterjee et al. (2018) reported significantly higher levels of soil carbon in agricultural areas compared to treeless agricultural systems.

Moreover, SWF integrated in agricultural areas provide a range of economic benefits, including increased crop yields, improved soil fertility, and the production of timber and other forest products (Bhusara et al., 2018; Ivezić et al., 2021). Additionally, they also provide cultural and social services such as aesthetic value, enhanced community identity, and the preservation of traditional knowledge and practices (Brandt et al., 2012; Moreno et al., 2018).

However, contrasting findings have been presented by Duflot et al. (2018), who observed that in permanent grasslands situated within agricultural lands in north-western France, species more characteristic of open farmland habitats were negatively affected by wooded habitat edges. These landscape elements were found to reduce both the richness and abundance of breeding farmland birds and open-habitat carabids, suggesting that the presence of these species relied on sufficiently expansive areas of open land devoid of wooded habitats.

From a landscape perspective, SWF also play a crucial role in enhancing structural and functional heterogeneity. Acting as corridors, they facilitate functional connectivity among semi-natural habitat components for many species, also serving as boundaries that enclose habitats (Pereira and Rodríguez, 2010; Cranmer et al., 2012; Neumann et al., 2016; Scholefield et al., 2016; Sullivan et al., 2017; Lajos et al., 2020). SWF connect landscape patches with heterogeneous levels of degradation and habitat quality by facilitating seed deposition, which is vital for their dispersion, and the preservation or restoration of ecosystems (Garcia et al., 2010). The multifunctionality of SWF increases landscape complexity and diversity, with the density of woody elements being one of the factors that mainly contribute to increase the number of functions of the landscapes (Boinot et al., 2023).

The extent and distribution of SWF within agricultural landscapes are influenced by the quantity and arrangement of dominant woody habitat types, such as hedgerows and shelterbelts (Scholefield et al., 2016; Lajos et al., 2020). Therefore, for biodiversity conservation, both the overall amount of habitat at the landscape scale and the connectivity of local patches are crucial factors (Schüepp et al., 2010). Some authors have regarded SWF as conforming intermediate habitats between croplands and forests (Slade et al., 2013) while others, like Rey Benayas and Mesa Fraile (2017), proposed that a well-developed hedgerow network could be considered a type of forest within agricultural landscapes. It is noteworthy that a 'land spanning more than 0.5 ha with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ', would already constitute a closed forest formation as defined by the Food and Agriculture Organization (FAO) (De Foresta et al., 2013).

1.2. *Policy and research needs for SWF*

Recent global and European policies on sustainability, biodiversity, and landscape ecology include, among their objectives, the need to incorporate SWF into agricultural landscapes due to the ecosystem benefits that these types of features provide. According to Castle et al. (2021), SWF in agricultural areas offer a wide range of benefits that support sustainable land use and contribute to the achievement of the UN Sustainable Development Goals. The European Commission (2021) has set an objective within the European Union Biodiversity Strategy for 2030 to have 10% of agricultural land designated as high diversity landscapes, which encompass hedgerows and other semi-natural habitats. Within the context of the Common Agricultural Policy (CAP) for 2023–2027, SWF contribute to several key objectives related to climate action and environmental preservation. The main contributions can be linked to the different impact and results indicators established by the European Commission, focusing on climate change mitigation and adaptation, as well as on agricultural land (European Commission, 2023). More specifically, SWF could aid in achieving the impact indicator 'I.10./C.44. Contributing to climate change mitigation: Greenhouse gas emissions from agriculture', as these landscape features have the potential to reduce greenhouse gas emissions from cropland and grassland within agricultural areas. Furthermore, SWF could also contribute to the achievement of the objectives set out in impact indicator 'I.10/C21. Enhancing provision of ecosystem services: Share of agricultural land covered with landscape features', which aims to estimate the area of agricultural land covered by landscape features. These features encompass linear elements such as hedgerows, patches (trees, woodlands, etc.), water and wet spots (ponds, water bodies, stream, etc.), moderately managed areas (e.g. field margins), among others. This indicator comprises two specific indicators: 1) the share of agricultural land covered by landscape features (I.21), and 2) a detailed index of landscape elements structure (currently under development). Hence, it is necessary to determine the extent and spatial distribution of different types of SWF in Europe and to categorise the different agricultural systems associated with these types of features. Therefore, an evaluation of data availability, accessibility, and feasibility is required.

1.3. *Available resources to assess small woody features*

A broad range of remote sensing tools and data are available to map SWF in agricultural areas. Vannier and Hubert-Moy (2014) employed an object-oriented approach using various remote sensing data images to map and analyse the structure of hedgerow networks in six study areas of the bocage landscapes in north-western France. Other researchers have employed remote sensing techniques to automatically detect hedgerows in very high-resolution imagery (Vannier and Hubert-Moy, 2008; Aksoy et al., 2010; Ducrot et al., 2012; Fauvel et al., 2014; O'Connell et al., 2015; Ahlswede et al., 2021). Álvarez et al. (2021) mapped hedgerow networks in Mediterranean mountainous regions. However, conducting these types of studies on a European scale is not feasible.

The Copernicus Land Monitoring Service offers two products that allow to evaluate and quantify SWF at European scale. One is the High-Resolution Layer Small Woody Features *(HRL Small Woody Features)*, which employs Object-Based Image Analysis and cloud computing solutions to extract different features from the Very High-Resolution imagery dataset (Langanke, 2019). This product encompasses woody linear structures such as hedgerows, shrubs or tree rows along field boundaries, riparian and roadside vegetation, as well as isolated patches of trees and shrubs (Langanke, 2019). It is available in different formats (vectorial and raster) and for different survey years (2015 and 2018). In their study, Golicz et al. (2021) used the 2015 dataset to assess the extent of these features in agricultural landscapes in Germany and to estimate their carbon stocks, aiming to explore the potential of expanding agroforestry areas to offset greenhouse emissions from agriculture. More recently, Kleeschulte et al. (2023) used the 2018 dataset to determine the agricultural area at European scale. Additionally, they explore which Copernicus data are useful to provide information on the extent and spatial distribution of SWF within the agricultural area.

Another valuable resource to analyse the distribution of SWF within agricultural areas at European scale is the Land Use and Land Cover Survey (LUCAS). It offers data that had been obtained through field observations at geographically referenced points every three years since 2006 (Eurostat, 2022). These observations include land cover (biophysical coverage of land, e.g. crops, grass, woodland, or built-up area), land use (the socio-economic use of land, e.g. agricultural, forestry, recreation or residential use), as well as agro-environmental and soil data. This database also provides information on different types of SWF sampled in the field along transects of 250 m (heath and shrubs, single or avenue trees, hedgerows, grove or woodland margins) (Eurostat, 2015). Transect data is only available for 2012 and 2015 survey years.

1.4. *Research gaps addressed with novel approaches*

The studies referenced above indicate that a fully comprehensive analysis of SWF to evaluate their significance in agricultural areas and understand their spatial patterns, as well as the landscapes shaped by different SWF types in Europe, is missing. Additionally, it is crucial to conduct a comparison between AF_{SWF} (woody vegetation found on field boundaries of agricultural areas) and AF systems, where trees and shrubs usually grow within agricultural fields. The latter is referred to as common AF (AF_C) in contrast to AF_{SWF}. This distinction in data regarding different types of AF is crucial for policymaking and practical farming as in-field or around-field has implications for farm management, productivity, and the acceptance of agroforestry.

These issues are addressed in this paper by pursuing several objectives. Firstly, we identify and characterise different agricultural systems associated with SWF using the LUCAS 2015 dataset. Secondly, we analyse in detail the extent and spatial distribution of these systems in the EU. Thirdly, we characterise the different types of SWF present in agricultural areas, as well as their spatial patterns. Finally, the extent and spatial distribution of AF_{SWF} and AF_C systems are compared. By accomplishing these objectives, we aim to enhance our understanding of SWF and their role in shaping European landscapes, as well as to evaluate the importance and distribution of AF_{SWF} at a detailed scale all over Europe.

2. Methodology

2.1. *LUCAS data*

The analysis of SWF in the EU was conducted using data from the LUCAS 2015 survey, which is the most recent one including SWF data. The database provides information for the 28 member states that constituted the EU at the time of sampling in 2015, including the United Kingdom.

The survey dataset considers as SWF those that have a width between 1 and 3 m and with a minimum length of 20 m. These features include heath and shrubs, avenue trees or hedgerows, as well as small patches (<0.5 ha; LUCAS, 2022) such as grove or woodland margins, or even single trees and shrubs. Non-woody features such as grass strips, dams, roads, water bodies, wetlands or rock outcrops, are not considered in our study. During field work, surveyors recorded the sequence of land cover types as well as the presence of SWF, and other elements along transects that extend 250 m eastwards in a straight line from each LUCAS sample point (Eurostat, 2015). Transect information is available for 270,267 points, together with their geographical coordinates, and consider the following SWF types (Eurostat, 2015):

a) Heaths, shrubs and tall herb fringes (*heaths and shrubs*).
b) Single bushes and trees (*single trees*): represent real single trees being a "landmark" in a grassland/bushy or cropped area.
c) Avenue trees or other line of trees (*avenue trees*): refers to one line of trees, not clustered trees; or two lines of trees separated by a road.
d) *Conifer hedges*
e) Managed bush or tree hedges or coppices (*managed hedgerows*): represent hedgerows visibly managed, e.g., pollarded (generally <5 m height).
f) Not managed bush or tree hedges (*unmanaged hedgerows*): refers to single trees or shrubs deriving from a maintenance abandonment, corresponding to shrub or woodland margins found as field boundaries within agricultural land or along roads or watercourses.
g) *Grove and woodland margins*: refer to grove and woodland margins that are not classified as hedgerows. Wood margins also represent riverside vegetation.

