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Contribution of agroforestry to ecosystem services in Europe

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Contribution of agroforestry to ecosystem services in Europe independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 14.04.2022

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Abstract

In Europe, the agricultural intensification of the last century led to an unprecedented increase in agricultural productivity, but at the same time, it brought about many negative impacts on the ecology of agroecosystems. Agroforestry is gaining increasing worldwide attention as it is believed that it can be a sustainable alternative to many conventional agriculture systems because of its ability to provide a number of ecosystem services. This literature review aimed to bring a comprehensive summary of the actual state of knowledge on the agroforestry systems and practices provision of main ecosystem services in the region of Central Europe (CE). Information from 84 scientific studies was used to examine five major identified ecosystem services: (1) biodiversity conservation; (2) soil conservation; (3) carbon sequestration; (4) water management, and; (5) cultural services. Information gathered from the studies shows generally positive effects of agroforestry on all the reviewed ecosystem services. However, a large part of the studies suggests that additional enhancement of the effects can be achieved by adequate spatial composition of the system, species composition, uptake management, and other factors. It was found that amongst all included studies, biodiversity conservation was the most investigated service, while the lowest number of studies observed the potential for carbon sequestration. The largest proportion of the identified studies comes from Germany, while the smallest number originates from Austria. Additionally, significant variability related to the amount of found studies for each ecosystem service has been observed among the CE countries.

Key words: biodiversity conservation, soil conservation, water management, carbon sequestration, cultural services

Contents

List of tables

List of figures

List of the abbreviations used in the thesis

AF	-	Agroforestry
CE	-	Central Europe
ES	-	Ecosystem services
HWEOC	-	Hot water extractable organic carbon
MBC	-	Microbial biomass carbon
MBN	-	Microbial biomass nitrogen
SOC	-	Soil organic carbon
TN	-	Total nitrogen
TOC	-	Total organic carbon
UAA	-	Utilized agricultural area

1. Introduction

Since the beginning of the second half of the 20th century, as the world population started to rapidly increase, both agriculture in developing countries, as well as industrialized agriculture in developed countries, was characterized by a paradigm of fertilizers, improved seeds, and pesticide use approach. Such a production model was standing on short-term production of a small number of crop species, mainly cultivated in monoculture systems, promoting the simplification and specialization of agroecosystems through the increase of landscape homogeneity. These systems successfully achieved their goals of feeding the rapidly increasing population, however, they came short in finding the balance between the food production and environmental sustainability. Therefore, such agricultural systems can be very effective in provision of high yields but it is more and more clear that they are not so effective in providing all the other ecosystem services which are not less important in the world where about 55% of global habitable land is used for agriculture and where the agriculture generates up to 30% of the world greenhouse gas emissions (Horrigan et al. 2002; Scherr & McNeely 2008; Ellis et al. 2010; Tubiello et al. 2013).

Reflecting this reality, many alternative approaches combining productivity with environmental enhancement and sustainability are increasingly gaining attention (Scherr & McNeely 2008). A growing number of studies from around the world and especially from regions of the tropics are suggesting that one such alternative that can provide a wide range of provisioning, regulating, and supporting ecosystem services is agroforestry (Jose 2009; Nair 2011). Even in temperate regions, agroforestry is becoming part of strategies and policies of different countries with the intention of changing their agricultural practices to more sustainable ones as there is increasing evidence that agroforestry potential in the provision of many ecosystem services and environmental benefits is not limited only to tropical and subtropical regions of the world (Santiago-Freijanes et al. 2021; Castle et al. 2022).

However, agroforestry systems are much more complex than many uniform and simplifying conventional agricultural systems, and therefore there is a need for scientific knowledge background that can identify not only potential benefits and disadvantages connected to agroforestry but also possible adjustments of these systems that can further enhance their potential in real implementation and achievement of specific objectives. For decision-making processes on different levels, apart from observing individual agroforestry benefits separately, it is also important to bring comprehensive reviews and synthesis, that can provide a summary of concrete examples of where different agroforestry systems and practices might provide sustainable alternatives to conventional agriculture systems (Garrity et al. 2006; Nair 2007).

2. Aims of the thesis

The main objective of this thesis was to find to what extent studies from countries of Central Europe provide information on agroforestry's contribution to ecosystem services.

In the context of Europe, most of the studies come from southern parts of the continent, as there is a significantly higher concentration of agroforestry systems, but an increasing number of studies are also emerging from temperate regions. Torralba et al. (2016) made a meta-analysis, which demonstrated that information on agroforestry influence on ecosystem services provision is covered by studies from across all the European ecoregions, including the Continental and Pannonian regions. However, from 53 included studies, only 3 were from the countries of CE.

Therefore, the goal was to find whether more studies from this region exist and to review their findings of agroforestry systems and practices' contribution to five main ecosystem services: (1) biodiversity conservation; (2) soil conservation; (3) carbon sequestration; (4) water management, and; (5) cultural services.

Additionally, this thesis aimed to also look at the spatial distribution of the found information in order to see how large are the differences in the number of identified studies for individual countries in general, as well as for particular ecosystem services, to provide a broader picture of how the identified studies cover CE countries.

3. Methodology

Information included in this literature review has been mainly obtained from scientific databases such as Web of Science (http://www.webofknowledge.com/), SCOPUS (https://www.scopus.com/), ScienceDirect (http://www.sciencedirect.com/) and ResearchGate (https://www.researchgate.net/).

For the search of studies from CE, especially following combinations of key word and terms have been used: Topic: (biodiversity OR diversity OR species richness OR species abundance OR species composition OR soil conservation OR soil health OR soil erosion OR soil protection OR wind erosion OR wind speed OR water erosion OR soil enrichment OR soil fertility OR soil productivity OR soil organic carbon OR carbon sequestration OR carbon stock OR water management OR water runoff OR infiltration OR soil moisture OR microclimate OR humidity OR cultural service OR aesthetic OR heritage OR recreation OR tourism) AND: (agroforestry OR alley cropping OR silvopast OR silvoarable OR wood pasture OR grazed orchard OR traditional orchard OR scatter tree OR hedgerow OR windbreak OR shelterbelt OR intercropping OR pollarding OR streuobst OR woodlot) AND: (Central Europe OR Germany OR Poland OR Czech republic OR Slovakia OR Hungary OR Austria)

After the removal of duplicates, 84 scientific studies from CE connected to one or more of the five chosen ecosystem services have been selected for the literature review. The vast majority of the selected studies were published after 2003, however four included studies were published before the year 2000.

4. Literature review

4.1. Agroforestry definition and classification

There are several different approaches to defining agroforestry and thus many definitions exist. Nairs (1993) suggests, that scientific definitions should emphasize two concrete characteristics that all agroforestry forms have in common and that separate them from any other land use systems:

- Intentional growing of shrubs or trees on the same unit of land as agricultural crops and/or animals.
- There must be a high level of interaction between the woody and nonwoody components in such a system. This interaction can be ecological and/or economical (Nair 1993).

According to FAO: „Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence."

Leaky (1996) argues that the definition of agroforestry should take into account the fact, that it is generally practiced to develop land use that is more sustainable and that aims to raise farm productivity as well as the welfare of the rural communities. He points out that it should be emphasized that agroforestry has a strong potential of mitigating deforestation and soil degradation which results in alleviating poverty and that it provides important environmental services and economic products. Therefore, he suggests that agroforestry should be recognized as a:

„ Dynamic, ecologically based, natural resource management system that, through the integration of trees in farm- and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits" (Leakey 1996).

In Europe, rather simple but practical definition was made by the European Commission, which defines agroforestry in Article 23 of the Rural Development Regulation 1305/2013:

"a land use system in which trees are grown in combination with agriculture on the same land".

Based on the previous definitions, a wide range of particular agroforestry systems can be categorized. Because of this diversity within the systems, comprehensive and easy-to-understand classifications are needed.

For the aims of this work, classification compatible with the European specifics and contexts was used (Table 1). The primary classification of agroforestry systems can be made on the basis of the nature of components and silvopastoral, silvoarable, and agrosilvopastoral are the three main groups that arise from this division. However, these are not the only systems that meet the definitions of agroforestry (Rigueiro Rodríguez et al. 2009; Dupraz et al. 2018).

Table 1 Classification of agroforestry systems and practices as proposed by EURAF (modified by Dupraz et al. 2018)

Tree Location	**Agroforestry System**	**Forest Land**	**Agricultural Land**
Trees inside parcels	Silvopastoral AF	Forest grazing	Wood pasture
	Silvoarable AF	Forest farming (including food forests)	Tree alley cropping Coppice alley cropping Multi-layer tree-gardens
	Permanent crop AF		Orchard intercropping Orchard grazing
	Agrosilvopastoral AF		Alternating cropping and grazing
Trees between parcels	Field boundary AF (Tree landscape Features)		Wooded hedges Windbreaks and shelterbelts Trees in line Riparian tree buffer zones
Trees in settlements	Urban AF	Homegardens, allotments, etc.	

4.2. Extent of agroforestry in Europe

Agroforestry is far from being a new concept of land management in Europe. It has been always present in many traditional systems and thus in one way or another, it is and was practiced on the continent. Despite the fact that both the term and its definition emerged relatively recently, different land use systems integrating trees and agriculture have been practised for thousands of years (Smith 2010). There are regions that maintained these practices until today, others where they almost completely disappeared because of the intensification and mechanization of agriculture as well as those where they are finding their place again in the form of modern agroforestry practices. Trees were always an important element of farmlands across Europe, as they not only offered multiple functions by delivering timber, fruit, fodder, or cork but also because they had always had an important role in the cultures of individual countries. And so we can say, that agroforestry is somewhat a new word for rather old practices (Nerlich et al. 2013). Agroecosystems, like *Dehesa*, which is a woodland pasture that extends on more than 3,500,000 ha in Spain and Portugal (where it is called *Montado*) and that is practiced for about 4, 500 years, is clear proof of such a statement (Vicente & Alés 2006; López-Sáez et al. 2014)

Even though agroforestry systems can be found across all of Europe, it is difficult to find reliable information on the exact extent of these systems. A study, that is quantifying and maps the distribution of agroforestry across the European union using LUCAS Land Use and Land Cover data, estimates that around 15.4 million ha of EU27 land cover is under agroforestry systems (den Herder et al. 2017). This is equivalent to around 8.8% of agricultural land area and 3.6% of the territorial area. Agroforestry systems were found to be much more concentrated in countries of southern portions of the continent than in the rest of the EU. The largest absolute area under agroforestry systems can be found in Spain (5.6 million ha), followed by France (1.6 million ha), Greece (1.6 million ha), and Italy (1.4 million ha).

