Agroforest Syst (2025) 99:246
https://doi.org/10.1007/s10457-025-01352-z

Effects of tree features on hydrophysical soil properties in European agroforestry systems: systematic review

Anna Mária Mitrová · Tomáš Vichta · Petr Zapletal · Jiří Volánek · Štěpán Neubauer · Valerie Vranová

Received: 26 March 2025 / Accepted: 23 September 2025

Abstract Hydrophysical soil properties are critical determinants of agricultural sustainability and ecosystem resilience. These properties influence soil–water dynamics, nutrient cycling, and overall soil health. Although the potential of agroforestry to mitigate soil degradation is well-established, a comprehensive synthesis of its effects on hydrophysical properties in European contexts has been lacking. This review systematically analyzes 40 studies examining the effects of woody vegetation in European Agroforestry Systems (EAFS). Findings reveal that woody components generally enhance hydrophysical soil properties across diverse EAFS. A consistent decrease in bulk density and increase in porosity were reported, leading to improved water infiltration, retention, and storage capacities. Hedgerows and shelterbelts were particularly effective in increasing hydraulic conductivity and mitigating surface runoff and erosion, with positive effects localized near woody vegetation. Silvopastoral systems demonstrated significant improvements in soil water content and infiltration rates, particularly in Mediterranean regions. However, variability was evident, influenced by tree age, species composition, spatial configurations, and management practices. Critical research gaps were identified, including limited data on subsoil dynamics, geographic biases favouring Mediterranean systems, and methodological inconsistencies across studies. Addressing these gaps through standardized protocols and multidisciplinary approaches is essential to fully realise the potential of EAFS in enhancing soil functions and adapting agro-ecosystems to climate challenges. Implementing tailored management practices that consider local climatic and edaphic conditions is essential for maximizing the hydrological and ecological benefits of EAFS.

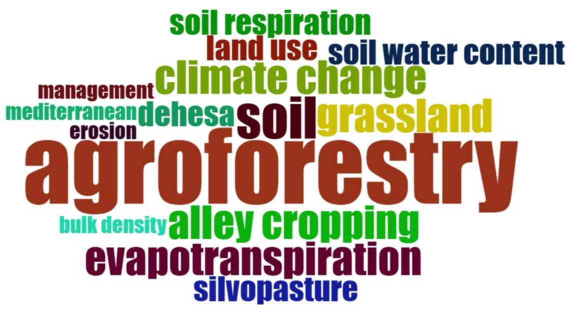
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10457-025-01352-z.

A. M. Mitrová (✉)
Department of Silviculture, Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic
e-mail: anna.mitrova@mendelu.cz

T. Vichta (✉) · P. Zapletal · J. Volánek · Š. Neubauer · V. Vranová
Department of Soil Science, Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic
e-mail: tomas.vichta@mendelu.cz

Published online: 04 October 2025

Graphical abstract



Keywords Agroforestry · Soil · Europe · Hydrological soil properties · Physical soil properties

Introduction

Soil hydrophysical properties play a crucial role in agro-ecosystem functioning and farm revenues, offering significant ecological and economic benefits (Grover et al. 2024). Properties, such as water retention and hydraulic conductivity, are essential for soil–water interactions and transport of dissolved compounds (Bakker et al. 2019; Zhu et al. 2020). Unfavourable soil structure, high clay content or poor aggregation, high bulk density and low porosity are strongly linked with enhanced erosion processes, increased runoff and low infiltration rates (Cardoso et al. 2013; Blanco and Lal 2023), thereby influencing overall soil health and agricultural productivity (Sassenrath et al. 2018; Lehmann et al. 2020). Increased bulk density, influenced by inherent soil properties (e.g. texture, mineral composition) or resulting from agricultural operations but also other land management practices, directly affects crop root development and soil water dynamics (Dexter 2004). Additionally, available water capacity and texture have been proven to strongly correlate with biomass production (Hatfield and Dold 2019; Priori et al. 2019). Consequently, enhancing these properties is imperative for the long-term viability of agriculture and the rehabilitation of ecosystems (Delgado and Gómez 2016).