2.2. Classification of small woody features agroforestry systems (AF_{SWF})

From the bibliographic review and as outlined in the introduction section, two distinct groups of AF systems can be distinguished, always categorised based on the land cover and land use information provided by the LUCAS survey and their respective definitions (Eurostat, 2015). The first group, referred to as 'common agroforestry systems' (AF_C), encompasses silvopastoral, silvoarable, agrosilvopastoral, grazed and intercropped permanent crops, as well as kitchen gardens. The latter, also known as homegardens, are acknowledged as agroforestry systems wherein a diverse assortment of plant species is cultivated across multiple layers, integrating herbaceous plants, food crops, fruit trees, medicinal herbs, ornamentals, and animal components (Castro et al., 2018; Musvoto et al., 2022). The LUCAS survey classification report describes this type of systems like a land use 'where the crops are planted heterogeneously and mainly for own consumption'. The definition also adds that 'these areas are mostly fenced (by metal fences or hedges) and mostly situated in residential areas or as allotment gardens'. Globally, these systems are recognised as essential components of agroforestry systems that contribute significantly to sustainable land management interventions (Musvoto et al., 2022). Furthermore, they are being considered for public funding (Mosquera-Losada et al., 2018). The second group, termed 'small woody features agroforestry systems' (AF_{SWF}), comprises SWF adjacent to agricultural lands, forming borders or boundaries between parcels, excepting singles trees that could be found within parcels. This category also includes riparian buffer strips or rows of trees and/or shrubs planted at specific distances, such as windbreaks.

With the aim of classifying AF_{SWF} systems, different combinations of land covers were employed within areas designated as agricultural land uses following definitions of LUCAS (Eurostat, 2015), such as agriculture or fallow land, and the presence or absence of grazing livestock (in LUCAS considered as land management). The combination of annual or permanent crops with SWF were selected. Furthermore, grasslands with SWF, as well as forestry, semi-natural or natural land uses with grazing activity were also included. In the same way, grasslands with agricultural land use and presenting SWF were also considered. Other land uses such as artificial areas or abandoned areas were not included in the analysis, always considering the definitions of the LUCAS survey. Land covers with trees or shrubs (i.e., woodland, shrubland and grassland with sparse tree cover) combined with agricultural use were not considered because they constitute AF_C. These also include permanent crops (e.g., fruit trees, olive groves, vineyards) in combination with grazing livestock or cropland. The resulting categories of AF_{SWF} are listed in Table 1 and include: arable crops with SWF, grazed grassland with SWF, ungrazed grassland with SWF, and permanent crops with SWF.

Table 1
Criteria used to identify agricultural areas with small woody features (AF_{SWF} classes) from LUCAS data. LC = land cover; LU = land use; U = Undetermined means that any combination is possible.

AF_{SWF} class	LC	LC code	Grazing	LU	LU Code
Arable crops with SWF	Arable crops	B11-B54, Bx1	U	Agriculture Fallow land	U111 U112
Grazed grasslands with SWF	Grasslands without tree cover	E20, E30	Yes	Agriculture Fallow land Forestry Semi-natural or natural areas	U111 U112 U120 U420
Ungrazed grasslands with SWF	Grasslands without tree cover	E20, E30	No	Agriculture Fallow land	U111 U112
Permanent crops with SWF	Permanent crops	B71-B83, B84K, B84m Bx2	No	Agriculture Fallow land	U111 U112

Furthermore, SWF within AF_C were not included in the analyses as they fall under the category of AF_C systems, previously discussed in Rubio-Delgado et al. (2023).

The extent of each AF_{SWF} class associated with SWF for each EU member state was estimated following the methodology proposed by Den Herder et al. (2017), i.e. the number of classified points in each member state was divided by the total number of LUCAS points surveyed in the respective country and multiplied by the surface area of the country. The surface area of member states was taken from Eurostat (2015a). It is important to clarify that the obtained result does not represent the real surface area, but rather an estimation based on the proportion of AF_{SWF} classes in relation to the total number of sample points within a country. The cumulative sum of the calculated surface areas for each class provides an estimate of the total surface area occupied by AF_{SWF} in Europe. However, it is essential to note that this estimation only covers the identifiable systems within the LUCAS dataset, which are subject to limitations due to the sampling methods use on the transects and the detection of woody features by the surveyors.

Additionally, the proportion of Utilised Agricultural Area (UAA) occupied by agroforestry systems was analysed by country, using data from Eurostat (2015b).

2.3. Quantification and characterisation of SWF within agricultural areas

Two approaches were used for quantifying SWF within agricultural areas: 1) the number of transects containing at least one SWF and 2) the total count of SWF along transects and their respective types, since within a specific transect, various types of SWF could exist, or the same type of SWF could occur more than once.

Additionally, the analysis includes an examination of SWF coverage within transects in order to characterise each type of feature. Different dimensions were estimated for this purpose.

The LUCAS 2012 survey provides a sample of 1,283 data points with detailed information about the length (in meters), measured in the field, of each feature along a transect. These points represent 0.5% of the total number of sample points (270,267) and are used to estimate the average length occupied by each type of SWF. The obtained values are applied for extrapolation to the complete transect dataset which only offers information on the type and frequency of SWF. Fig. 1 displays a graphical representation of an example of this sample dataset, illustrating its information. To determine the average length of each type of SWF, the length of features of the same type appearing in each transect were

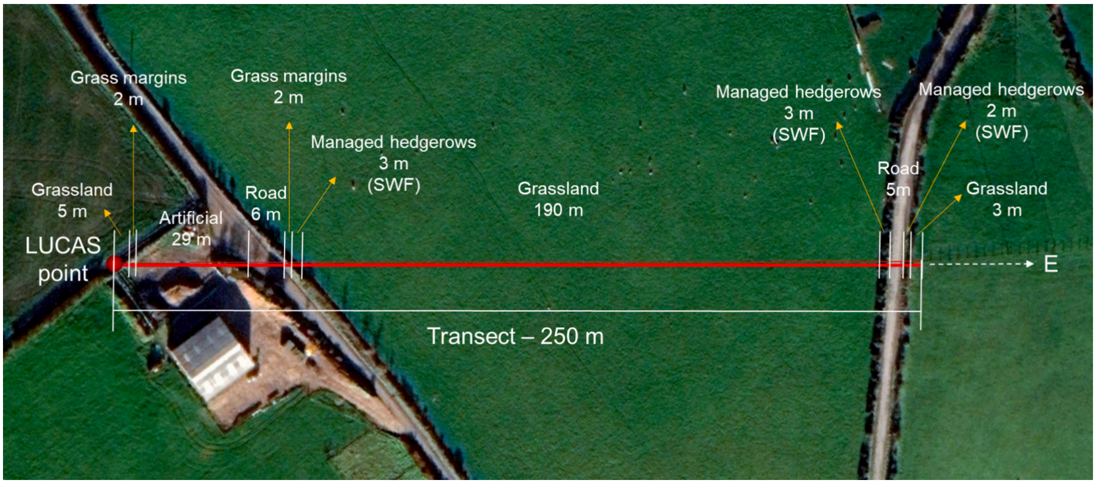

Fig. 1. Example of the information represented in a LUCAS sample transect. The identified features include: land covers (here: Grassland and Roads), small woody features (SWF) and other elements (here: Grass margins). The length of each feature (m) along the transect is indicated. In this example the total length of managed hedgerows is 3 + 3 + 2 = 8 m, with an average length = 8 m / 3 = 2.7 m.

summed and then divided by the number of times the feature appeared. Subsequently, the average length of each SWF type was calculated by summing all the average lengths of the transects and then dividing by the number of transects.

The average length of each SWF type from the sample transects was used to estimate the average length for the complete dataset. It has to be taken in mind that the latter only offers information on the occurrence of SWF along each transect. Therefore, the average length of each SWF type was extrapolated to estimate the total cover and the average length cover per transect in the complete LUCAS 2015 data base. To determine the total length cover of each SWF type, we multiplied the frequency of appearance in the transects by the average length derived from the sample dataset. Furthermore, we estimated the average length per transect for each SWF type by dividing the total length cover by the number of transects in which the particular SWF type was observed. Finally, we calculated the average percentage length cover occupied by each SWF type per transect, considering a transect length of 250 m.

2.4. Spatial data analysis

The spatial distribution of AF_{SWF} and of the different types of SWF were analysed in the EU, using Geographical Information Systems (ArcGIS Pro®, 2023).

AF_{SWF} were analysed at both the country level and by biogeographical regions using data from European Environment Agency (2016). Then, the spatial distribution of the different types of SWF across the EU were assessed creating density maps. This helps identifying distinct patterns and trends in the data. Additionally, a comparison of the density maps for AF_{SWF} and AF_C systems across the EU was performed. AF_C systems were analysed using the LUCAS points categorised as silvopastoral, silvoarable, kitchen gardens, and permanent crops in combination with grazing livestock or intercropping presented in Rubio-Delgado et al. (2023).

Density maps were created using the point kernel tool, establishing a pixel size of 1 km^2 and considering a search radius of 5 km, based on the average distance between sampled points. Then, the data were represented using the natural break classification method, which groups together similar data based on significant jumps or shifts in the calculated density values.

3. Results

3.1. Spatial distribution of small woody feature agroforestry systems (AF_{SWF})

An initial analysis of the LUCAS 2015 dataset was conducted to determine the presence or absence of SWF across the EU. In 17.5% of the transects ($n = 59{,}674$), surveyors recorded the presence of SWF, with 57.4% of these occurrences located in agricultural areas.