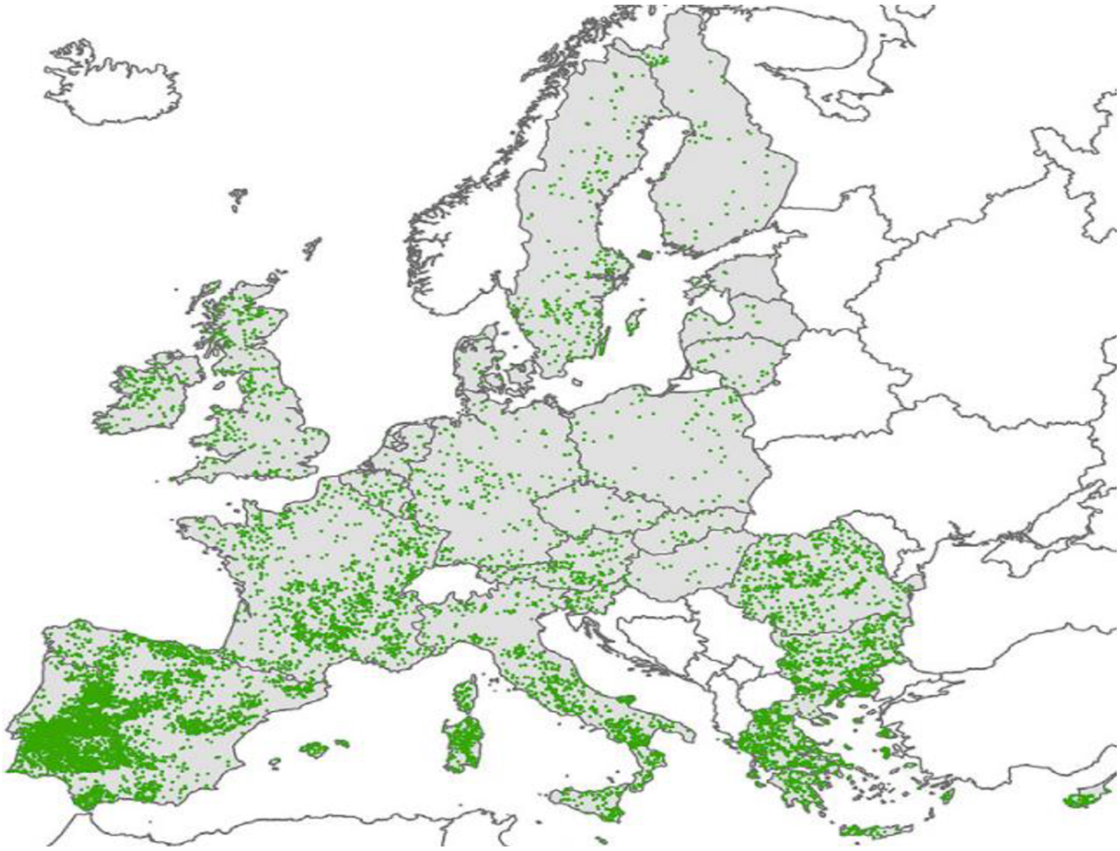

Figure 1 Distribution of agroforestry systems in the EU as identified by den Herder et al. (2017)

Compared to southern Europe, temperate regions of the continent, with exceptions of features like hedgerows, shelterbelts, windbreaks, and buffer strips, are not as rich in presence of traditional agroforestry systems, and it is rather novel agroforestry systems like alley cropping that are being increasingly applied and developed here. Big part of this region has been heavily industrialized and thus the approach was rather one of finding the compatibility between the already present mechanization and its operational efficiency and the external positive effects provided by traditional agroforestry (Herzog 1998).

4.2.1. Agroforestry in Central Europe

Information used in this work is primarily from, but not limited to countries of CE. The issue of how to define the area of CE is the subject of debate. Numerous definitions based on different historical, sociological, geographical, and political aspects and viewpoints exist. A universally accepted definition of CE does not exist as there are no clear geographical or cultural boundaries that could comprehensively define such a region (Okey 1992). For the purposes of this work, most of the information used comes from studies from Germany, Poland, Hungary, Austria, Czechia, Slovakia, and Slovenia, as these are the countries that are part of most existing definitions of CE.

In general, we can say, that the climate of CE is characterized by the interaction of both maritime and continental air masses. If Koppen-Geiger climate classification is used, six climate types exist within the region defined by mentioned countries.

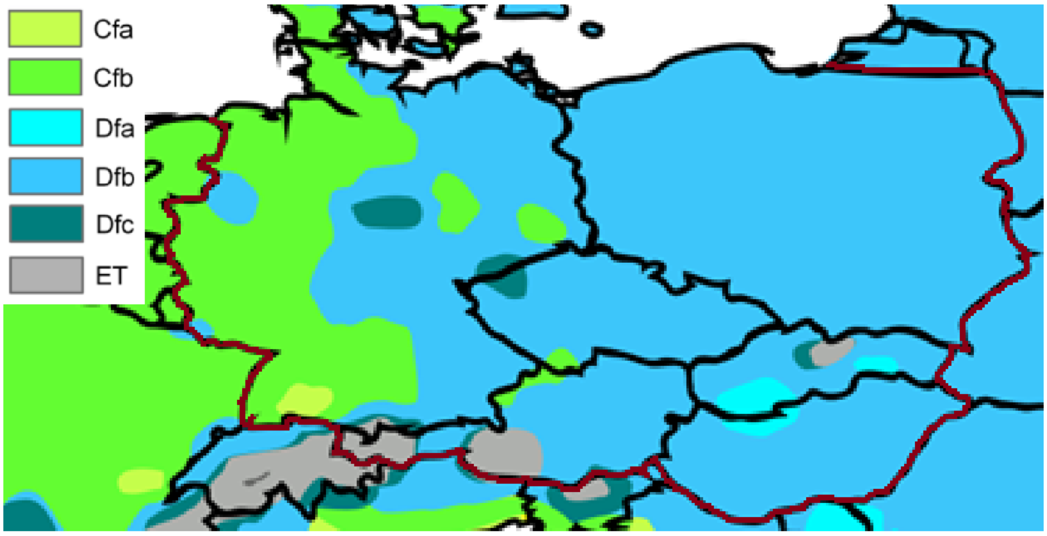

Figure 2 : Koppen-Geiger climate type map of Central Europe. Warm summer continental (Dfb), oceanic (Cfb), hot summer continental (Dfa), humid subtropical climate (Cfa), cool continental climate (Dfc), tundra climate (ET), (adapted from Peel et al. 2007)

The warm summer continental climate (Dfb) covers most of the territory, but a significant part, lying mostly in western Germany has an oceanic climate (Cfb) (Peel et al. 2007). In general, most of the region experiences relatively cold winters and warm summers. Precipitation is abundant with summer maximums. The range between summer and winter temperatures increases eastward and altitude affects significantly both the average temperatures and average precipitations (Mücher et al. 2003).

Landscape, with exceptions of the Alps, the Carpathians, and some smaller mountain ranges and uplands is characterized by lowlands, notably the Pannonian Plain that covers all the territory of Hungary, southern Slovakia as well as north-eastern parts of Austria, and south-eastern Czechia, and North European Plain, which covers big parts of Poland and Germany. The vast majority of of the lowlands are used for agricultural production, and they are generally composed of fertile soils (Mücher et al. 2003).

The actual overall situation of agriculture in CE varies from country to country, always originating in the complexity of historic, socio-economic, political, cultural, geographical, ecological, and other factors. While the preindustrial agriculture of CE was characterized by strong diversity of land use systems, 200 years of industrial modernization brought fundamental transformations. The most significant changes in agricultural systems came after World War II when the use of fossil-fuel-based technologies resulted in the disintegration of nonuniform and locally interconnected land use practices which led to the separation and specialization of agricultural land use and enormous growth of agricultural areas as well as to increase in labour productivity and overall capacity of supporting increasing population with enough food (Krausmann 2004).

Another factor that had a particularly significant impact on agriculture in this region was the level of nationalisation and collectivization of agriculture as except for Austria and Slovenia, all countries had been to some extent part of the Eastern Bloc almost for a half-century before 1990 (Bański & Bednarek 2008). The complexity of all the factors resulted in a situation, where today the top three countries with the biggest average farm size within the EU, are to be found in CE, namely Czechia, Slovakia, and Germany (Table 2).

Table 2: Average farm sizes in Central Europe (data from Eurostat)

	Average farm size in ha	
	2007	2013
Germany	45.7	58.59
Poland	6.47	10.08
Hungary	6.75	9.48
Austria	19.28	19.42
Czechia	89.29	133.01
Slovakia	28.07	80.68

Even though intensive industrial agriculture dominates in CE countries, agroforestry systems are not unknown practices and in one way or another are or had been traditionally practiced across the region (von Maydell 1995). Some of those common and expanded traditional agroforestry systems are windbreaks, shelterbelts and hedgerows (Poschlod & Braun-Reichert 2017; Vacek et al. 2018). *Streuobst* is another well-known system that is still practiced across some CE countries. *Streuobst* can be defined as „tall trees of different types and varieties of fruit, belonging to different age groups, which are dispersed on cropland, meadows, and pastures in a rather irregular pattern" (Herzog 1998). Also wooded pastures and meadows are still practiced in some regions, especially in Germany, Slovakia, and Hungary. (Krčmářová & Jeleček 2017), but also in Austria (Herzog 1998) and Czechia (Lojka et al. 2022). However, the number and extent of wood pastures that were before widespread across most of the regions in CE has drastically declined in the last century, and some systems, such as wood pastures with pollarded trees or species-specific wood pastures like those with sweet chestnut (*Castanea sativa*), almost completely disappeared (Smith 2010; Pástor et al. 2018).

Figure 3: Chestnut wood pasture in central Slovakia (Pástor et al. 2018)

Already mentioned study conducted by den Herder et al. (2017) which used LUCAS Land Use and Land Cover data estimates that the extent of agroforestry systems, if expressed as a proportion of utilized agricultural area (UAA), is significantly lower within CE countries than the average of EU countries (9.2% of UAA, excluding Croatia which was not included in the study) as can be seen below (Table 3).