Common land management practices can rapidly degrade soil properties, potentially leading to long-term soil deterioration (FAO and ITPS 2015; Rees et al. 2018). Land use change and agricultural intensification in Europe have placed significant pressure on soil health, accelerating ecological degradation. The anthropogenic pressure on agroecosystems has been apparent especially in the last decades (Bridges and Oldeman 1999; Stoate et al. 2009). This trend underscores the urgent need for sustainable management practices and ecosystem restoration strategies (Cardoso et al. 2013). Agroforestry can mitigate aspects of soil degradation by improving hydrophysical soil functions (e.g., enhanced infiltration/topsoil hydraulic properties near hedgerows) (Holden et al. 2019; Ivezić et al. 2021; Majaura et al. 2024). Studies show that agroforestry systems can also restore degraded lands, improve water conservation, and enhance soil fertility (Jose 2009; Fagerholm et al. 2016; Torralba et al. 2016) in some cases increasing farm revenues (Staton et al. 2022; Thiesmeier and Zander 2023). Additionally, agroforestry practices contribute to biodiversity restoration and mitigate climate change impacts (Mayer et al. 2022; Staton et al. 2022).

However, agroforestry systems are inherently complex, exhibiting high spatial and temporal variability (Gordon and Jose 2008). The wide range includes systems with mixed arrangements, typical for silvopastoral systems (dehesas, montados), or zoned, with lines typical for alley cropping or hedgerow systems (bocage) (McAdam et al. 2008). This broad interface comes with intricate interactions between components. The presence of woody plants, particularly their root systems, plays a crucial role in shaping hydraulic soil properties, such as through the hydraulic lift (Fernández et al. 2008; Inurreta-Aguirre et al. 2022; Thompson et al. 2010). One of the primary challenges in agroforestry management, especially in temperate regions, is competition for water between trees and crops (Jose et al. 2004). On the other hand, the integration of deep-rooted woody species can provide benefits, such as the hydraulic lift of water resources that are inaccessible to annual crops (Ludwig et al. 2003; Hirota et al. 2004; Thompson et al. 2010); increase in hydraulic conductivity resulting in higher infiltration rates (Carroll et al. 2004); and overall increase in soil water storage capacity (Cubera and Moreno 2007; Quinkenstein et al. 2009). Nevertheless the extent of these effects varies significantly depending on vegetation type, spatial arrangement, and climatic conditions (Moreno Marcos et al. 2007;

Rigueiro-Rodróguez et al. 2009; Schnabel et al. 2013; Kumar et al. 2022).

Along these lines, research on the hydrophysical impacts of woody vegetation has yielded promising but fragmented findings. Existing studies often compare agroforestry systems to monocropping (Ivezić et al. 2021; Majaura et al. 2024), while comparative analyses with forested systems, which share similar natural conditions, are scarce. The extent to which woody vegetation influences hydrophysical soil properties in EAFS is still not fully understood. Therefore, this review aims to synthesize the current knowledge on the effects of woody vegetation on hydrophysical soil properties in EAFS, identify key knowledge gaps, and highlight methodological shortcomings. Ultimately, the goal is to provide practical insights to inform experimental designs and guide agroforestry management strategies.

Methodology

Research question and management of the systematic review

The first step of this review development was the definition of our research question: "According to the literature, how does woody vegetation in European Agroforestry Systems affect hydrophysical soil properties? "

The systematic review followed a predefined Protocol (see Supplementary material) based on the PICO framework, using Covidence software for reference management, article screening and PRISMA diagram creation. To ensure transparency and completeness in reporting, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were used to structure and document the review process (Page et al. 2021). All processes were planned and recorded in The Systematic Review Protocol.

Literature search strategy and information sources

To comprehensively identify relevant studies, a structured search strategy was developed based on primary concepts central to the research question: agroforestry, hydrophysical soil properties and geographic focus on Europe.

Two scientific databases, Scopus (Elsevier) and Web of Science (Clarivate), were searched using a predefined query combining keywords, synonyms, and controlled vocabulary related to the primary concepts:

- Agroforestry systems: Covered through terms like "agroforest*", "silvopast*", "hedgerow*", "alley cropping", etc.
- Hydrophysical soil properties: Addressed with terms like "porosity", "hydraulic conductivity", "bulk density", "infiltration", "soil water content", and more.
- Geographic focus: Filters applied to limit results to studies from Europe.