To quantify the extent and spatial distribution of AF_{SWF}, these systems were categorised in four classes as described in Table 1: arable crops AF_{SWF}, grazed grasslands AF_{SWF}, permanent crops AF_{SWF}, and ungrazed grasslands AF_{SWF}. They occupy an estimated total area of 443,770 km^2 in the EU, constituting 9.9% of the total EU extent and 24.8% of the UAA (Table 2).

Analysing each class according to the data provided in Table 2, arable crops AF_{SWF} were the most extensively represented systems, covering 196,175 km^2 (11.0% of UAA). This is equivalent to 44.2% of the total AF_{SWF} area, the largest part. The second largest class comprised ungrazed grasslands AF_{SWF}, covering an area of 108,394 km^2, which accounts for 24.4% of the total AF_{SWF} extent (6.1% of the UAA). Grazed grasslands AF_{SWF} occupied 103,238 km^2, representing 23.3% of the total area occupied by AF_{SWF} (5.8% of the UAA), and permanent crops AF_{SWF}, with 35,963 km^2, occupied the smallest area, corresponding to 8.1% of the total AF_{SWF}.

When analysed by country, France showed the highest concentration of AF_{SWF}, representing 23.8% of the EU total. Following France were the United Kingdom, Germany, Spain, Italy, Poland, Ireland and Romania, each representing a share between 5% and 10% of the total surface area occupied by AF_{SWF} (Table 2). However, Malta, Ireland and Cyprus showed the highest values if the AF_{SWF} area is expressed as percentage of UAA, accounting for 68.2%, 60.3%, and 50.4%, respectively. Other countries, such as Finland, The Netherlands, and Belgium, also presented significant percentages of UAA occupied by this type of system, with values exceeding 30%, despite the fact that AF_{SWF} constituted <2% of the total AF_{SWF} surface area in the EU in each of these countries. Arable crops AF_{SWF} (Fig. 2A) predominated in France, Germany, the United Kingdom, Poland, Italy, Spain and Romania (Table 2). Grasslands AF_{SWF}, both grazed (Fig. 2B) and ungrazed (Fig. 2C), were mainly concentrated in France and the United Kingdom (Table 2). Finally, permanent crops AF_{SWF} (Fig. 2D) were mainly found in Spain and Italy (Table 2).

When analysing the distribution of the different types of AF_{SWF} across biogeographical regions (Table 3; European Environment

Table 2

Extent (km^2) of four types of AF$_{SWF}$ (arable crops, ungrazed and grazed grasslands, permanent crops) and total extent of AF$_{SWF}$ by country (Extent AF$_{SWF}$). Also shown is the percentage (%) of AF$_{SWF}$ per country in relation to both, the total AF$_{SWF}$ area and the Utilised Agricultural Area (UAA). The data is ordered based on the extent of AF$_{SWF}$ as percentage of the total area.

	Type of AF$_{SWF}$ and area cover (km^2)					Percentage (%)	
Country	Arable crops	Ungrazed grasslands	Grazed grasslands	Permanent crops	Extent AF$_{SWF}$	Respect to the total extent of AF$_{SWF}$	UAA occupied by AF$_{SWF}$
France	44,241	23,346	33,561	4,333	105,480	23.8	36.3
United Kingdom	21,137	15,989	21,151	311	58,588	13.2	34.2
Germany	23,943	10,580	5,364	1,049	40,935	9.2	24.5
Spain	14,813	4,237	5,897	10,244	35,191	7.9	14.7
Italy	15,497	6,443	2,053	8,222	32,215	7.3	25.4
Poland	16,397	9,271	2,606	624	28,899	6.5	20.1
Ireland	2,537	7,469	16,649	57	26,713	6.0	60.3
Romania	11,549	6,473	4,406	2,809	25,237	5.7	18.2
Greece	4,239	1,735	673	3,218	9,866	2.2	18.6
Portugal	1,823	2,550	1,567	3,134	9,073	2.0	24.6
Finland	5,943	1,827	294	21	8,085	1.8	35.6
Sweden	3,845	1,797	1,595	34	7,270	1.6	24.0
Netherlands	2,861	1,794	1,705	133	6,492	1.5	35.2
Denmark	4,849	773	527	187	6,336	1.4	24.1
Hungary	4,409	1,152	360	216	6,136	1.4	11.5
Lithuania	2,638	2,101	812	29	5,579	1.3	18.6
Latvia	2,416	2,199	517	0	5,132	1.2	27.2
Bulgaria	2,921	969	766	188	4,843	1.1	9.7
Czechia	2,817	1,298	539	69	4,722	1.1	13.5
Belgium	1,650	1,417	1,164	169	4,400	1.0	33.1
Austria	1,442	1,461	427	171	3,502	0.8	12.9
Estonia	997	1,066	292	17	2,373	0.5	23.9
Croatia	817	1,138	112	272	2,339	0.5	15.2
Slovakia	1,477	534	71	125	2,207	0.5	11.5
Slovenia	380	538	74	148	1,139	0.3	23.9
Cyprus	386	75	5	172	638	0.1	50.4
Luxembourg	114	134	52	0	300	0.1	22.8
Malta	40	28	0	12	80	0.0	68.2
Total AF$_{SWF}$	196,175	108,394	103,238	35,963	443,770	9.9	24.8
Total AF$_{SWF}$ (%)	44.2	24.4	23.3	8.1	100	–	–
EU (%)	4.4	2.4	2.3	0.8	9.9	–	–
UAA (%)	11.0	6.1	5.8	2.0	24.8	–	–

Agency, 2016), it is important to note that the analysis was carried out using the number of LUCAS transects classified as AF$_{SWF}$, rather than the surface area of the classes. Furthermore, the data were standardised according to the total number of points sampled within each biogeographical region. Thus, the results indicated higher concentrations of AF$_{SWF}$ systems in the Atlantic (24.2%) and Continental regions (13.0%), followed by the Steppic (10.3%), the Pannonian (9.1%), and the Mediterranean (9.0%). The Black Sea, the Boreal, and the Alpine bioregions represented lower shares. Arable crops AF$_{SWF}$ were the dominant system in almost all regions, except for Alpine area, where ungrazed grasslands showed higher concentrations than the other systems.

3.2. *Characteristics and spatial distribution of SWF types*

In order to characterise the different types of SWF present in AF$_{SWF}$ systems, a first analysis of the average length of each type of SWF was conducted (Table 4). To accomplish this, the database that includes the actual measurements of each type of element along a sample representing 0.5% of the transects in the LUCAS 2012 survey was used (see Section 2.3). The results of the lengths occupied by SWF along the 250 m sample transects indicate that avenue trees were the features with the largest average length of 7.7 m (± 11.2 m), while conifer hedges had the smallest, 1.2 m (± 0.5 m). However, it is important to note that only 6 samples of conifer hedges were found in the dataset. Hedgerows, both managed and unmanaged, had similar average length (around 4.0 ± 8.0 m), while grove and woodland margins presented only slightly smaller average values than hedgerows, but showing a smaller standard deviation (3.8 ± 3.6 m). Finally, heath and shrubs displayed an average length of 2.1 m (± 0.8 m).

The average length of each type of SWF was extrapolated to the LUCAS 2015 survey database to estimate the length cover in the 250 m transects. Table 5 summarises, by type of SWF, the total number identified in the transects, the number of transects where each type was present, the average length cover in each transect, and the average percentage length cover per transect. Additionally, the density range of each type of SWF across the EU are included. The number of SWF registered was 58,504 in a total of 34,217 transects, averaging 1.7 SWF per transect. These values result in an average percentage length cover per transect of 2.8%, corresponding to 7.1 m in a 250 m transect. The most frequently observed SWF type corresponded to unmanaged hedgerows ($n = 18{,}200$). However, this type of feature occupied on average 2.3% of the transect, lower than the value estimated for avenue trees (4.1%), that showed a lower frequency ($n = 10{,}195$). Managed hedgerows were less frequent than unmanaged ones, representing 1.8% of the transect length. Heaths and shrubs were also observed with high frequency ($n = 9{,}795$), but they accounted for only 1.2% of transect length. However, this specific SWF type displayed the highest density value, with 0.45 heaths and shrubs per km^2. This finding suggests that while heaths and shrubs are not as common as hedgerows or avenue trees, they showed a higher frequency of elements in the areas where they were observed. Finally, conifer hedges were the least frequent SWF type with 430 cases.

An analysis was conducted using GIS tools aimed at the identification of spatial patterns in the distribution of the different types of SWF within agricultural areas across the EU. Table 6 shows the distribution of each SWF type by country. Additionally, Fig. 3 illustrates the density of SWF