Table 3 Extent of agroforestry systems in countries of Central Europe, expressed as proportion of agricultural area, as identified by Herder et al. (2017)

Country	**% of UAA**
Germany	1.6
Poland	0.7
Hungary	0.8
Austria	5.6
Czechia	1.3
Slovakia	2.3

Despite the fact that in CE, traditional agroforestry systems except for some practices such as windbreaks and hedgerows, almost disappeared, overall mood is starting to change. Increasing awareness of environmental problems like land degradation by erosion or overexploitation of natural resources as well as all the spectrum of possible consequences of climate change, decrease of natural resources, and at the same time need of maintaining agricultural productivity is making agroforestry to gain more and more attention. It is becoming clear that alternative land use management can play a big role in both the mitigation and the adaption to climate change (Quinkenstein et al. 2009; Chapman et al. 2020). Due to the high level of agricultural landscape uniformity and high level of agriculture intensification within the region, linear systems such as different types of alley cropping systems could be particularly suitable for this region as they were developed with the intention of maintaining and enhancing the productivity hand in hand with ecological benefits provision, and are easily adaptable to farmer's needs, as they can be established in many different configurations (Garrett et al. 2021). Consequently, in CE, alley cropping systems are becoming increasingly popular (Quinkenstein et al. 2009).

4.3. Agroforestry for biodiversity conservation

Biodiversity has been declining at an alarming rate and agriculture is its biggest threat as it is the biggest contributor to habitat and species diversity loss, especially in Europe. Scientists as well as policymakers are becoming more aware of the urgent need to implement more sustainable practices in agriculture that will be able to feed the increasing world population without damaging natural environments (Mclaughlin & Mineau 1995; Kirschenmann 2007; Dudley & Alexander 2017). The unique role that biodiversity plays in ecosystem services exists on different levels. In this relationship, we can consider biodiversity as a regulator of ecosystem processes as well as a final ecosystem service, but we can also see biodiversity as a good (Mace et al. 2012). Whether we look at biodiversity as to a part of cultural, provisioning, or supporting services or we look at biodiversity separately, it is clear that its role is unique, interconnecting, irreplaceable, and essential both for ecosystem functions as well as to service delivery (MEA 2005).

Growing scientific evidence on agroforestry's contribution to biodiversity enhancement and conservation exists both in tropical (Harvey et al. 2008; Kalaba et al. 2010; Warren-Thomas et al. 2020) as well as from temperate regions (Burgess 1999; Price & Gordon 1999; Banerjee et al. 2016; Vanneste et al. 2020). Generally, agroforestry contributes to biodiversity conservation on five different levels: (1) agroforestry provides habitat for species; (2) agroforestry supports conservation of germplasm of sensitive species; (3) agroforestry helps to reduce the amount of conversion from natural habitat by providing a sustainable alternative to traditional agriculture systems that many times include clearing of natural habitat; (4) agroforestry provides connective function by production of bio-corridors interconnecting remnant natural areas that may support area-sensitive species of both flora and fauna, and; (5) agroforestry contributes to the provision of other ecosystem services like water recharge and erosion control which has a positive effect on preventing degradation and disappearance of the surrounding habitat (Jose 2009).

4.3.1. Agroforestry for arthropod diversity

As different case studies from CE show, agroforestry systems have a positive effect on different species from the phylum Arthropoda, both on the surface and subsurface species. Agroforestry has been shown to affect arthropod population density as well as species diversity and richness. For example, a study on harvestman communities of hedgerows in the Western Carpathians in Slovakia shows that hedgerows play a very important role in providing habitat refugia for harvestman species that are sensitive to land use and disturbance (Stašiov et al. 2020). Authors found 43% of all harvestman species of Slovakia in hedgerows within a small study area (<2km2). A different study from Pardubice Region in Czechia shows that traditional orchards serve as important refugia for saproxylic beetles. In total, 13% of trapped species from 25 traditional fruit tree orchards used for the experiment are red-listed in the territory of Czechia. This study also suggests that canopy openness can be considered one of the key elements for species richness of saproxylic beetles and therefore traditional fruit orchards might act as an alternative habitat for organisms associated with open canopy deciduous woodlands (Horak 2014). Extensive orchard meadows, which are a very important part of the cultural landscape of CE, support a high diversity of arthropod species, being particularly important for, among others, steppe spider species, as a study from Central

Bohemia shows (Čejka et al. 2018), as well as for above-ground nesting species of important pollinators and predators, bees and wasps (Steffan-Dewenter & Leschke 2003). Wild bees were also studied in Poland, where authors proved that linear woodlots in agricultural lands increase the abundance of wild bees as they provide them with additional forage sources (Sobieraj-Betlińska et al. 2022).

Beneficial aphidophagous syrphid fly species studied in Lower Saxony, Germany were found to be attracted by hedgerows, especially by those connected to the forest, and authors suggest that they might have a positive effect on biological control in highly intensified land-use systems (Haenke et al. 2014). In northern Hungary another natural enemy of serious pests, lacewing species, were also found to be benefiting from the presence of hedgerows as their presence here was significantly higher than in the field borders with only scarcely grown trees and shrubs (Bozsik 2006). Sobczyk (2004) demonstrated that shelterbelts as young as 1-2 years are contributing to enhancing abundance and species richness of butterfly species. While young shelterbelts were characterised by domination of butterfly species typical for open habitat, older shelterbelts had much higher share of species typical for woodlands and forests.

There is strong evidence that subsurface arthropods that are essential for breaking down organic matter are also significantly benefiting from the presence of agroforestry systems in agricultural landscapes. Myriapod communities were studied in hedgerows of an upland agricultural landscape in Slovakia and results show a high diversity of both centipede and millipede species (Stašiov et al. 2017). Authors have concluded that most probably it is the diversity of environmental conditions and connectivity to other habitats provided by hedgerows that are responsible for the species diversity. An older study of artificially created poplar windbreaks effect on the abundance of arthropods in heavy soils of eastern Slovakia shows similar results, with a high abundance of arthropods in windbreaks (Miko et al. 1992). A significantly positive effect of agroforestry systems was also found on oribatid mites species (Ľuptáčik et al. 2012).

4.3.2. Agroforestry for bird diversity

The positive impact of agroforestry can be seen also on bird species. The presence of semi-natural habitat in the agricultural landscape is important for farmland bird diversity. It is recognized that different landscape elements like hedgerows and windbreaks are providing foraging resources, nesting sites as well as shelter for roosting and hiding from predators (Hinsley & Bellamy 2000; Fuller et al. 2004; Herzon & O'Hara 2007; Billeter et al. 2008). Results from studies from our region of interest support such a statement. Various studies from Poland show that traditional, extensively used orchards, in contrast to conventional monocultural plantations of fruit trees reinforce bird diversity. Kajtoch (2017) found, that extensively used orchards sustained on average 1.5 times more species, and there were 1.7 times more counted birds than at intensively managed orchards. Chmielewski (2019) also found a very high density of birds in traditional orchards when compared to other habitats.

Some studied species like barred warbler (*Curruca nisoria*), common whitethroat (*Curruca communis*), and lesser whitethroat (*Curruca curruca*), were found to prefer linear habitats with trees and shrubs with high spatial heterogeneity (Szymański & Antczak 2013). Additional data from Poland shows that woody and shrubby margins of fields are not only retaining high bird species richness and abundance (Sanderson et al. 2009) but that they also support rare and threatened species (Wuczyński et al. 2014). However, not only spatial heterogeneity and distribution but also the length of the woody edge habitat can be a strong predictor of the abundance of individual bird species (Sanderson et al. 2009). A similar result was brought by Bátary et al. (2010) which were comparing bird diversity and abundance in hedges and in the field, both on meadows and on winter wheat fields. It was conducted on selected paired organic and conventional meadows and wheat fields in Germany. Their results show that more bird species occurred on organic fields than on fields with conventional agriculture but regardless of land use type (meadow and wheat field). Yet, the length of hedges had a stronger effect on species richness than the type of management. Overall, most individuals occurred near or in hedges. When Kujawa (2004) studied breeding avifauna in shelterbelts of different ages, it was found that while younger shelterbelts supported lower overall species richness and densities, they are just as important as older shelterbelts because they are important for species that nest on ground and in low vegetation.

Agroforestry might have a positive effect also on birds of prey species. A survey of owl species in southern Slovakia found that windbreaks, hedgerows, and even street tree lines in villages are important breeding territories of long-eared owl (*Asio otus*) (Václav 2016). Tracking of five juveniles of the imperial eagle (*Aquila heliaca*), in the border area between Austria, Slovakia and Hungary showed that for this species, windbreaks also serve as night roosting places in agricultural landscapes (Nemček et al. 2014). However, one study from south-western Poland found, that hedgerows on the roadsides increased the mortality of different bird species, as it brought birds into close vicinity of road traffic. Authors, therefore, suggest that new hedgerows should be planted further away from the roads in order to make them safer for wildlife (Orłowski 2008).

4.3.3. Agroforestry for mammal diversity

Linear woody elements in the agricultural landscape are proven to be useful for almost all taxa, including mammal species (Graham et al. 2018). Many variables contribute to overall mammal species richness and abundance in the agriculture landscape. A study of hazel dormice (*Muscardinus avellanarius*) in Northern Germany shows that for this species it is important that at least 12 woody plant species occur in hedgerows to provide a suitable habitat. They also conducted that a coherent network of hedgerows between isolated woodlands is important for dormouse migration and the exchange of individuals between the habitats (Ehlers 2012). Small mammalian species occurrence in three different types of poplar windbreaks and adjacent fields were investigated in Eastern Slovakia lowlands where five species occurred both in the fields and in windbreaks (Stanko 1994). The value of relative abundance was twice as high in windbreaks than in the fields. The species equitability and diversity indices as well as the number of constantly occurring species in windbreaks were significantly higher than those found in the fields and the authors found also a positive correlation between the width of windbreaks and the total dominance of forest rodent species. Other research was comparing small mammal abundance and diversity in conventional and organic farmlands both on cropland and non-cropland sites. They found no significant differences between organic and conventional farming, but their results show that higher diversity was connected with the heterogeneity of the landscape, with most of the individuals being trapped inside hedgerows (Kalivodová et al. 2021). The relationship of small mammal communities to different habitats was also observed in southern Moravia, Czechia, where they found mammal communities to be more abundant in permanent habitats like windbreaks than in crop fields (Heroldová et al. 2007).

Windbreaks and hedges were also proved to be important habitat corridors for carnivorous species. Even though the most crucial factor affecting the use of corridors by carnivores was the availability of principal prey, corridor width and proportion of shrubs were also important factors (Červinka et al. 2013).