The search was conducted on 13th of June 2024 using following string for Web of Science:

((ALL = (agroforest* OR agropast* OR agrosilvopast* OR silvoarable OR silvopast* OR "isolated tree*" OR "landscape tree feature*" OR "nature based solution*" OR "scattered tree*" OR "tree* outside forest*" OR "farm tree*" OR "alley cropping" OR hedgerow* OR "living fence*" OR "meadow orchard*" OR windbreak* OR "riparian woodland*" OR "riparian buffer strip*" OR shelterbelt* OR "living fence*" OR "woody vegetation" OR "short rotation coppice*")) AND ALL = ("hydraulic conductivity" OR "preferential flow" OR "soil water content" OR infiltration OR "soil organic matter" OR "bypass flow" OR "soil health" OR "soil water retention" OR "pF curves" OR "soil temperature" OR "bulk density*" OR "soil microbial communit*" OR "soil water storage" OR drainage OR porosity OR "soil physical propert*")).

For Scopus ALL = () was replaced with TITLE-ABS-KEY.

To ensure the inclusion of primary studies from Europe, search filters were applied based on study characteristics, as summarized in Table 1.

Study characteristics

To outline the current scientific knowledge about the effects of tree features on hydrophysical soil properties in EAFS and to identify its main approaches and shortcomings, inclusion and exclusion criteria were

Table 1 Inclusion and exclusion criteria applied in the systematic review, structured according to the PICO framework (population, intervention, comparator, outcome)

Component	Inclusion criteria	Exclusion criteria
Population	Studies focusing on agroforestry systems in Europe, including field experiments, comparative studies, and simulation studies with field data	Review papers, meta-analyses, systematic reviews Modelling studies without any field experiment
Intervention	Studies addressing hydrophysical soil properties such as bulk density, porosity, soil water, soil texture, infiltration, hydraulic conductivity, and preferential flow; in Silvoarable, Silvopastoral, Hedgerows/Shelterbelts or Other similar systems	Other systems that are not agroforestry. Studies solely focused on other soil properties (i.e. biological, chemical)
Comparator	Studies including both agroforestry plots and control plots (e.g., grassland, forest, or monocrop) or retrospective studies documenting land-use change	Studies without control plot and/or a documented baseline
Study characteristics	Articles (primary research) in English language Publication Years: 0–2024 Location: Europe	Other types of publications (conference abstracts, reports); non-English language publications; Outside Europe
Outcome	Studies reporting Effects of tree features on hydrophysical soil properties in European Agroforestry Systems	Relevant studies with data on hydrophysical soil properties in agroforestry systems but without findings on effects of woody vegetation on these soil properties

applied. The criteria followed the PICO framework, focusing on study type, population, intervention, comparator, and outcome measures.

Only primary research articles reporting hydrophysical soil properties in European agroforestry systems were included in the synthesis. Review papers were consulted only for context but excluded from screening and data extraction.

Screening

The Scopus database retrieved 884 studies and The Web of Science database retrieved 1058 studies. A total of 1942 references were imported to Covidence for screening as 1942 studies. 6 duplicates were identified manually, and 414 duplicates were identified by Covidence. 1522 studies were screened against title and abstract. 1440 studies were excluded and 82 studies assessed for full-text eligibility. Full-text screening was conducted for studies meeting preliminary eligibility, and reasons for exclusion were documented (see Table 4 for the list of excluded full-text articles and reasons). Finally, 40 studies were included for data extraction (Fig. 1).

Four reviewers were involved in the screening process, for both Title and Abstract screening and Full text stage. To ensure objectivity and reduce the risk of bias, the screening was undertaken in duplicate and conflicts were resolved by consensus.

Data extraction

Henceforward, all processes were performed manually in the MS Excel environment. Relevant information from included studies was collected and recorded by the team into an MS Excel Sheet. Extracted data were categorized into 4 main themes: General information, Location and Natural conditions, System components and Management, Methodology and findings (see Tables 2 and 3 in the Supplementary Material: Table 2 provides general study characteristics and Table 3 presents the detailed extracted information forming the basis for synthesis). This structure enabled effective analysis of the studies without the need to revisit the original sources. Each study extraction was then proofread by at least two reviewers.