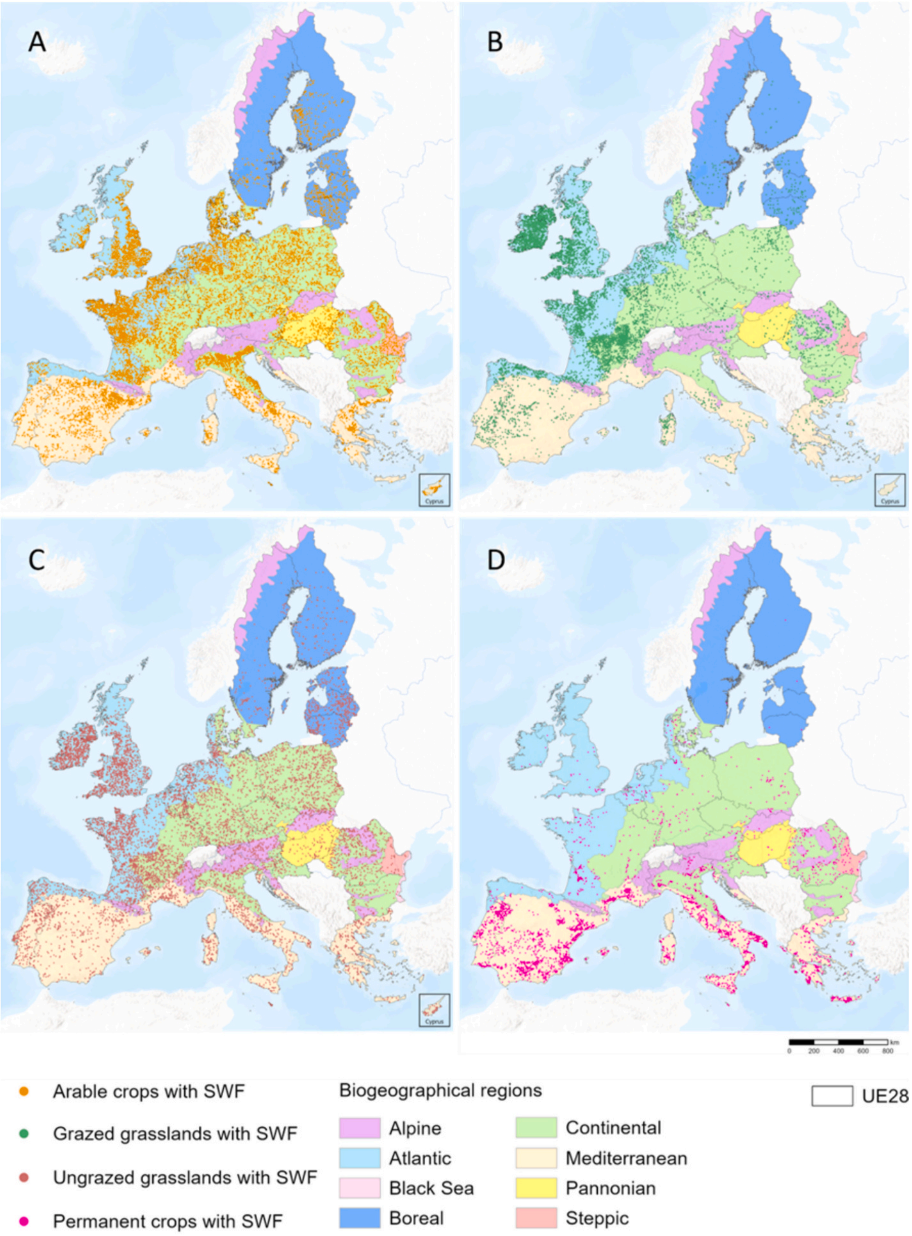

Fig. 2. Spatial distribution of AF_{SWF} in the EU. A) Arable crops AF_{SWF}; B) grazed grasslands AF_{SWF}; C) ungrazed grasslands AF_{SWF}; D) permanent crops AF_{SWF}. Bioregion data source: https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3

in the EU, including aerial photographs showing some of the most representative landscapes characterised by the presence of these elements (pictures 1–9 in Fig. 3). Each example was chosen based on the information provided by the LUCAS transects located in the areas of the pictures. Fig. 4 shows the density of the individual SWF types.

In France, both unmanaged and managed hedgerows are the most frequent features, with 31.0% and 31.3% respectively; however, their patterns differ. The highest densities of unmanaged hedgerows were found in the regions of Manche and Nord (0.32 features/km^2; Fig. 4A), while managed hedgerows were denser, with maximum values of 0.30 features/km^2, in the regions of Deux-Sèvres, Indre, Allier, Creuse, Saône-et-Loire, Nièvre, Mayenne, or Finistère (Fig. 4B). These areas are characterised by the presence of hedgerows that serve as boundary markers between properties and contribute to the distinctive landscape known as *bocage* (Fig. 3.8).

In the United Kingdom, managed hedgerows also hold a significant presence, accounting for 58.4% of the total SWF composition. Regions such as South-West England, Wales, East Midlands, Cumbria (North-West England) and North Yorkshire (Yorkshire and The Humber) showed higher concentrations of managed hedgerows, with up to 0.30 features/km^2 (Fig. 4B). Like the French bocage landscape, these hedgerows are commonly utilised to demarcate boundaries of small arable or pasture lands (Fig. 3.6).

In Ireland, hedgerows were also a prevailing SWF, particularly unmanaged hedgerows that dominate with 55.2% over unmanaged ones with 32.1%. As illustrated in Fig. 4A and B, the spatial distribution in Ireland of each of these SWF types were highly polarised, with the regions of high density of managed hedgerows (0.12 to 0.30 features/km^2) entailing the lower densities of unmanaged ones, and vice versa. The landscapes associated with these types of SWF share similarities with the bocage landscapes observed in France or England, albeit typically with larger parcel sizes (Fig. 3.4).

In Italy, unmanaged hedgerows were also more common than other SWF (40.0%), exhibiting a relatively even distribution throughout the

Table 3
Percentage (%) distribution of the four types of AF_{SWF} by bioregions, where ALP = Alpine, ATL = Atlantic, BS = Black Sea, BOR = Boreal, CON = Continental, MED = Mediterranean, PAN = Pannonian, and STE = Steppic. The data are standardised based on the total number of points sampled within each biogeographical region. Additionally, the percentages of points sampled in agricultural land of each bioregion not classified as AF_{SWF} are also presented.

Types of AF_{SWF}	ALP	ATL	BS	BOR	CON	MED	PAN	STE
Arable crops	0.3	9.9	2.9	2.0	6.4	3.5	6.5	7.1
Ungrazed grasslands	1.2	5.8	0.6	1.3	3.4	1.5	1.6	1.0
Grazed grasslands	0.6	8.1	0.3	0.5	2.6	0.9	0.7	0.9
Permanent crops	0.2	0.4	0.1	0.0	0.6	3.1	0.4	1.3
All AF_{SWF} systems	2.3	24.2	3.9	3.7	13.0	9.0	9.1	10.3
Not classified as AF_{SWF}	97.7	75.8	96.1	96.3	87.0	91.0	90.9	89.7

Table 4
Average length (m) occupied by each SWF type in the LUCAS sample transects of 250 m and sample size.

Small Woody Features	Average length (m)	Standard deviation (m)	Range (m)	N samples
Unmanaged hedgerows	4.0	± 7.8	1–70	79
Heath and shrubs	2.1	± 0.8	1–7	90
Managed hedgerows	3.6	± 7.7	1–75	95
Avenue trees	7.7	± 11.2	2–80	63
Single trees and shrubs	4.7	± 3.0	2–12	25
Grove and woodland margins	3.8	± 3.6	2–16	18
Conifer hedges	1.5	± 0.5	1–2	6

Table 5
Characteristics of SWF types: number of transects with SWF, total number of SWF, proportion of SWF type per total number of SWF (% of total), average length cover by transect (ALCT), percentage length cover by transect (PLCT), and density range in number of SWF per km^2.

SWF types	Number of transects with SWF	Total number of SWF	% of total	ALCT (m)	PLCT (%)	Density range (SWF/km^2)
Unmanaged hedgerows	12,241	18,200	31.1	5.7	2.3	0.02–0.32
Managed hedgerows	7,948	12,200	20.9	4.6	1.8	0.02–0.30
Avenue trees	7,563	10,195	17.4	10.2	4.1	0.02–0.26
Heath and shrubs	6,363	9,795	16.7	3.0	1.2	0.02–0.45
Single trees and shrubs	5,619	6,228	10.7	5.2	2.1	0.02–0.14
Grove and woodland margins	1,156	1,456	2.5	4.1	1.7	0.02–0.18
Conifer hedges	361	430	0.7	1.7	0.7	0.02–0.06
Total	34,217	58,504	100	7.1	2.8	0.02–0.45

country. In contrast, managed hedgerows accounted for 23.1%, being particularly concentrated in some regions such as Veneto and Lombardy, where the densities ranged from 0.12 to 0.30 managed hedgerows per square kilometre (Fig. 4B).

In Spain, heaths and shrubs predominated (43.7%), being mainly concentrated in the Ebro Valley, the Galician province of Ourense, and the province of Alicante (Valencia), with maximum densities of 0.45 heaths and shrubs/km^2 (Fig. 4C). It is worth noting, however, that the uses of these features differ depending on their specific locations. For instance, in the Ebro Valley, heaths and shrubs are utilised to mitigate the effects of soil erosion (Fig. 3.1). Conversely, in the Ourense region they delimitate boundaries between small ownerships, often in combination with other features such as hedgerows or single trees (Fig. 3.2). On the other hand, grove and woodland margins (14.2%) were mainly found in the region of Lugo, with maximum densities of 0.18 groves and woodlands/km^2 (Fig. 4D). In this particular area, they contribute to a distinctive landscape characterised by small ownerships where patches of vegetation are interspersed (Fig. 3.3).

Germany, similar to Spain, showed notable concentrations of heaths and shrubs, comprising 33.7% of the total SWF composition. These heaths and shrubs are primarily found in the regions of Dithmarschen, Nord Friesland and Schleswig-Flensburg, in the northwest of Schleswig-Holstein, where densities ranging from 0.14 to 0.45 features/km^2 has been recorded (Fig. 4C). Avenue trees represent the second most prevalent type of SWF in Germany, accounting to 32.6%. Higher densities of avenue trees (0.08 to 0.26 trees/km^2) can be observed in regions such as Diepholz, Minden-Lübbecke, Cloppenburg, Osnabrück–Landkreis, Steinfurt, Osterholz or Grafschaft Bentheim (Fig. 4E). As hedgerows in other regions, these features highly contribute to shape the landscape, occupying small parcels, and being also commonly associated with linear elements at roadsides (Fig. 3.7).

The high density of heaths and shrubs observed in Finland is also worth noting, ranging from 0.14 to 0.45 features/km^2, in the Keski-Suomi and Etelä-Pohjanmaa regions (Fig. 4E). In these areas, these types of SWF also serve as boundaries between ownerships and often contribute connecting larger vegetation patches (Fig. 3.5).