Not only terrestrial mammals are taking advantage of the presence of different agroforestry systems. Many bat species that are well known for their contribution to ecosystem services and environmental balance, mainly because of their ability to control different arthropod pests in agricultural landscapes (Kunz et al. 2011), are benefiting from the presence of hedgerows, windbreaks, and different linear woody elements of landscapes. Bats like a brown long-eared bat (*Plecotus auritus*), greater horseshoe bat (*Rhinolophus ferrumequinum*), lesser horseshoe bat (*Rhinolophus hipposideros*), and common pipistrelle (*Pipistrellus pipistrellus*), which are all bats inhabiting, among other regions, CE, were all found to prefer flying along hedgerows and other linear elements than flying in open space, as these features function as commuting routes and they also provide them with higher densities of insects (Downs & Racey 2006). A study from north-eastern Germany that was observing bat activity in relation to distance from hedgerows, and at the same time observing spatial activity patterns between spring and summer, shows similar results, with the highest overall activity of bat species near hedgerows, however with considerable variation in species-specific spatial activity between the two seasons (Kelm et al. 2014). Some species were more active near hedges in both seasons, and some were more active close to hedges in spring. They suggest that these differences occur due to different ecological niches and variations in the foraging behaviours of individual species. In a different experiment, also in Germany, bat species were divided into main functional groups of edge, narrow and open space foragers and they were monitored by ultrasound recorders over different types of landscape cover. Compared with a wheat field that served as control site, the activity of bat species over hedgerows increased threefold for edge space foragers and sevenfold for narrow space foragers (Krings et al. 2022). Also ancient oak wood pastures of the Gavúrky protected area, Slovakia, are found to be creating unique habitat characteristics, resulting in a diverse assemblage of bat species. 39% of all bat species that live in Slovakia have been detected here (Kaňuch & Ceľuch 2007).

Worldwide populations of bats, which serve as, important bioindicators, have experienced significant declines in the last century, and the proposed drivers of this decline include loss of habitat and agricultural intensification (Hutson et al. 2001; Wickramasinghe et al. 2003; Jones et al. 2009b). Therefore, an increase in presence of linear features like windbreaks and hedgerows but also silvopastures as well as an increase in the overall heterogeneity of agricultural lands could help protect these important species (Boughey et al. 2011).

4.3.4. Agroforestry for plant diversity

Different agroforestry systems can also have a positive effect on plant species diversity. Traditional, extensively used orchards can serve as particularly important habitats for many herbaceous plants, especially stress-tolerant species. When comparing orchard meadows that were grazed, mown, and left fallow, Steffan-Dewenter & Leschke (2003) found, that abandoned orchards had significantly lower plant species richness, and that mowing mainly promoted species richness of herbs whereas grazing increased species richness of grasses. In grazed orchards and woody pastures, vegetation is influenced by solar irradiance, shading, and, most significantly, by the intensity of grazing. Intermediate grazing supports the most heterogeneous vegetation and the largest plant species diversity, especially if combined with the right amount of woody plants that provide some amount of protection from the excess of sunlight (Kovář et al. 2014).

As a consequence of the high proportion of agricultural land use in the landscape of CE, many forest species are threatened by habitat loss and fragmentation. Even though landscape elements like hedgerows are not representing equal habitat conditions as forests because of their bigger wind exposure and sunlight penetration, they are still useful for the dispersion of many forest species and can even help to preserve threatened species (Wehling & Diekmann 2009). Forest species are particularly favoured by high connectivity between hedgerows as well as connectivity to forests that serve as source populations, but they are also found to be avoiding west-easterly oriented hedgerows as these present rather extreme microclimates, with one side being exposed to too dry and warm conditions with high evapotranspiration (Wehling & Diekmann 2008). However, resurvey from Germany shows a dramatic change in the composition of herbaceous species in hedgerows over the past five decades. They found an overall decline in species richness, particularly in the number of herbaceous forest species and forb species (Litza & Diekmann 2017). Compared to the original study, only the richness of grass species increased significantly, being the functional group that profited most from the agricultural intensification of past decades, probably because of, among other factors, higher tolerance towards herbicides. They also found the loss of many formerly common, red-listed species.

4.4. Agroforestry for soil conservation

Soil degradation is one of the world's most concerning and rapidly worsening environmental problems. Globally, almost 25% of agricultural land is already highly degraded. The combination of population growth and therefore enlarging demand for agricultural production, and the increasing occurrence of extreme weather events in form of prolonged droughts, heavy floodings, and many others, only emphasize the urgent need for actions towards soil protection and conservation (Jones et al. 2009a; DeLong et al. 2015). We can look at soil degradation as a natural process that can be either dampened or enhanced by human intervention. While many naturally occurring events as well as earth processes and environmental changes contribute to soil degradation, human-induced soil degradation, also known as accelerated degradation, is a much faster process than natural degradation, and overgrazing, agricultural mismanagement, and deforestation are known to be the main reasons of soil degradation (Jie et al. 2002; Lal 2007).

Globally, agroforestry systems are proven to be effective in soil conservation, which primarily refers to the maintenance of soil fertility and the control of erosion. While soil erosion control is achieved through the mitigation of soil losses, soil fertility maintenance is achieved through the accumulation of organic matter, mostly by litterfall and mulching, nitrogen fixation, provision of mycorrhizal associations, and others (Atangana et al. 2013; Gupta 2020).

4.4.1. Agroforestry for soil erosion control

One of the biggest threats to soil resources in Europe is soil erosion (Verheijen et al. 2009). While in Mediterranean Europe soil erosion problems are known to date back to the Greek and Roman periods, in CE it came much later, with the onset of arable agriculture (van Andel et al. 1990; Dotterweich 2012). Yang et al. (2003) made a coarse-scaled global model and they estimate that almost 88% of soil erosion in Europe is human-conducted.

Reducing the wind speed is particularly important in the time when the field soil is not covered by cultivated vegetation cover, the time when the soil is much more vulnerable to wind-conducted erosion. A study in Czechia that was observing efficiency in windspeed reduction provided by windbreaks in two regions, conducted a measurement by four stations, where one station was placed at the windward side of the windbreak at a distance of three times the height of the windbreak and three stations were placed on the leeward side of the windbreak, at the distance of 3, 6, and 9 times the height of the windbreak (Reháček et al. 2017). They found that the airflow was significantly reduced by the windbreak even at a distance of six times the height of the windbreak. At the same time, they found a strong correlation between optical porosity and speed reduction. Different research was observing the effect of shelterbelts on wind speed reduction in erosion-endangered localities with heavy soils in the South Moravia region, Czechia. As in the previous study, they found a noticeable reduction of wind speed on the leeward side and a less pronounced wind speed reduction on the windward side. Overall seasonal variation in relation to foliage cover was also identified. However, even though with reduced efficiency, still a significant effect of shelterbelts on airflow was manifested even in the period when trees were not in leaves (Mužíková & Středa 2011). Středová et al. (2012) also measured the wind velocity at different distances from windbreaks combined with the influence of optical porosity in different periods. They found that a windbreak with full foliage and optical porosity of 10%, reduced the wind speed by 30% on the leeward side 150 m from the windbreak in comparison with wind speed at 150 m on the windward side. They proved that full foliage windbreak had some influence even at a distance of 200 to 250 m. Authors also suggest, that the efficiency of windbreaks could be further improved by incorporating evergreen trees, such as different conifers, which could better protect the soil from erosion between autumn and spring, when there are higher optical erosion values. Vacek et al. (2018) demonstrated that not only the presence of foliage, the height of the windbreak, and the density of branches but also the number of rows of trees had a significant effect on windbreak efficiency on wind speed reduction.

Bartus et al. (2017) studied a site situated on the Great Hungarian Plain in Hungary, intending to determine the wind erosion hazard potential by modelling in GIS, using a combination of two already existing model functions: the WEPS windbreak subroutine and the TEAM length factor function. Windbreak system was found to decrease the deflation potential even with the occurrence of a very strong wind event (15 m/s at 10 m height). Their simulations showed that the windbreak systems had a more significant influence than the size of the plot on the potential wind erosion control. It was also concluded that the effectiveness of windbreaks in reducing wind speed is much higher if it is appropriately oriented in relation to the prevailing wind direction of the site.

Dufková (2007) studied, how three different shelterbelts influence the erodibility of soil, and it was found that on the leeward side of shelterbelts, not only wind velocity was decreased, but also both soil humidity and soil resistance were significantly higher than on the windward side of the shelterbelts.

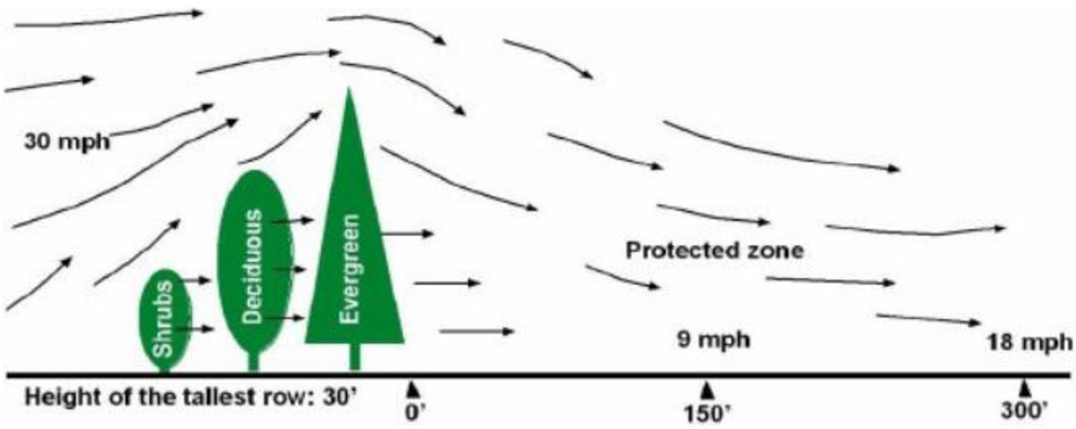

Figure 4 : Effect of windbreaks and their height on the amount of protected area behind them, as proposed by Tamang et al. (2009)

But it is not only intentionally developed agroforestry systems for soil erosion control, like shelterbelts and windbreaks, that are found to be effective in wind speed reduction. Böhm et al. (2014) studied short rotation alley cropping systems' impact on wind reduction. The experiment was conducted at two sites in eastern Germany, where anemometers were installed on crop alleys with different orientations and widths as well as distances to the stripes of trees, and at adjacent fields. The efficiency of hedgerows of short rotation alley cropping systems on wind reduction was found to be highly dependent on their structural nature and orientation but even tree strips of the height of two meters were able to significantly reduce wind speed. On an annual average basis, wind speed decreased more than 50% at the central point of 24 m wide crop alleys, when compared to wind speeds of adjacent open fields.