Data analysis

A narrative synthesis of the included studies was conducted to qualitatively describe the reported effects of woody components on hydrophysical soil properties. In addition, other soil properties influencing the study area, such as texture, were considered where relevant, particularly when hydrophysical properties were only addressed peripherally. The process involved systematically extracting and comparing study findings to identify common patterns and divergences. The extracted information is presented in tabular (Tables 2 and 3) summaries, organized by agroforestry system type and the corresponding woody vegetation component: Silvoarable alley cropping, Silvopastoral, Hedgerows/Shelterbelts and Other systems.

The categorization of the studies according to the type of agroforestry system was conditioned by the typical spatial arrangement of woody components in the respective systems. Silvopastoral systems were characterized by a scattered or alley arrangement, which differed markedly from densely planted Hedgerows/Shelterbelts, which are typically located at field boundaries and planted densely. Silvoarable alley cropping was characterized by linear planting of woody plants with inter-rows designed for field crop production with periodic soil disturbance (Fig. 2).

Studies were also categorized according to their location in Northern or Southern Europe. Systems from Southern Europe were assessed separately due to their significant different agroclimatic conditions (Metzger et al. 2005), particularly water availability limitations (Moreno Marcos et al. 2007; Schnabel et al. 2013).

Furthermore, a quantitative descriptive analysis was performed to summarize the number of studies addressing specific properties, agroforestry system types, and tree characteristics, and to visualise these patterns in figures.

For each study, the measurement technique used for each hydrophysical property (e.g. infiltration tests, saturated hydraulic conductivity in situ vs. on cores, soil water content by TDR/gravimetry, water-retention curves) and the sampling depths were recorded. Given the between-study heterogeneity in techniques, depths and monitoring designs, a formal meta-analysis was not undertaken; findings were synthesised narratively and via descriptive counts/figures.

Finally, a bibliometric analysis of the 40 included studies was conducted, and visualizations were generated with the Bibliometrix software (Aria and Cuccurullo 2017). Specifically, the following were produced:

1. Most-cited countries (Fig. 3);
2. A keyword/title co-occurrence network (Fig. 4);
3. Thematic map derived from co-word analysis (Fig. 5);
4. Most-relevant sources (Fig. 6);
5. Annual scientific production (Fig. 7).