Single trees were scattered across all the countries, being difficult to identify areas with contrasting densities. However, some regions of Portugal, Spain, France, Italy, Northern Ireland and Cyprus appeared to show more places with high density than other countries (Fig. 4F).

Finally, conifer hedges were the least prevalent SWF, and did not display significant spatial pattern, being the region of Vaucluse, in France, the one that exhibit the highest densities of these features, ranging from 0.05 to 0.06 hedges per square kilometre. As other SWF types, these hedges are commonly used to define the boundaries of small parcels of arable land (Fig. 3.9).

Regarding AF_{SWF} systems, each category is composed of a specific land cover: arable crops, ungrazed grasslands, grazed grasslands, or permanent crops, which can be associated with a variety of SWF. To characterise the different AF_{SWF} classes, Fig. 5 illustrates how each type of SWF is associated with its respective land cover by presenting the frequency percentages. Thus, the main results showed that unmanaged hedgerows were the most prevalent, exhibiting similar percentages in all land covers (32.4% - 34.6%), except for arable crops, where they constituted 27.4% of the total SWF. Furthermore, heaths and shrubs, avenue trees, and unmanaged hedgerows shared similar percentages in arable crops AF_{SWF} (21.0%, 21.0%, and 18.1%, respectively). In the case of grazed and ungrazed grasslands AF_{SWF}, managed hedgerows were the second most dominant, representing 29.1% and 21.5%, respectively, of the total SWF associated with these land covers. Finally, in permanent crops, apart from unmanaged hedgerows, also heaths and shrubs were frequent, representing 25.7% of the total number of SWF.

3.3. *Comparing the extent of AF_C and AF_{SWF} in Europe*

The surface area of AF_C systems in the EU in 2015 was estimated by Rubio-Delgado et al. (2023) as 132,317 km^2 (2.9% of the total EU extent and 7.4% of the UAA). Silvopastoral was the dominant system, with 113,717 km^2, followed by kitchen gardens (12,490 km^2), grazed permanent crops (4,953 km^2), silvoarable (591 km^2), and intercropped permanent crops (566 km^2). AF_C systems that also have SWF occupied 29,466 km^2 in 2015, representing 22.3% of the total AF_C surface area. It

Table 6
Distribution of each SWF type within agricultural areas by country of the EU expressed as percentage (%) of the total SWF composition.

Country	Percentage of total SWF per type (%)						
	Heath and shrubs	Single trees	Avenue trees	Conifer hedges	Managed hedgerows	Unmanaged hedgerows	Grove and woodland margins
France	4.0	8.3	22.1	1.1	31.3	32.0	1.2
United Kingdom	4.6	7.9	6.5	0.4	58.4	21.7	0.6
Spain	43.7	14.5	6.5	0.7	3.0	17.4	14.2
Italy	7.3	12.3	15.6	1.1	23.1	40.0	0.6
Germany	33.7	10.1	32.6	0.6	3.4	18.3	1.4
Ireland	5.7	2.5	4.5	0.0	32.1	55.2	0.0
Romania	16.6	12.7	22.1	0.0	0.4	48.0	0.3
Poland	1.8	16.7	46.0	1.1	1.7	31.1	1.7
Greece	39.8	7.4	1.8	1.1	2.3	47.6	0.0
Portugal	35.7	25.8	6.9	0.2	1.0	30.1	0.3
Netherlands	36.6	5.1	39.9	0.6	11.2	5.6	0.9
Finland	58.1	3.9	7.4	0.9	2.0	22.0	5.7
Latvia	34.1	11.6	7.2	0.3	0.1	45.9	0.8
Denmark	44.9	11.1	9.2	2.0	17.1	14.9	0.7
Belgium	1.2	9.1	38.4	1.8	24.0	25.5	0.0
Sweden	25.4	11.1	5.8	0.2	7.3	35.6	14.7
Lithuania	38.1	12.5	9.8	0.5	0.9	36.5	1.6
Hungary	21.1	6.9	32.1	0.2	0.4	38.7	0.6
Bulgaria	16.2	25.8	23.5	0.0	2.2	31.3	1.0
Austria	16.1	21.0	20.1	1.9	5.7	32.8	2.3
Czechia	12.1	17.8	55.9	1.4	0.5	11.0	1.4
Croatia	21.6	18.8	10.6	0.0	3.7	42.0	3.3
Estonia	7.1	13.3	9.5	2.4	4.3	61.9	1.4
Cyprus	4.5	28.6	20.1	1.0	2.0	43.7	0.0
Slovakia	38.3	17.5	24.0	1.1	4.9	13.7	0.5
Slovenia	12.1	15.4	3.3	1.6	12.6	54.4	0.5
Luxembourg	2.0	12.2	30.6	2.0	34.7	18.4	0.0
Malta	9.1	33.3	39.4	0.0	0.0	18.2	0.0
Total EU	16.7	10.6	17.4	0.7	20.9	31.1	2.5

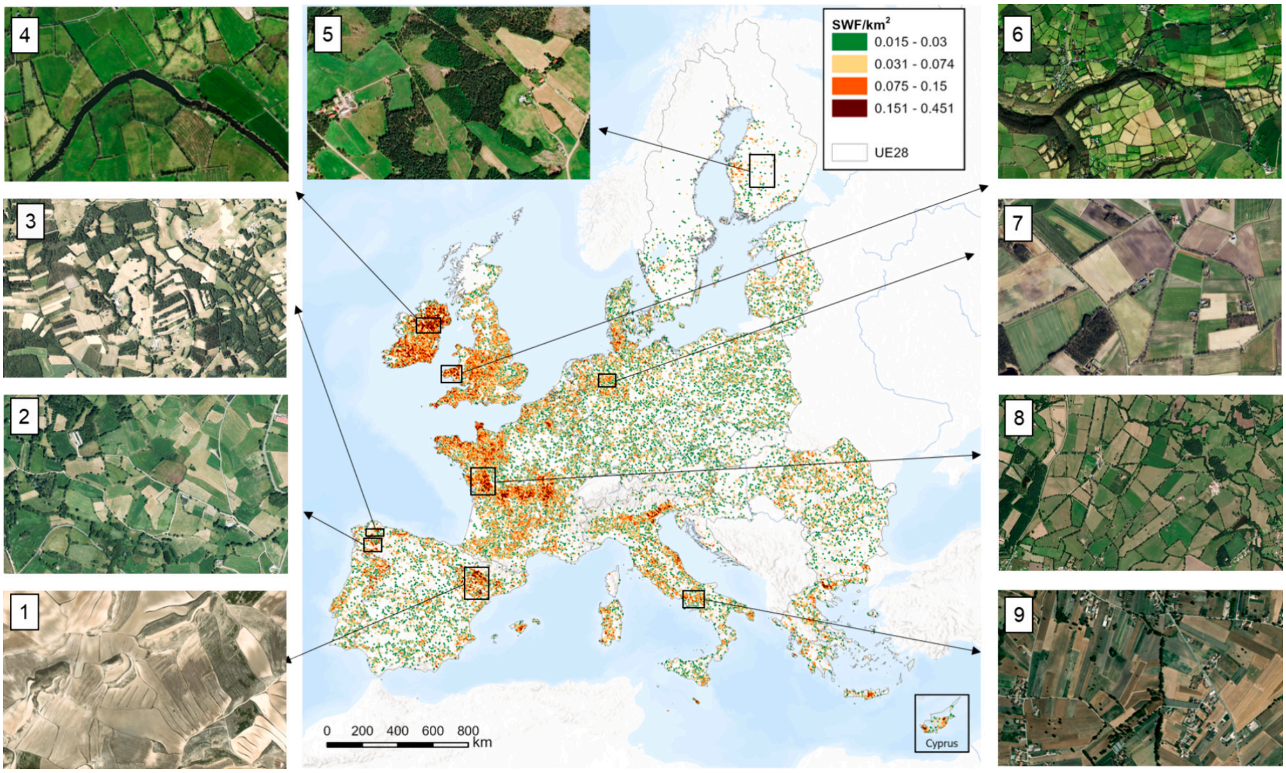

Fig. 3. Density of SWF/km^2 within agricultural areas in the EU, including some examples of representative landscapes associated with different types of features: 1) heaths and shrubs in the Ebro Valley (Spain); 2) heaths and shrubs in Ourense (Spain); 3) grove and woodland margins in Lugo (Spain); 4) unmanaged hedgerows in Border (Ireland); 5) heaths and shrubs in Keski-Suomi (Finland); 6) managed hedgerows in South West Wales (England); 7) avenue trees in Minden-Lübbecke (Germany); 8) managed hedgerows in Deux-Sèvres (France); and 9) conifer hedges in Vaucluse (France). Source of images: Google Earth 2023.