Even though we identified only one study that was observing water erosion control by agroforestry systems within the region of CE, it is well documented, including in different temperate regions, that agroforestry systems are effective in reducing soil erosion inducted by water, as trees on the agricultural land act as a barrier and provide surface cover which is formed by dead and living plant material that reduces surface runoff and velocity of raindrops (Nair 1993). For example, Palma et al. (2007), studied the effect of alley cropping and farming practices following contour lines on water erosion by modelling the effect at test sites in Scherpenzeel (Netherlands), Torrijos (central Spain) and Champlitte (eastern France). They found the best results if both the alley cropping and contouring practices were combined, as this combination was able to reduce soil erosion by up to 70%. Therefore, they suggest, that in order to maximize soil erosion reduction inducted by water, alley cropping systems should be established along contours. The mentioned study that we found from within the region of CE, was conducted in southern Germany, and it was observing, among other things, erosion and nutrient losses at silvoarable agroforestry system composed of four rows of trees like wild cherry (*Prunus avium*), hybrid walnut trees (*Juglans* spp.) and sycamore (*Acer pseudoplatanus*), and two strips of short rotation poplar (*Populus deltoides x nigra*). Measurements were conducted during November 2009 and April 2010 after torrential rain of up to 25 l/m^2 per day, up to 3.5 l/m^2 per hour or after prolonged periods of rain and after snowmelt. Both at the agroforestry system and at the adjacent arable field with no trees, an experiment was conducted using erosion pans connected with pipes to barrels. Eroded soil was collected in the pans. Results showed that while erosion was detected in the arable field, no erosion was observed within the agroforestry system. On average, within the agroforestry system, phosphorus losses were reduced by up to 70% and nitrogen losses by up to 25% when compared to the adjacent field (Oelke et al. 2013).

In the research that was observing Czech farmers' perception of the provision of ecosystem services provided by woody plants in agroforestry, 44% of the farmers responded that one of their reasons for planting woody plants on cultivated land is that woody plants protect the soil against erosion (Červená et al. 2022). Similarly, in survey conducted by Lojka et al. (2022), also in Czechia, 59% of interviewed farmers agreed that trees within agricultural landscape are important for soil protection.

4.4.2. Agroforestry for soil enrichment

The role of agroforestry in enhancing and maintaining long-term soil productivity and fertility has been widely accepted as a major benefit since its establishment as a scientifically recognized discipline (Nair 2011; Dollinger & Jose 2018). In agroforestry systems of the tropics, it is common practice to incorporate trees and shrubs with the ability to biologically fix nitrogen, which further enhances the potential of agroforestry systems to improve soil quality (Munroe & Isaac 2014). Seiter et al. (1995) found, that this practice can work even in temperate regions, as they demonstrated that 32 to 58% of total N in sweet corn was obtained from N fixed by red alder (*Alnus rubra*) in an alley cropping system in Oregon. The role of both the N-fixing and non-fixing trees and shrubs in the improvement of soil physical, chemical, and biological properties by not only adding above and belowground organic matter and releasing as well as recycling nutrients is a subject of an increasing number of investigations across the temperate regions (Jose et al. 2004).

A study conducted in Germany analysed different soil quality indices such as total nitrogen (TN), soil organic carbon (SOC), microbial biomass N (MBN), and microbial biomass C (MBC) of topsoils at two alley cropping systems within one site: willows (*Salix* sp.) intercropped with grassland and poplars intercropped with rotation of barley, rape, and wheat (Beuschel et al. 2018). They found that the implementation of poplars has increased TN, SOC, MBC-to-SOC, ergosterol-to-SOC as well as ergosterol-to-MBC ratios in soil depth of 0-5 cm within the strips of trees, indicating a higher proportion of saprotrophic fungi to microbial biomass and improved C-use. The effect of willows was found to be less significant if compared to the effect of poplars. Veldkamp et al. (2023) demonstrated, that alley cropping agroforestry with short-rotation trees is able to improve habitat for soil biological activity, as they found, that these systems supported bigger population sizes of bacteria, earthworms, and fungi when compared to open cropland fields.

Enzymes activity was studied by Szajdak et al. (2019) in the West Polish Lowland. They observed the influence of the age of shelterbelts on the activity of urate, phenol, and xanthine oxidase in the soils of two 200 years old and one 25 years old shelterbelts and their adjacent fields. While the young shelterbelt was composed of several different species, one of the old shelterbelts was dominated by black locust (*Robinia pseudoacacia*), and the other old shelterbelt dominant species was the common hawthorn (*Crataegus monogyna*). They found that annual mean activity of urate, xanthine and phenol oxidase were significantly higher in the soils of the two old shelterbelts when compared to both the new shelterbelt and the adjoining cultivated fields, as well as that the age of shelterbelts was the main factor causing differences in enzymes activity. The activity of urate and xanthine oxidase indicated that the soils of old shelterbelts were more effective for the degradation of peptides and purine basis. The soil under black locust had the highest enzymatic activity of all the measured sites. In post-mining areas of eastern Germany, black locust grown in short rotation coppice and alley cropping systems was found to significantly improve the soil fertility by the humus accumulation when compared to the cultivation of lucerne (*Medicago sativa*), which is considered a traditional recultivation crop in this region (Böhm et al. 2011).

A different study demonstrated that even agroforestry systems of age 5-8 years are able to enhance soil quality. Three poplar-based alley cropping systems were studied and the results showed that the implementation of trees in arable land increased microbial biomass and its activity in upper topsoil, fungal abundance as well as soil organic carbon. However, within alleys, they did not find differences in soil quality indices depending on the distance from trees, and therefore authors suggest, that long-term studies are needed to evaluate, whether the beneficial effect of trees extends towards crop alleys when mature (Beuschel et al. 2019). An older study from Slovakia observed the influence of windbreaks on different biological characteristics of heavy soils (Miko et al. 1989). Positive effects of windbreaks on nearby soils of the field were identified, but only to a certain distance from the windbreaks (less than 50m), and the intensity of these effects was dependent on the actual season, with the strongest effects being observed in autumn. Humus content as well as organic C and P, N total were highest amidst the windbreaks and the content decreased with growing distance, with a more expressive decrease on the windward side. Bacterial biomass corresponded to the humus content, also decreasing with the increasing distance from the windbreak more pronouncedly on the windward side.

4.5. Agroforestry for carbon sequestration

Human activities have significantly increased concentrations of atmospheric carbon dioxide (CO_2) which is contributing to climate change (Hofmann et al. 2009). Agroforestry is recognized as a greenhouse gas-mitigation strategy for its ability to sequester C above and below ground (Nair et al. 2009). Trees and woody shrubs in agroforestry systems add C into the soil by litterfall as well as by the decomposition of roots, which happens in deeper layers of soil than under agronomic crops. C is also stored in all plant parts (Lorenz & Lal 2014). While strong evidence of agroforestry's contribution to C sequestration exists from all climatologic regions, it is found that agroforestry systems in the tropics are more effective in C sequestration than those in temperate zones (Feliciano et al. 2018). In temperate regions, differences in SOC sequestration rates are found to be, among other things, determined both by the type of agroforestry systems as well as by present tree species, with agroforestry systems composed of broadleaf species generally contributing to higher SOC sequestration rates than systems composed of coniferous species (Mayer et al. 2022).

In the region of CE, a big part of identified studies are observing systems that included black locusts. When Nii-Annang et al. (2009) evaluated the impact of alley cropping systems of black locust and poplars on post-lignite mine soils of Germany after nine years of recultivation, they found that the content of SOC more than doubled and that it was significantly higher under poplar and black locust when compared to the crop alley planted with rye as well as when compared with the transition zone. The effect of alley cropping on SOC sequestration was generally most significant at the top 3 cm soil layer. Kanzler et al. (2021) studied 6 years of the initial phase of short rotation alley cropping systems' impact on the development of SOC of post-mining sites in Brandenburg, Germany. They annually investigated the hedgerows composed of black locust and crop alleys. They found a significant increase in both the hot-water-extractable organic C (HWEOC) and the SOC in black locust hedgerows, but it was mainly restricted to the uppermost layer of the soil (0-10cm). The accumulation rates of SOC and HWEOC were superior in the hedgerows than in the crop alleys. Higher stocks of SOC and HWEOC were also found in the litter layer of hedgerows. Authors have pointed out that since their results only reflected the initial stage of the systems, future investigations for the determination of long-term effects such as C sequestration in deeper layers are needed. Mazurek & Bejger (2014) observed the impact of black locust shelterbelts on the stabilization of C pools of chernozems in southern Poland. Samples of the soil were taken at different distances from shelterbelts on the adjacent arable land as well as from under the shelterbelts, from a depth of 0-25 cm, in order to determine the spatial arrangement of carbon pools. The highest SOC content and pools were found in the samples that were obtained from the area closest to the shelterbelt.

Figure 5 : An alley cropping agroforestry system with *Robinia pseudoacacia* managed as short rotation coppice on reclaimed mine sites of Lower Lusatia, Germany (Quinkenstein et al. 2012)

Futa (2016) also studied the effect of black locust midfield shelterbelts on the soil. This experiment was conducted in Lublin Upland in eastern Poland and it included two shelterbelts on flat terrain and one shelterbelt on a 15% slope. Samples were obtained from inside of the 5 m wide tree strips as well as from adjacent fields at a distance of 2 and 20 m from shelterbelts, in the depth of 0-20 cm. It was detected that all shelterbelts had a significant influence on SOC sequestration and that C contents of humic substances and fluvic acids decreased with increasing distance from shelterbelts. Field experiments that were conducted by Sun et al. (2018) observed alley-cropping systems with poplars and black locusts incorporated both into the organic farming and integrated farming systems in southern Germany. Experiments revealed that SOC was significantly higher in parcels with organic farming and that the mean SOC was also significantly higher in the systems that included black locusts than the systems with poplars. They concluded that as they observed the additive effect of black locust and organic farming on SOC increase, a combination of alley cropping agroforestry with hedgerows of black locust and organic farming management have a great potential for C sequestering in the soil.