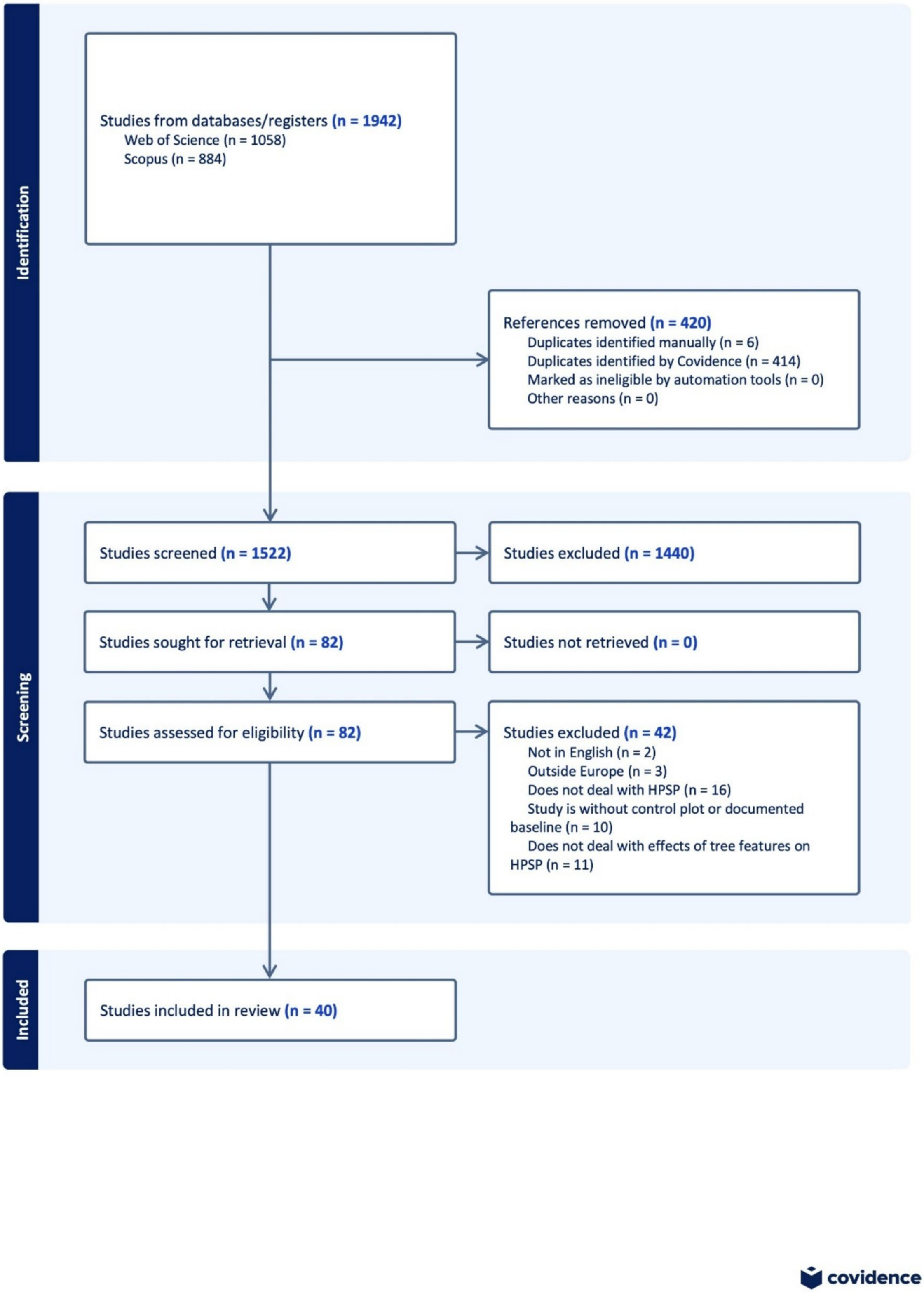
Prior to analysis, bibliographic fields were harmonised (lowercasing, removal of punctuation/diacritics) and duplicates removed.

Quality assessment and limitations

To evaluate the methodological quality of the included studies, we considered several aspects relevant for agroforestry research: (i) study design (field experiments vs. laboratory or modelling approaches, inclusion of a comparator such as adjacent treeless plots), (ii) sample size and replication (number of plots, transects, or measurements), and (iii) study duration (short-term measurements vs. multi-year monitoring). No strict minimum thresholds were applied for sample size, as the diversity of agroforestry contexts and measurement approaches precluded the use of a uniform cut-off. Instead, these criteria were taken into account when interpreting the strength and reliability of the reported findings. The review was limited to studies published in English and indexed in the selected databases. Potential biases may exist due to exclusion of grey literature and non-English studies.

Results

Throughout the Results, the number of studies supporting each statement is conveyed by the number of in-text citations accompanying that statement; category-level totals (studies per system and per hydrophysical property) are summarised in Fig. 2. Study-level details are reported in Tables 2 and 3 (Supplementary Material) provides the dataset extracted from each included study. These data


Identification
Studies from databases/registers (n = 1942)
Web of Science (n = 1058)
Scopus (n = 884)
References removed (n = 420)
Duplicates identified manually (n = 6)
Duplicates identified by Covidence (n = 414)
Marked as ineligible by automation tools (n = 0)
Other reasons (n = 0)
Screening
Studies screened (n = 1522)
Studies excluded (n = 1440)
Studies sought for retrieval (n = 82)
Studies not retrieved (n = 0)
Studies assessed for eligibility (n = 82)
Studies excluded (n = 42)
Not in English (n = 2)
Outside Europe (n = 3)
Does not deal with HPSP (n = 16)
Study is without control plot or documented baseline (n = 10)
Does not deal with effects of tree features on HPSP (n = 11)
Included
Studies included in review (n = 40)
covidence

◂**Fig. 1** PRISMA flow diagram. PRISMA flow diagram showing identification, screening, eligibility assessment and final inclusion of studies in the review; numbers indicate record counts at each step and reasons for exclusion

serve as the basis for the narrative and quantitative synthesis presented in the following sections.