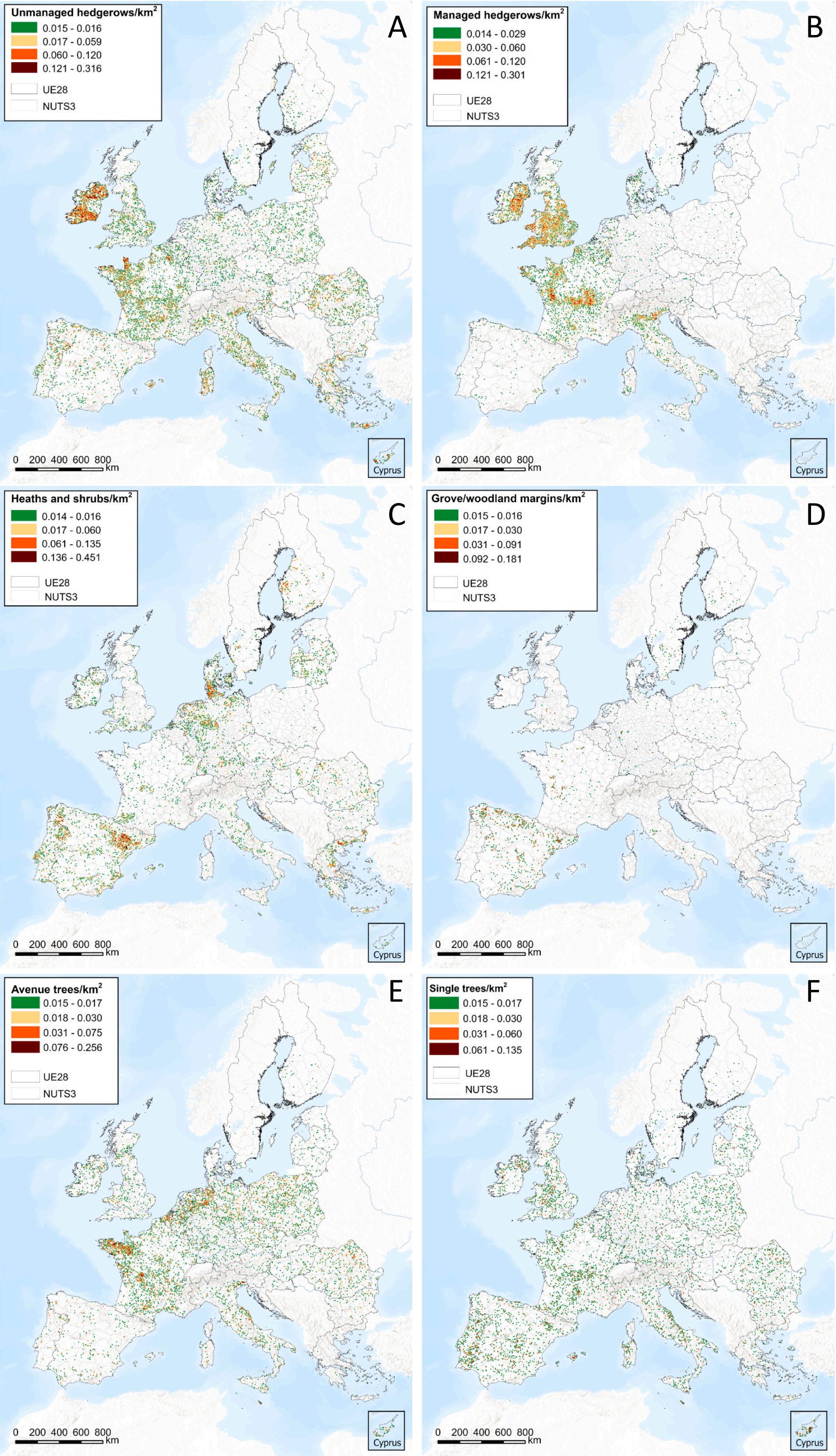

Fig. 4. Density of each type of SWF (SWF/km^2) in the EU. A) Unmanaged hedgerows; B) managed hedgerows; C) heaths and shrubs; D) grove and woodland margins; E) avenue trees; F) single trees. Conifer hedges were not included in the graph due to the low relevance of density.

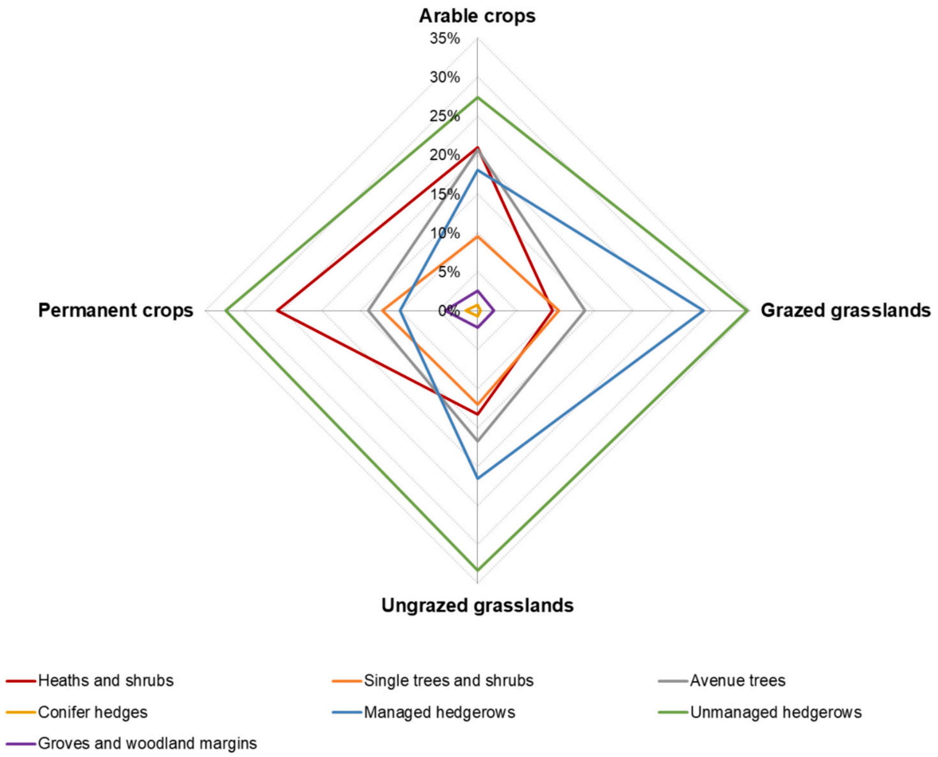

Fig. 5. Percentage distribution of different types of SWF found in the four land covers considered as AF_{SWF} in the EU.

has to be taken in mind that these were not considered in the group of AF_{SWF} systems. The resulting total surface area of AF_{SWF} occupies 441,564 km^2, representing 3.3 times the area of AF_C (Fig. 6).

The area covered by arable and permanent crops AF_{SWF} (232,138 km^2) were 38.0 times greater than the surface occupied by those AF_C which include permanent crops (grazed or intercropped) or silvoarable systems (6,110 km^2) (Rubio-Delgado et al., 2023). In contrast, the extent of grazed grasslands AF_{SWF} (103,238 km^2) was slightly less than that occupied by silvopastoral systems (113,717 km^2), which encompass grazed woodlands and shrublands as well as grasslands with sparse tree cover.

Furthermore, overlapping areas where both AF_C and AF_{SWF} systems were found (Fig. 6), were mainly concentrated in small regions of France, Ireland, United Kingdom, Spain, Portugal, Greece, and Romania, suggesting that each type of system exhibited different spatial distribution patterns. In fact, Fig. 6 illustrates that AF_C systems were more densely concentrated in the Mediterranean region, with higher densities in countries such as Spain, Portugal or Greece. In contrast, AF_{SWF} were more widespread across the other EU countries, particularly in Atlantic and Continental countries such as Ireland, United Kingdom, France, Denmark, and Germany. Regions such as Northern Italy or the Ebro Valley in Spain also presented higher densities than other areas of the EU. Additionally, the polarity between Sweden and Finland is worth noting. Sweden showed higher densities of AF_C than Finland, where there were higher densities of AF_{SWF}. However, the density of AF_C systems in Boreal regions were underestimated since LUCAS did not allow the identification of woodland areas grazed by reindeers, which was estimated by Jernsletten and Klokov (2002) to cover 274,000 km^2 in Sweden and Finland. This surface area is about two times the total area covered by AF_C in the EU based on data from the 2015 LUCAS survey (Rubio-Delgado et al., 2023). Therefore, densities of AF_C must be higher in both countries.

4. Discussion

The results obtained in this study have demonstrated the usefulness of the LUCAS dataset for understanding the typology, extent, and distribution of AF_{SWF} systems across the EU. By recording detailed information on land cover, land use, grazing activity and presence of SWF, based on the field observations of each sampled transect, this dataset enables the classification of different AF_{SWF} categories. It also allows to obtain detailed information on their spatial distribution and density in agricultural areas.

4.1. *LUCAS data: Possibilities and limitations*

Automatic mapping and monitoring of SWF coverage on a national or international scale, as well as monitoring changes over time using remotely sensed imagery, constitute outstanding research issues (Aksoy et al., 2010). To address this, the LUCAS data provides useful information aimed at detecting temporal changes in the extent of these types of systems along successive surveys. The LUCAS 2022 survey is the most recent one, featuring a specific module on landscape features that includes information on SWF (Eurostat, 2022). However, this data was not yet available at the time of compiling this paper.

The LUCAS survey allowed the identification of different types of SWF within agricultural areas and the establishment and characterisation of various AF_{SWF} categories. However, the type of data poses some limitations to calculate surface areas. LUCAS provides data at a point scale, with valuable information representative of the small parcels where the points are placed. Since the survey does not indicate the extent of the represented land covers, the calculation of surface areas is based on extrapolations, considering the proportion of sampled LUCAS points in each territory, and not the real surface areas. Nevertheless, the estimated extent obtained for the total AF_{SWF} systems and for each category are useful to understand their spatial distribution and facilitate comparisons among the various systems.