Matos et al. (2011) observed the effects of conversion from silvopastoral to different land use systems on carbon distribution in north-eastern Germany. Four different land use systems were compared: (1) silvopasture composed of apple trees and cattle grazing use for >50 years; (2) grassland use for 4 years after >46 years of described silvopasture; (3) arable land use for 4 years after >46 years of described silvopasture, and; (4) arable land use for >50 years. They found that arable land contained the lowest total organic C (TOC) stock, being 21% lower than stock in the silvopasture system and that after 4 years of conversion, C stocks in arable land with former silvopasture and grassland with former silvopasture were similar to C stock in silvopasture. When the TOC distribution was compared between the 0-10 cm and 10-20 cm layers, silvopasture and grassland soils presented the highest TOC content in the upper layer while no variation was observed in arable land and arable land with former silvopasture land useThe authors concluded that this is probably a result of vertical redistribution of C caused by tillage. Additionally, they suggest that long-term observation should be conducted for better identification of the effect of land use conversion on C stocks. Beuschel et al. (2020) studied the effect of the conversion of poplar-based short rotation coppice to an alley cropping system after one year of conversion. Samples were taken from soils under poplars and the re-converted arable alleyway. They found that partial conversion of short rotation coppice to arable cropping significantly decreased the SOC in the depth of 0-5 cm of alleyways. They discussed that this could be caused by different factors, for example, vertical redistribution of C caused by tillage.

Not only type of management, type of agroforestry system or used tree species influence the carbon stocks. Masoudi et al. (2021) observed the relationship between the circumference of the tree trunk and tree density with different soil chemical properties in the old midfield tree line area at a landscape with chernozems in northern Hungary. Their results showed that the plots that contained more trees and with a higher circumference of trunks provided higher concentrations of SOC. Additionally, they found that the correlation between the tree trunk and SOC was slightly stronger compared to the correlation between SOC and tree density and therefore they concluded that plots that contain older and larger trees can be important for increasing the amount of SOC. High organic C stock was also detected in the karstic soils of the Silica Plateau, southern Slovakia, with a centuries-long agroforestry management record (Ahmed et al. 2012). Samples were taken at a depth of 0-60 cm in the area of a very dynamic mixture of cropland, pastureland, and forestland, and the average overall SOC stock of the area was on average reaching 207.4 Mg ha^{-1}. 66% was found to be stored within 0-30 cm and 34% within 30-60 cm.

Golicz et al. (2021) used different geospatial datasets to estimate the extent of small woody landscape features and agroforestry systems in the agricultural landscapes of Germany and estimated their carbon storage. They estimated that these systems and features represent about 900 000 ha of the total Germany's farmland area and that their carbon storage in SOC and above and below ground biomass is at 111 ± 52 Tg of carbon. They also found that even though these systems and features by their estimates cover only 4.6% of agricultural area, they store about 7.3% of total biomass carbon and SOC of agricultural land in Germany.

Bertsch-Hoermann et al. (2021) have studied scenarios of hypothetical transition to agroforestry systems with wild cherry (*Prunus avium*) in Eisenwurzen, an alpine region in Austria from 2020 to 2050, and quantified above-ground C dynamics inherent to those scenarios. Their results indicated that the transition to silvoarable agroforestry showed a significant amount of sequestered carbon in perennial biomass of up to 3.4 t C ha^{-1} yr^{-1}. Additionally, their calculations also showed a significant reduction in yields. However, authors found that over time, cherry yields would overcompensate for losses in crop and grass yields and concluded that agroforestry implementation in this region qualifies as an option for sustainable mountain agriculture.

4.6. Agroforestry for water management

Agroforestry systems can contribute to the enhancement of water-related ecosystem services mainly because of the ability of trees and shrubs to capture and retain water (Udawatta & Gantzer 2022). It is demonstrated that agroforestry systems are particularly effective in surface runoff reduction (Nair 1993; Carroll et al. 2004; Jacobs et al. 2022). Increased amounts of litter input, the presence of perennial vegetation as well as deeper-reaching root systems positively affect rain interception, infiltration rates, and water holding capacity (Ellis et al. 2006; Pavlidis & Tsihrintzis 2018). Additionally, the creation of a microclimate provided by the presence of trees can further improve the efficiency of water usage. Even though the evapotranspiration of trees is generally greater than the evapotranspiration of arable fields, fields protected by linear agroforestry systems like shelterbelts are found to evaporate less water than open fields (Patro & Zubala 2020). Reduction of wind speed results in reduced water vapor removal from the crop surface which leads to a build-up of moisture around the crop and consequently the surrounding air becomes more humid which declines the rates of evapotranspiration. Wind speed reduction also leads to reduced evaporation of soil moisture, which can on the other hand result in higher evapotranspiration as the plant has more water available to transpire. Moreover, agroforestry systems can reduce heat advection, which can also reduce evapotranspiration (Nuberg 1998; Donnison 2012). Furthermore, agroforestry systems can ensure an even distribution of snow in the winter and gradual melting of the snow in early spring (Gerersdorfer et al. 2009; Kort et al. 2012). Deep roots of trees are also known to be able to transport the water from deeper, moist layers of the soil to drier upper soil layers via roots in a passive mechanism known as hydraulic lift. Water that is lifted by the roots is released mainly during the night when the transpiration ceases and becomes available for transpiration during the day. To what extent the water lifted by trees becomes available to neighbouring plants depends on many factors such as concrete soil conditions, ecosystem type, involved species, and even on whether donor and receiver species share common endo and ectomycorrhizal network (Allen 2007; Bayala & Prieto 2020).

When Nagy et al. (2020) observed soil moisture retention on slope landscapes under three different agricultural land use systems in south-western Hungary, significant differences in moisture dynamics between the three land use types were found, with arable field having the highest risk of drought, while grazing land and particularly tree rows within orchards were found to have high water retention capacity. Although significant water stress conditions were reached even in orchards, orchards were able to mitigate drought conditions more effectively when compared to arable land. They also found that tree rows parallel to the slopes diminished run-offs. Also in Hungary, Kovács et al. (2019) studied the effect of a special type of alley cropping system that intercrops establishing forest, on soil microclimate, and observed the development of seedlings in this system, comparing it to conventional practices of afforestation. They found that soil microclimate was more favourable in the forestry alley cropping system and that it positively affected the development of seedlings. During the drought period, the agroforestry parcel had more favourable soil moisture values and there were no drought damages on seedlings recorded, while in the control plot mortality of seedlings reached 50%. Furthermore, in the following years after the experiment, trees in the alley cropping system had significantly better growing in height, reaching on average up to 21 cm more in height than the trees at the control parcel.

Figure 6 Alley cropping system composed of poplar seedlings intercropped with maize (*Zea mays*) as a strategy for successful afforestation in Kapuvár, Hungary (Kovács & Vityi 2022)

By analysing data records from the agrometeorological station, tensiometers, and soil thermometers Vityi et al. (2018) observed how alley cropping system with fast growing paulownia (*Paulownia tomentosa*) affected the soil microclimate of crop alley at four different depths: 0-10 cm, 10-20 cm, 20-40 cm, and 40-60 cm, within a period of four years of measurements. When compared to the control site at an adjoining open field, the upper layers of soil (0-20 cm) were found to be significantly drier in the open field than at the crop alley, having a more frequent and higher dryness, while the majority of data that was collected in agroforestry system were located within a more favourable range. Authors concluded that already in the first years of cultivation of trees on arable land, the presence of trees has a positive effect on the content of water in the upper soil layers as they are reducing the drying effect of the wind ad direct sunlight.

The effect of black locust shelterbelts on different water-air properties of adjoining arable brown soil was observed by Mazurek & Zaleski (2008) in eastern Poland. They found that soil moisture, soil porosity, as well as field capacity of soil, were decreasing with increasing distance from shelterbelts, while soil density and density of solid soil were increasing with the distance from the shelterbelts. They concluded that such an arrangement of parameters could be connected to the influx of organic matter from trees in zones near the shelterbelts. The importance of shelterbelts in increasing soil moisture by reducing wind speed was also demonstrated by Honfy et al. (2018) on arid sites in eastern Hungary.

Gerjets et al. (2017) studied the soil hydrology of the agroforestry system in Lower Saxony, Germany by measuring soil water potential and soil moisture in crop strips of alley cropping system as a function of distance to the rows of trees at different depths as well as meteorological parameters. This agroforestry system contained both the willow and poplar trees, but each species was in a different tree strip. In May 2016 when a period of dry conditions with less than 2 mm of precipitation within four weeks occurred, authors detected an overall positive effect on hydrological conditions by the agroforestry system, where lower temperature and higher soil moisture were observed when compared to the reference site. Additionally, authors found that the two tree species behaved differently as the strips of poplar showed more pronounced diurnal changes in soil water potential with rapid drying during the day and rewetting during the night and they suggest that the rewetting can be caused by a hydraulic lift which passively adds water from the deeper layers to the drier upper layers of the soil. An older study conducted by Olejnik & Kedziora (1991) showed, among other things, that introducing elements such as windbreaks and shelterbelts to the agricultural landscape could significantly reduce water needs for irrigation.

Somfalvi-Tóth et al. (2019) observed and compared the soil moisture and microclimate of a field protected by a shelterbelt and open field. They found that in the agroforestry plot, heat fluctuation, as well as daily humidity, were higher compared to the control plot, which they concluded was due to a significant decrease in wind speed. Soil moisture measurements showed that in summers, the open field had a greater degree of soil drought than the agroforestry system. A moderate increase in air humidity was also observed by Mužíková et al. (2011) on fields protected by windbreaks in eastern Czechia.

Thaler et al. (2012) made a simulation of the impact of climate change and alternative adaptation options on winter wheat (*Triticum aestivum*) production in a dry climate area of north-eastern Austria. Their results showed that air temperature warming of 2 °C could shorten the winter wheat growing period by up to 20 days and would significantly decrease the potential yields of this crop on almost all of the soil types of the region. However, they predicted that the implementation of hedgerows in combination with reduced tillage could rise the regional mean-yield level of this crop by up to 4% when compared to no management changes in future climatological conditions. Such alternative adaptations would significantly contribute towards reducing the increasing water demand. They suggest that the implementation of hedgerows would have a particularly positive effect on fine-textured soils such as Chernozems and Fluvisols and that the effect of accumulation of snow near hedges could further increase the yields. Winter wheat yields were also observed by Kanzler et al. (2019) in Germany. They studied the microclimatic changes caused by poplar hedgerows of short rotation alley cropping system and their effect on evaporation and the yields of winter wheat in direct comparison to conventional agricultural crop system. They found that in the alley cropping system, the optimal value range of vapour pressure deficit for plant growth was more frequent than in the open field. Their results also demonstrated that Piché evaporation was significantly lower in the agroforestry system than in the open field and the authors suggest, that it indicates that climate conditions in alley cropping led to lower atmospheric evaporative demand. At the same time, the average grain yield within the agroforestry system was 16% higher than on the open field. When Mirck et al. (2016) observed how alley cropping system impacted sugar beet yields in the relatively dry growing season, yields were found to be reduced in close proximity to the hedgerows, which authors suggest can be a result of competition for light and water between the crop and the trees, lack of soil tillage and increased weed competition. However, yields at and beyond the distance of 12 m from hedgerows were higher when compared to the yields of nearby conventional agriculture field, which authors explain is a result of the reduction of evapotranspiration, temperature extremes, erosion, and increased moisture availability. Short rotation alley cropping systems that were observed by Böhm et al. (2013) in eastern Germany were found to be contributing to the establishment of favourable microclimatic conditions for crops and contrary to authors' expectations, at the site, which was assessed as susceptible to drought stress, crop yields were highest at the crop alley edges, in the close vicinity of the trees and therefore authors assumed that the crop has benefited from the higher water availability in this area.

4.7. Agroforestry for cultural services

The contribution of agroforestry systems to the provision of non-material benefits obtained from ecosystems, also known as cultural services, is primarily based on the maintenance and enhancement of landscape aesthetics, tourism, and local recreation but also on the preservation of cultural and natural heritage, including traditional knowledge and local customs of specific regions (Nair 1993; Nair et al. 2017; Moreno et al. 2018). For example, Hertel et al. (2017) observed farmers' perception of values provided by trees of ancient oak wood pastures within a rural region in Transylvania, Romania, and found that while mature scattered trees were primarily appreciated for their tangible values (mainly for their provision of shade for livestock), old trees were appreciated for their intangible values (e.g., beauty and relaxation, age, and cultural identity). Fagerholm et al. (2016) showed that 58% of places that were visited by the population within the studied areas with dehesas in western Spain were directly related to different cultural services such as outdoor recreation, social interaction, and aesthetics. Agroforestry can be also important in relation to spiritual context. In Bali, Indonesia, local agroforestry systems are an important source of religious ceremonial materials (Purba et al. 2020). The contribution of agroforestry to religious values was also identified in local coconut (*Cocos nucifera*) based systems in Odisha, India (Panda et al. 2020).

When Lojka et al. (2022) observed Czech farmers reasoning behind the retention of trees on their agricultural land, 61% of them strongly agreed and 19% agreed that aesthetical function is one of such reasons, which was by far the strongest motivation among these farmers. Rois-Díaz et al. (2018) studied driving factors for the implementation of agroforestry practices by farmers in eight countries of the EU. Both the farmers from Germany and farmers from Hungary responded that tradition and aesthetic values for tourism were among their driving forces for practicing agroforestry. Tsonkova et al. (2018) made qualitative interviews with 32 farmers in Germany with the aim of identifying their opinions on the benefits and downsides of agroforestry implementation. Ten of these farmers mentioned landscape aesthetics and nine mentioned tourism as a positive aspect.

Van Zanten et al. (2016) conducted a choice experiment with photorealistic visualizations of different comparable landscape attributes and they found that visitors of an agricultural landscape in eastern Germany highly valued groups of trees within the landscape as most of them preferred scenarios with a high amount of diversification of the landscape by groups of trees over scenarios of homogenization of agricultural landscape with only small number of trees.

Bezák & Dobrovodská (2019) studied the local inhabitant's perception of traditional agricultural landscape practices in different regions of Slovakia, including the surroundings of Hriňová village, a cadastral area where collectivization never took place and instead association of local farmers managed the land since 1968 almost without any implementation of intensification. This resulted in a very heterogenous agriculture landscape composed of small plots of arable land, mown and abandoned grasslands, orchards, scattered fruit trees, terraces, and non-forest woody vegetation in different spatial compositions. A total of 382 people were interviewed in Hriňová and they mostly perceive their traditional agricultural landscape positively, especially as something that "*constitutes the potential for a tourism industry*" and "*increases the aesthetic landscape quality*".

Figure 7 Mosaic landscape of the surroundings of Hriňová in spring (Belko 2022)

Spáčilová & Středová (2014) that studied windbreaks in Southern Moravia, Czechia, showed that windbreaks can be important for recreational use, especially if they are in the vicinity of human settlements. However, they concluded that the recreational value is directly connected to the presence of paths along the windbreaks as well as the overall condition of windbreaks. In CE, also another linear element, fruit alleys, which were traditionally planted along roads can contribute to the provision of cultural services, mainly by increasing aesthetics of the landscape. Nowadays, their number has decreased and most of the fruit tree alleys exist along low-traffic side roads but there are existing educational and informational campaigns that aim to popularise fruit tree planting, for example, the "Krakow-Moravia-Vienna Greenways" initiative. This international Polish-Czech-Austrian cultural and natural heritage route is a 780 km long bike route that connects important heritage sites and among other things, encourages people that live along this route to plant local fruit tree varieties with the aim of making this route the longest fruit tree alley of Europe (Fortuna-Antoszkiewicz & Lukaszkiewicz 2017).

When Janeček et al. (2019) studied rural agroforestry artefacts in Prague, Czechia, they identified 76 existing freely accessible fruit orchards in the city, with their total area exceeding 130 ha. As the authors found, most of these orchards are still actively managed and therefore they pointed out it is a positive fact regarding their future existence, as they can be important not only in providing environmental benefits but also for recreational functions.

The importance of the cultural and aesthetical value of trees within the agricultural landscape is often reinforced by their size and age, and as Orłowski & Nowak (2007) demonstrated, different marginal habitats within agricultural landscape including hedgerows, mid-field clumps, and shelterbelts are often important places for conservation of tree champions (heritage trees). In their study that covered 5480 ha of the intensively managed agricultural landscape of Lower Silesia, south-western Poland, they identified 493 champion trees and found that the highest number of champion trees was in water-edge hedgerows. 2000 biggest trees (considering girth) of Hungary were observed by Takács & Malatinszky (2021) and they found that 8% of them are growing in wooded pastures, which is a significant number if considering that only a marginal part of Hungary's landscape is under this agroforestry system. As Varga & Molnár (2014) reported, wooded pastures in Hungary are also a place of community gatherings for special occasions such as the May fest and Birds and Trees day. Also in Slovakia, wooded pastures such as Gavúrky protected area are places with a high number of old, previously pollarded trees, especially pedunculate oaks (*Quercus robur*) of which many reach an age of more than 400 years, and provide a landscape with high cultural, natural, and historical value (Wiezik et al. 2018).

As Tóth & Verešová (2018) found in Slovakia, within the agricultural landscape, trees are also likely to reach high age when they are planted as complementary natural monuments of small sacral architecture, where they can contribute not only to the enhancement of aesthetical and cultural but also spiritual values of the landscape. They found that in Slovakia, the most frequent tree species in such places are horse chestnuts (*Aesculus hippocastanum*) small-leaved lindens (*Tilia cordata*), and large-leaved lindens (*Tilia platyphyllos*).

5. Discussion

As only a marginal number of reviews and meta-analyses observing agroforestry's contribution to different ecosystem services include studies from countries of CE, this review aimed to summarise and synthesize evidence from this region. It was found that in general, agroforestry positively contributes to the provision of all five selected ecosystem services which is in line with findings from other regions (Sileshi et al. 2007; Torralba et al. 2016; Shin et al. 2020).

While den Herder et al. (2017) showed, that when using his method, the vast majority of agroforestry systems within CE are silvopastoral systems, in the case of this review, from all identified studies only a marginal proportion studied effects of silvopastures. On contrary, most of the included studies observed contributions of linear systems such as hedgerows, windbreaks, and shelterbelts. This evidence can therefore serve not only as a scientific base for future promotion and establishment of these concrete systems but also of alley cropping systems that are also composed of linear features and hence, to a great extent can have similar impacts on different ecosystem services.

Even though findings from CE show a generally positive effect of agroforestry systems on the provision of all selected ecosystem services, it was found that strong evidence exists that desirable characteristics such as proper spatial distribution, implementation of adequate management and maintenance, diversification of incorporated woody perennials species and other factors can positively enhance and strengthen effects of agroforestry on the provision of all selected services. Therefore, for a more comprehensible summary of different desirable characteristics of agroforestry systems for a stronger effect on the provision of individual ecosystem services, the following table was made (Table 4).

Table 4: Desirable characteristics than can further enhance agroforestry's contribution to provision of different ecosystem services

Ecosystem service	Concretely	Desirable characteristics for further enhancement of the AF effects on ES
Biodiversity conservation	Arthropods, birds, & mammals	Increase in woody perennials species composition, presenting early, mid and late succession stages
		Interconnectivity between the systems and to the natural habitats or their fragments
		In linear AF, increase in width/ number of rows trees
		Avoiding establishment of the systems in close vicinity to high traffic roads
	Plants	Reduction of herbicides in the surrounding area
		Interconnectivity between the systems and to the natural habitats or their fragments
Soil conservation	Wind erosion control	In linear AF, decreased optical porosity by higher density of trees, higher number of rows and incorporation of evergreen species
		Established perpendicularly towards predominant wind direction
		Incorporation of trees with the ability to reach significant height
	Water erosion control	Planting trees along contour lines
	Soil enrichment	Incorporation of trees with ability to biologically fix nitrogen such as *Robinia Pseudoacacia* and *Alnus* spp.
Carbon sequestration		Higher number of trees per plot
		Keeping old trees and leaving trees to reach high age
		Reduced tillage in silvoarable systems
Water management	Soil moisture	Incorporation of trees with higher potential of hydraulic lift abilities
		Decreased optical porosity of linear systems
		Incorporation of deep rooting trees and trees with lower water demand
		Pruning of trees side roots
	Runoff control	Planting trees along contour lines
Cultural services	Aesthetics, recreation & heritage	Proper maintenance of remnants of ancient wood pastures and other traditional systems
		Creation and maintenance of pathways along linear AF systems close to human settlements
		Proper maintenance of champion trees and places with their high concentration
		Incorporation of local fruit tree cultivars

Additionally, the distribution of identified studies between countries of CE was found to be very heterogeneous (Figure 8). By far, most studies originated in Germany (31). Surprisingly, only three studies were identified from Austria, even though Austria is found to have the highest extent of agroforestry within CE countries if expressed as a proportion of UAA (den Herder et al. 2017). Variability related to the amount of found studies for each ecosystem service has been also observed between the countries. For visualization of the distribution of individual ecosystem services within the region, simple maps have been created.