Additionally, the LUCAS survey provides detailed information on the various types of SWF, enabling the characterisation and analysis of their spatial patterns. It is also possible to calculate the percentage cover occupied by each SWF type along the transect. However, it is not possible to accurately estimate the surface cover of these features. This is

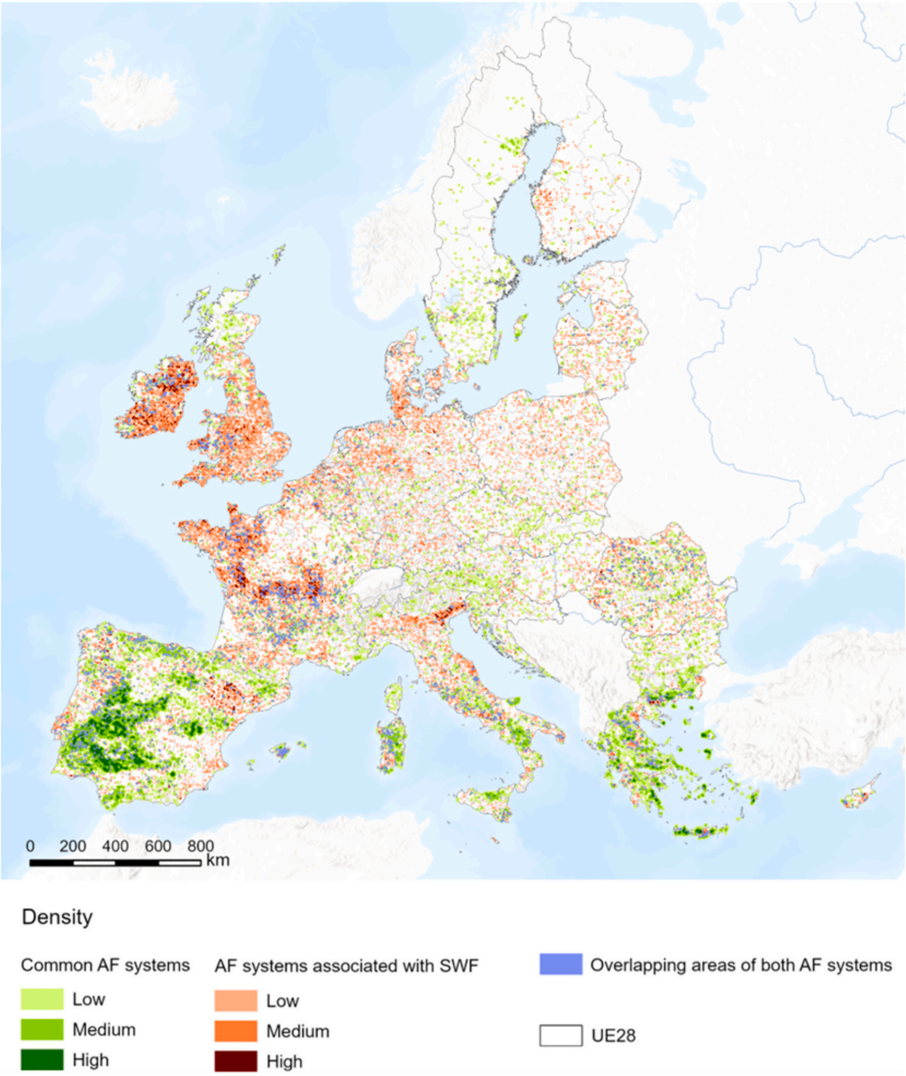

Fig. 6. Map of the densities of AF_C and AF_{SWF} systems in the EU. Overlapping areas of both types of AF systems are also represented.

because, even though the methodological guidelines of LUCAS data specify a minimum length of 20 m for each SWF (Eurostat, 2015), the surveys do not document their maximum length. Moreover, this data is not applicable to single trees and shrubs, as their lengths and shapes can vary. For example, features like groves, characterised by clusters of closely spaced trees, or woodland margins, which often have an undulating boundary, may not align with a linear feature having a minimum length of 20 m. These features typically constitute patches across landscapes (<0.5 ha), leading to an occupied area that exceeds what can be estimated using LUCAS data.

Other authors have utilised different resources to estimate the extent of SWF within agricultural areas at a national and European scale. Golicz et al. (2021) used the Copernicus SWF 2015 dataset along with the 5-ha Corine Land Cover product, provided by the German Federal Agency for Cartography and Geodesy. They reported a figure of 9,000 km^2, which is equivalent to 4.6% of the total farmland in Germany. More recently, in 2023, Kleeschulte et al. (2023) utilised the Copernicus SWF 2018 dataset to estimate a coverage of SWF within agricultural areas of approximately 5.0% of the 27 EU member states (excluding United Kingdom). It is important to note that they considered an approximate agricultural surface area of around 1,440,000 km^2, estimated using the Corine Land Cover 2018. However, due to disparities in the data resources used for the analysis and variations in the methodological approach, these results are not directly comparable to those obtained using LUCAS data.

4.2. The importance of SWF within agricultural areas in Europe

The total surface area occupied by AF_{SWF} was estimated at 441,564 km^2 in 2015. By class, arable crops AF_{SWF} were the most extensive systems, equivalent to 44.2% of the total. The second and third-largest classes comprised ungrazed and grazed grasslands AF_{SWF}, 24.4% of the total and 23.3% of the total, respectively. Permanent crops AF_{SWF} accounted for only 8.1% of the total AF_{SWF} area. The findings indicate that AF_{SWF} covered 25.3% of the UAA in the EU, a value 3.3 times greater than the UAA occupied by AF_C systems, which, according to Rubio-Delgado et al. (2023), was determined to be 7.4% in the same year. These results highlight the importance of SWF within the agricultural areas in the EU, however this aspect was not addressed by other authors such as Plieninger (2011), Den Herder et al. (2017), Mosquera-Losada et al. (2018), or Rubio-Delgado et al. (2023), who also used the LUCAS survey to analyse AF systems but only focused on common agroforestry systems. Mosquera-Losada et al. (2018) made an approach to calculate the extent of riparian buffer strips and hedgerows — which included avenue trees, conifer strips, managed and unmanaged hedgerows close or not to inner waters — using LUCAS 2012 survey. They estimated a surface area of 18,000 km^2 considering the coverage that their canopies have. This value differs from the one obtained in our study due to the type of SWF considered, as well as the methodology applied. Nevertheless, they found higher percentages of land associated with riparian buffer strips and hedgerows in the northwestern regions of France, in Ireland, in the centre and south of the United Kingdom, and in the northern regions of Italy, which aligns with our results.

Density maps allowed the analysis of the spatial distribution of different SWF types present in agricultural areas of the EU. The results indicate that the distribution of SWF was not homogeneous, exhibiting different patterns depending on the type of SWF. Hedgerows, both managed and unmanaged, predominate in France, the United Kingdom, Ireland, and Italy. Heaths and shrubs demonstrated a higher presence in Spain, Germany, and Finland. Avenue trees were notably concentrated in Germany, Poland, Romania, and the Netherlands. Grove and woodland margins exhibited higher densities in Spain compared to other countries. Single trees showed more locations of high density in Portugal, Spain, France, Italy, Northern Ireland, and Cyprus. Finally, conifer hedges only presented high concentrations in the region of Vaucluse in France.

Scholefield et al. (2016) investigated the spatial distribution of SWF in Great Britain and demonstrated results that support our findings. They constructed a model using national datasets to depict the distribution of woody linear features along boundaries in Great Britain. The resource data for their model included the Satellite-derived Land Cover Map 2007 and the Ordnance Survey Land-Form PANORAMA® digital terrain model. Consistent with our observations, they revealed greater densities of hedgerows in the southern regions compared to the north, with the southwest of the country exhibiting the highest concentration of these types of features. The polarisation observed in the south-north and east-west directions could be attributed to the increased complexity of landscapes in the southern and western regions of Great Britain. These areas typically feature smaller fields and potentially more cases of double boundaries, as noted by Scholefield et al. (2016).

There is a broad scientific consensus that a high density of SWF in agricultural areas characterises highly complex, diverse, and multifunctional landscapes (Zirbel et al., 2019; Golicz et al., 2021; Boinot et al., 2023). According to Boinot et al. (2023), a greater SWF density in the landscape provides more habitat for associated species, increases ecological corridors for the dispersal and reproduction of individuals, results in greater abiotic and biotic environmental heterogeneity, and can prevent the movement of certain predators or control their distribution across the landscape.

4.3. Benefits of small woody features within agricultural areas

AF_{SWF} and AF_C systems exhibit similarities in that both involve a blend of woody vegetation and agricultural practices. However, the functions of SWF in AF_{SWF} and trees in AF_C systems differ. SWF commonly comprises planted or naturally occurring woody vegetation serving as field boundaries or windbreaks, with no immediate commercially viable products other than biomass for energy production. In contrast, trees in AF_C systems are primarily planted for fruit or timber production, offering an additional source of income (Golicz et al., 2021).

Regarding their role in providing ecosystem services, the potential of agroforestry to sequester carbon and deliver other essential services has been recognised, calling for greater integration of scattered trees into agricultural landscapes to capitalise on their carbon sequestration potential (Plieninger, 2011). Furthermore, AF_{SWF} have also shown an important role in regulating greenhouse gas emissions and mitigating climate change through carbon storage (Ford et al., 2019), increasing, for example, the overall carbon stock in the soils. In this sense, several authors found significantly higher levels of soil carbon under agroforestry compared to agricultural systems or treeless pastures (De Stefano and Jacobson, 2018; Shi et al., 2018; Ma et al., 2020). Nevertheless, differences in the effectiveness of carbon sequestration have been observed depending on the type of agroforestry system. Golicz et al. (2021) demonstrated that the establishment of hedgerows in croplands and pastures results in greater carbon sequestration compared to incorporating tree lines in silvoarable AF, like alley cropping. This is attributed to the higher stem density of hedgerows and the closer planting arrangement compared to the greater inter-row spacing observed in tree lines. In addition, hedgerows show a greater capacity to regrow after regular trimming, resulting in high carbon inputs to soil through the turnover of litter and dead root material. Agroforestry systems incorporating multiple tree species also demonstrate higher biomass carbon stocks and a faster accumulation of biomass carbon compared to systems featuring a single tree species (Ma et al., 2020).