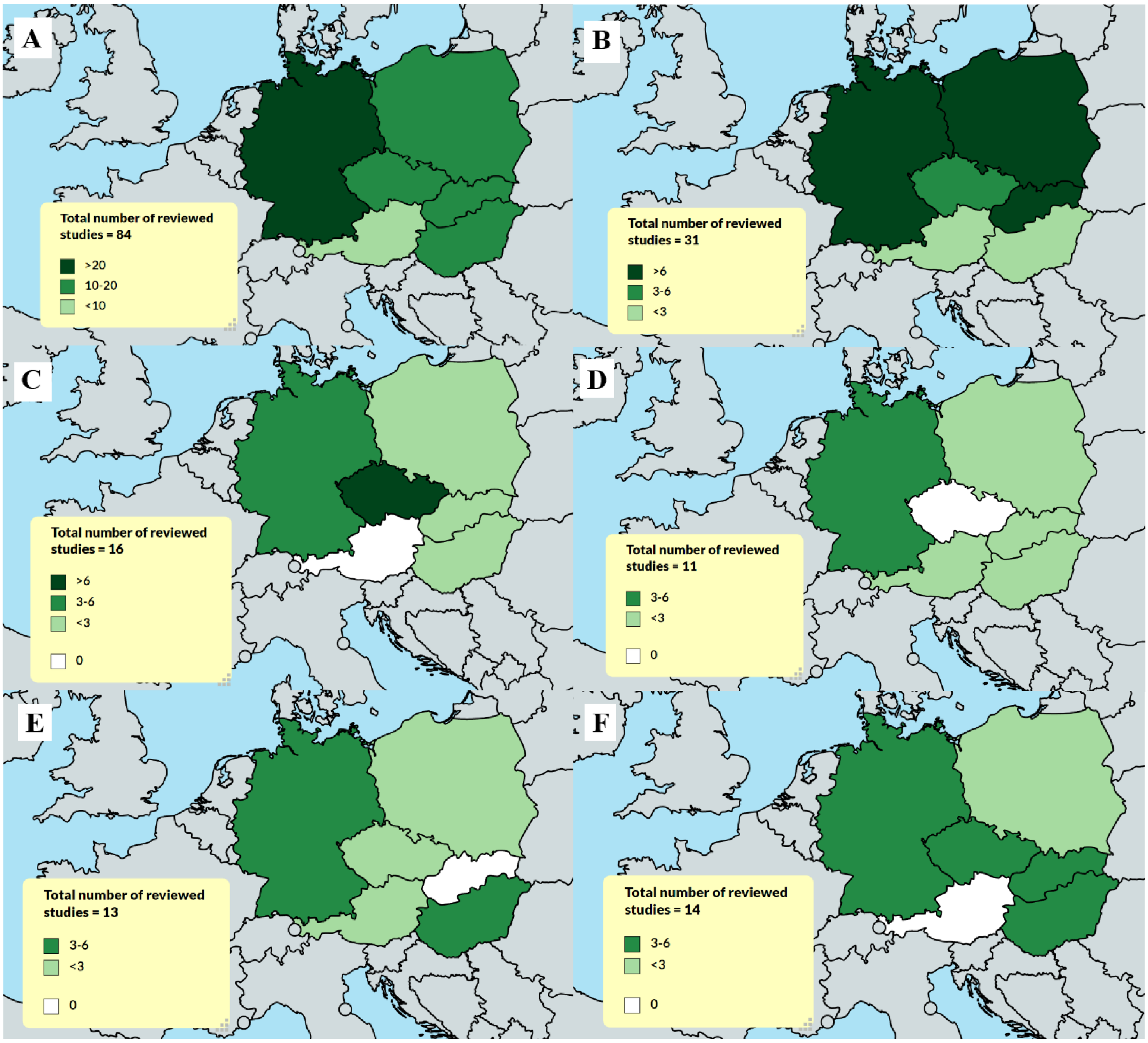

Figure 8: (A); Distribution of all identified studies on AF contribution to selected ES, (B); Distribution of identified studies on AF contribution to biodiversity conservation, (C); Distribution of identified studies on AF contribution to soil conservation, (D); Distribution of identified studies on AF contribution to carbon sequestration,, (E); Distribution of identified studies on AF contribution to water management, (F); Distribution of identified studies on AF contribution to cultural services

From all selected ecosystem services, biodiversity conservation was the most studied one, as it was part of 31 of all 84 identified studies. Overall, a strong positive effect of agroforestry on biodiversity was detected. Particularly high evidence exists on agroforestry's contribution to arthropod diversity, invertebrate animals that form fundamental phylum which includes most pollinators, important nutrient recyclers, and predators of many organisms that are considered agricultural pests. Strong evidence is also found on beneficial contribution to birds, however, one study found higher mortality in systems established in the vicinity to high traffic roads. Some evidence also exists on agroforestry's contribution to mammals, including bat species, nevertheless all but one included only small mammal species. No studies have been found on agroforestry's contribution to other animal taxa. Scientific focus on other classes of animals such as Reptilia and Amphibia could therefore bring a broader picture of agroforestry effects on biodiversity conservation. Three studies showed that plants can also benefit from the presence of agroforestry systems and that linear systems can contribute to their dispersion just as they serve as bio-corridors for animals. We also found strong evidence for all included taxa that interconnectivity between the systems and connectivity to natural habitats can further enhance agroforestry effect on biodiversity. Further enhancement can be achieved also by increasing the diversity of involved woody perennial species, diversity in species typical for different stages of succession and in the case of plants, and also by reduction of used herbicides in the surrounding area of agroforestry systems.

Within the studies observing agroforestry's contribution to soil conservation, the strongest evidence exists on agroforestry potential to control wind erosion. Nine of 16 identified studies observed this effect. However, further enhancement of this effect can be reached if all site specifics are taken into account. In the case of linear systems, it is demonstrated that they should be established perpendicularly towards the direction of prevailing winds. Most studies have observed systems composed of deciduous trees, but the highest risk of wind erosion at arable lands exists in the winter when a big proportion of fields are fully exposed as plant cover is missing. Therefore, more focus on the incorporation of evergreen trees should be considered, as they can maintain the low optical porosity of the systems even in winter. Only one study dealing with agroforestry effect on water conducted erosion has been detected, but in other regions strong evidence exists, especially for systems where trees are planted along contour lines (Roose & Ndayizigiye 1997; Zhang et al. 2008; de Aguiar et al. 2010)

Some evidence exists also on agroforestry's contribution to soil enrichment, but a large part of these studies show that this effect is strong only under the trees and close to the trees, with some extension of the effect on the leeward side of the systems, where more litterfall can accumulate. Just as in the case of studies observing agroforestry effect on carbon sequestration, a big part of these studies were looking at the effect of systems that were composed of black locusts. However, the incorporation of black locust can be controversial, as in Europe it is a non-native species that is considered invasive and known for its allelopathic effects. More focus could be therefore given to the incorporation of common alder (*Alnus glutinosa*), a native tree species that is also able to fix nitrogen, because of its symbiotic relationship with the bacteria *Frankia alni.* We did not identify any study from the region that would include common alder, however evidence from other regions on *Alnus* spp. contribution to soil enrichment exists (Seiter et al. 1995; Rhoades et al. 2001).

In the case of carbon sequestration, 11 studies have been identified and they show overall positive effects of agroforestry. However, like in the case of soil enrichment, SOC is generally increased in the vicinity of trees, which is also mainly connected to the limited ability of litterfall distribution. Therefore, if increasing SOC is the objective, trees with the ability to reach significant height could be incorporated for a higher range of litterfall distribution, or a higher density of planted trees should be considered. If carbon sequestration for long periods is the main objective, trees should be planted mainly with the vision of using them for non-timber production like fruit production or timber production where timber is a raw material used for durable products, such as furniture or as a building material.

More effective water management is also found to be provided by agroforestry systems, as 13 studies from CE indicate. The increase in soil moisture is mostly connected to wind speed reduction provided by trees, and trees can also work as an effective barrier against water runoff, providing better infiltration. Many variables enter this process and one of concern is the potential competition for water between the trees and crops in the case of silvoarable systems. Studies from CE suggest that while some reduction of yields in the vicinity of trees can happen, yields at certain distances from trees can be higher than those of open arable fields, as trees can provide favourable microclimatic conditions and protect the crop from drought stress. If below-ground competition is a big concern, trees' root pruning could be considered (Siriri et al. 2013). However, none of the identified studies from CE included this practice. Furthermore, the incorporation of deep-rooting trees or trees that are effectively able to redistribute water to their surroundings by the passive movement of water known as hydraulic lift could further decrease the competition for water. While in gathered studies, only one has observed the possible effect of hydraulic redistribution, in general, this process is gaining increasing scientific attention for its possible implementations in mixed systems such as agroforestry (Caldwell et al. 1998; Bayala & Prieto 2020).

In total, 14 quantitative and qualitative studies from CE also suggest the important contribution of agroforestry to the provision of cultural services. Trees on agricultural landscapes and the heterogeneity of landscape that trees provide positively affects the aesthetical, recreational, and even heritage values of traditional landscapes. This contribution is found to be valued both by farmers as well as by local inhabitants and visitors of landscapes with agroforestry. Just as other selected ecosystem services, cultural services can be further enhanced by management practices, the level of maintenance of existing systems, and other desirable characteristics.

6. Conclusions

Information obtained from identified studies that originate from CE countries showed an overall positive effect of agroforestry systems on the provision of all five selected ecosystem services. Agroforestry was found to be particularly effective in contributing to biodiversity conservation, but it was demonstrated that significant evidence within this region also exists on agroforestry systems' ability to protect soil from degradation, provide more effective water management, store more carbon when compared to conventional arable agriculture and that provision of cultural services should not be underestimated as they are found to be highly valued both by farmers as well as by local inhabitants and visitors of landscapes with agroforestry. Additionally, it was demonstrated that agroforestry effects on each ecosystem service can be further enhanced if proper management, spatial and species composition, maintenance, and other desirable characteristics are applied. The distribution of individual studies between the countries was found to be heterogenous, with by far the most studies originating from Germany, and the fewest studies from Austria. Furthermore, variability between the countries was also identified in relation to the number of studies for individual ecosystem services.

Even though sufficient evidence exists for agroforestry's contribution to the provision of different ecosystem services, including within CE; it is not consistently adopted by individual national strategies. However, agroforestry is already promoted by various European Union policies and strategies, such as the European Green Deal and the Farm to Fork Strategy. Therefore, power at the national level should enforce or motivate farmers by, for example, incentives or subsidies, to implement sustainable and environmentally friendly practices and systems for meeting the goals connected to dealing with current urgent challenges, such as climate change.

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