Hence, considering that SWF provide comparable or improved ecosystem services to trees or shrubs in AF_C; incorporating SWF into AF_C enables the integration of agroecological benefits associated to SWF, such as the increased biomass production and carbon sequestration, along with the fruit or timber production of specific tree species. This combination also encompasses various other ecosystem services associated with both structural elements (Golicz et al., 2021).

Additionally, SWF has also been characterised as a resilient farming system that help to re-establish forests, restore ecosystem services, and stabilise local livelihoods, highlighting its role in enhancing agricultural resilience (Hoang et al., 2017). For example, the incorporation of hedgerows in vineyards or orchards could enhance biodiversity conservation and pollination success (Golicz et al., 2021). Likewise, in a study conducted by Bengtsson et al. (2005) that centred on organic farming systems, the presence of hedgerows within crops contributed to a substantial positive influence on biodiversity and organism abundance. The increase amounted to 50%, surpassing the impact observed in conventional farming systems. This effect extended across diverse organisms, encompassing birds, predatory insects, soil organisms, and plants.

In a similar way, the presence of SWF in grasslands provide several benefits, including enhanced biodiversity and ecosystem services, reduced soil erosion, and increased soil fertility (Torralba et al., 2016; Den Herder et al., 2017). That is why such systems have been proven to provide multiple benefits for ensuring food security, resulting in increased crop yields, household food security, and income, as well as for environmental resilience, and ecosystem services (Garrity et al., 2010; Kuyah et al., 2019). In terms of biodiversity, the existence of SWF within grasslands functions as ecological filters for species traits while also providing habitats for different species that benefit from the interface between wooded areas and crops. Highly mobile species can adjust to rapid changes in resource distribution, whereas less mobile species find advantages in having more wooded habitats (Duflot et al., 2014). Moreover, the interactions between trees and grasslands promote the growth of under-canopy herbaceous vegetation and modify the microclimate by intercepting solar radiation and rainfall. Their root systems also extract nutrients that benefit the surrounding grassland (Vetaas, 1992).

Scaling up to the agricultural landscape function, the introduction of SWF into agricultural areas lacking agroforestry holds potential benefits. For instance, the inclusion of hedgerows has the capacity to establish a network of ecological corridors, facilitating the movement of beneficial organisms like pollinators (e.g., bees, butterflies) and natural predators (e.g., predatory insects) throughout the agricultural environment (Dainese et al., 2017). Moreover, this approach may prove to be more feasible, as farmers can conserve or establish high-quality habitats without necessitating alterations to their crop management practices (Dainese et al., 2017).

4.4. The relevance of hedgerows in AF_{SWF}

According to our results, 44.2% of the AF_{SWF} systems consisted of arable crops associated with SWF. The most frequent type of SWF within arable crops were unmanaged hedgerows. Hedgerows are common in agricultural landscapes and are recognised for their historical role in crop protection and livestock enclosure. As other SWF, they also have been shown to provide important aboveground biodiversity benefits such as serving as habitats for pollinators, shelter for beneficial insects, and corridors for wildlife movement within agricultural landscapes (Biffi et al., 2022). However, this type of features has declined significantly since the mid-20th century in many countries (Baltensperger, 1987; Pointereau and Bazile, 1995; Sklenicka et al., 2009; Van Den Berge et al., 2021), specially between 1950s and 1980s, when land consolidation processes were implemented (Van Den Berge et al., 2021). For example, in the United Kingdom, one of the countries with a higher concentration of hedgerows (16.9% of the total figure), several researchers have determined a significant reduction in the land area occupied by this particular feature. Robinson and Sutherland (2002) reported that nearly half of the hedgerow stock has been lost since the 1940s. O'Connell et al. (2004) documented a loss exceeding one million kilometres in England and Wales since 1945. Furthermore, Barr and Gillespie (2000) estimated a 23% reduction in hedgerows length between 1978 and 1990, while Carey et al. (2007) calculated a 21% decrease in managed hedgerows from 1984 to 2007. France, too, has witnessed a significant decline in hedgerows. Pointereau and Bazile (1995) revealed that approximately 65% of hedgerows were destroyed during the 20th century due to the land consolidation process, having profound implications for biodiversity and landscape connectivity. In the Plzen Region of the Czech Republic, Sklenicka et al. (2009) reported a drastic reduction in hedgerow length (71%), between 1950 and 2005. This decline has raised concerns about the loss of habitat and genetic diversity within these woody features. Van Den Berge et al. (2021) recorded that 70% of the hedgerow network in Belgium was cleared since 1960, creating many 'ghost' hedgerows.

The documented reduction in the abundance of hedgerows was related to various causes. According to Barr and Gillespie (2000), a predominant factor was the absence of long-term management, resulting in scattered lines of trees and rows of shrubs. Indeed, our findings indicate that unmanaged hedgerows were prevalent in the EU, constituting 30.6% of the total SWF. While these features contribute to wildlife abundance and other values, hedgerows require a certain level of management to ensure sustainability (Barr and Gillespie, 2000). Additionally, the proper management of hedgerows plays a crucial role in preventing the homogenisation of the species community and enhancing its biodiversity value (Watt, 2020). Furthermore, inadequate management can affect the composition, structure, and availability of food resources in hedgerows (Smigaj and Gaulton, 2021). In their study, Robinson and Sutherland (2002) also related the decline of hedgerows with the intensification of farming practices, resulting in a decrease in habitat availability for numerous species and a reduction in the overall diversity of the landscape. Furthermore, in specific studies, the decline of hedgerows has been associated with the reduction of specialised ground beetles and insect species that overwinter in the soil (Mazed et al., 2021), and has also played a role in the ongoing decrease of the hazel dormouse population in England (Phillips et al., 2022). For all these reasons stopping the decline and reversing the trend is paramount. Currently, regulations safeguard hedgerows and impose penalties for their removal in numerous European countries. Governments are actively offering financial assistance to landowners for the careful management, restoration, and planting of hedgerows via agri-environment schemes (Staley and Norton, 2023). As an example, farmers are receiving compensation for income losses resulting from measures aimed at enhancing the environment or biodiversity (Kleijn and Sutherland, 2003).

5. Conclusions

Our results show that AF_{SWF} are found throughout all 27 member states of the European Union and in the United Kingdom. The proportion of land occupied by arable crops and grasslands, whether ungrazed or grazed, associated with SWF is similar, while permanent crops with SWF were the least extensive category. These types of systems predominate in the Atlantic and the Continental regions, except for permanent crops associated with SWF, which are mainly found in the Mediterranean region. France, United Kingdom, and Germany are the countries with a larger surface area occupied by AF_{SWF} systems. However, Malta, Ireland and Cyprus showed the highest values if they are expressed as percentage of UAA. Hedgerows are the most frequent type of SWF within agricultural areas, representing 52% of SWF in the EU, with unmanaged hedgerows being more abundant than managed ones due to the lack of long-term management (30.1 and 20.9%, respectively).

Owing to the detailed information based on field observations provided by surveyors, our results demonstrate that LUCAS data offer valuable insights into the typology, extent and distribution of the AF_{SWF}, allowing for the characterisation of each type of SWF and the analysis of their spatial patterns and importance within agricultural areas. However, the LUCAS survey has limitations in accurately estimating the extent of both the AF_{SWF} systems and the different types of SWF within agricultural areas. These limitations are: 1) the LUCAS survey does not indicate the extent of the represented land covers because the data constitute point samples; 2) the LUCAS 2015 dataset does not provide the actual measures of the SWF present within the transects, so it is necessary to extrapolate the measurements provided in the sample dataset of LUCAS 2012; 3) the LUCAS survey does not offer the surface area occupied by the SWF within the transects.

The Copernicus SWF 2015 dataset allows for more accurate surface estimates of the extent of SWF at the European scale but does not provide information on the different types of SWF. Therefore, for further research, combining the LUCAS survey with the Copernicus SWF 2015 dataset could improve the accuracy of the surface estimates. Analysis trends in AF_{SWF} change, also regarding the effects of the EU Green Deal, Biodiversity Strategy and promotion of Agroforestry and Organic Farming, have an impact toward transforming landscapes for better biodiversity and ecosystem service outcomes.

Based on our estimates Small Woody Features agroforestry (AF_{SWF}) covers a 3.3. times larger land area compared to common agroforestry (AF_C) systems, emphasising the significance of these systems throughout Europe. SWF have the potential to deliver similar or enhanced ecosystem services compared to trees and shrubs found within fields of agricultural systems (AF_C). On the contrary they have the potential to increase crop and grass yields and soil health e.g., through changes in micro-climate and lowering wind erosion. Therefore, it is crucial for public and governmental institutions to advocate for policies that raise awareness about the importance of preserving these features in agricultural systems and promote the integration of SWF in such areas. This research has, to our best knowledge, for the first time documented the extend of AF_{SWF} in all 28 European EU member states. It has given detailed insights into the different types of AF_{SWF} and the distribution within countries and biogeographic regions. In contrasting AF_{SWF} with AF_C it has also greatly contributed to the better understanding of the different types of agroforestry systems and their spatial distribution. This research provides a baseline for monitoring the extent and distribution of SWF within the European Union. Furthermore, the findings can facilitate the formulation of policies and funding measures under the Common Agricultural Policy (CAP) and can help farmers make informed decisions when assessing the contribution of SWF to both productivity and biodiversity.

CRediT authorship contribution statement

Judit Rubio-Delgado: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Susanne Schnabel:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Conceptualization. **J. Francisco Lavado-Contador:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Conceptualization. **Ulrich Schmutz:** Writing – review & editing, Funding acquisition.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT and Assistant by Scite in order to improve language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

Authors declare no commercial activities or other conflict of interest regarding the topic of the research.

Data availability

No data was used for the research described in the article.

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