Of the 40 included studies, 35% (n = 14) examined hedgerows/shelterbelts, 32% (n = 13) silvoarable systems, 30% (n = 12) silvopastoral systems, and 3% (n = 1) other systems (Fig. 2). A large share of studies was conducted in Northern Europe (n = 23). In terms of citations, France accounted for 759 citations, followed by the United Kingdom (320) and Spain (127) (Fig. 3). The co-occurrence network of authors' keywords and title terms highlights Mediterranean systems as a recurrent theme (Fig. 5). Annual scientific production is shown in Fig. 7, and most relevant sources are provided in Fig. 6.

From the perspective of experimental design, the included papers mostly compared agroforestry plots with monocropped treeless controls, typically located in the adjacent fields or pastures. Comparisons with forested reference systems were rare and identified only once in our dataset (Candel-Pérez et al. 2024). Designs were predominantly plot- or transect-based with limited randomisation and modest replication, and landscape-scale hydrological monitoring was uncommon.

Across studies, infiltration was most often assessed by ring infiltrometers or rainfall simulation; saturated hydraulic conductivity was measured either in situ (e.g. permeameter) or on undisturbed cores in the laboratory; soil water content was typically determined by TDR/portable probes or gravimetrically; and water-retention characteristics were obtained from laboratory pF/pressure-plate methods. Sampling focused predominantly on topsoil (0–30 cm), with far fewer measurements in the subsoil (≥ 50 cm), and monitoring was largely short-term (seasonal or within-year campaigns), while multi-year or continuous high-frequency records were rare. These patterns, detailed for each study in Tables 2 and 3, limit strict cross-study comparability and underpin our choice of a narrative/descriptive synthesis.

Effects of trees in silvopastoral systems on HPSP

Studies from Northern Europe report consistent improvements in hydrophysical soil properties (HPSP) in silvopastoral systems (Wairiu et al. 1993; Lunka and Patil 2016; Manevski et al. 2019; Murphy et al. 2021). The most emphasized improvements included increased soil water content (Manevski et al. 2019; Murphy et al. 2021), enhanced soil infiltration capacity and/or rates and better soil water rentention (Lunka and Patil 2016; Murphy et al. 2021). Conversely, one study found lower soil water content in silvopastoral and woodland sites compared to pastures, with the driest soil below silvopastoral trees (Upson et al. 2016).

Additional positive effects, such as on soil porosity and hydraulic conductivity, were also attributed to the integration of a woody component (Wairiu et al. 1993; Manevski et al. 2019). Studies from Mediterranean agroforestry systems were mostly circled around the issue of water availability limitations and were variable in the hydrophysical findings. The presence of trees clearly modified soil moisture, especially in close proximity to the trees (Joffre and Rambal 1993; Uribe et al. 2015; Sanna et al. 2021; Candel-Pérez et al. 2024). Both decreases (Uribe et al. 2015; Rolo and Moreno 2019; Candel-Pérez et al. 2024) and increases in soil water content/soil water moisture (Joffre and Rambal 1993; Sanna et al. 2021) were observed in different management, spatial distribution, and tree/shrub species contexts.

Positive effects on water infiltration, water retention, and compaction were documented or suggested as a result of improved physical properties: for instance a decrease in bulk density (Joffre and Rambal 1993; Ferreiro-Domínguez et al. 2016; Upson et al. 2016; Candel-Pérez et al. 2024).

Effects of trees in silvoarable alley cropping systems on HPSP

Limited number of papers—only three—dealt with silvoarable alley cropping agroforestry systems in Northern Europe, out of which only one directly measured soil water content (Medinski et al. 2015). The remaining studies either utilised soil conductivity measurements or did not provide quantitative results. Consequently, the effects on HPSP in this region remain poorly documented.

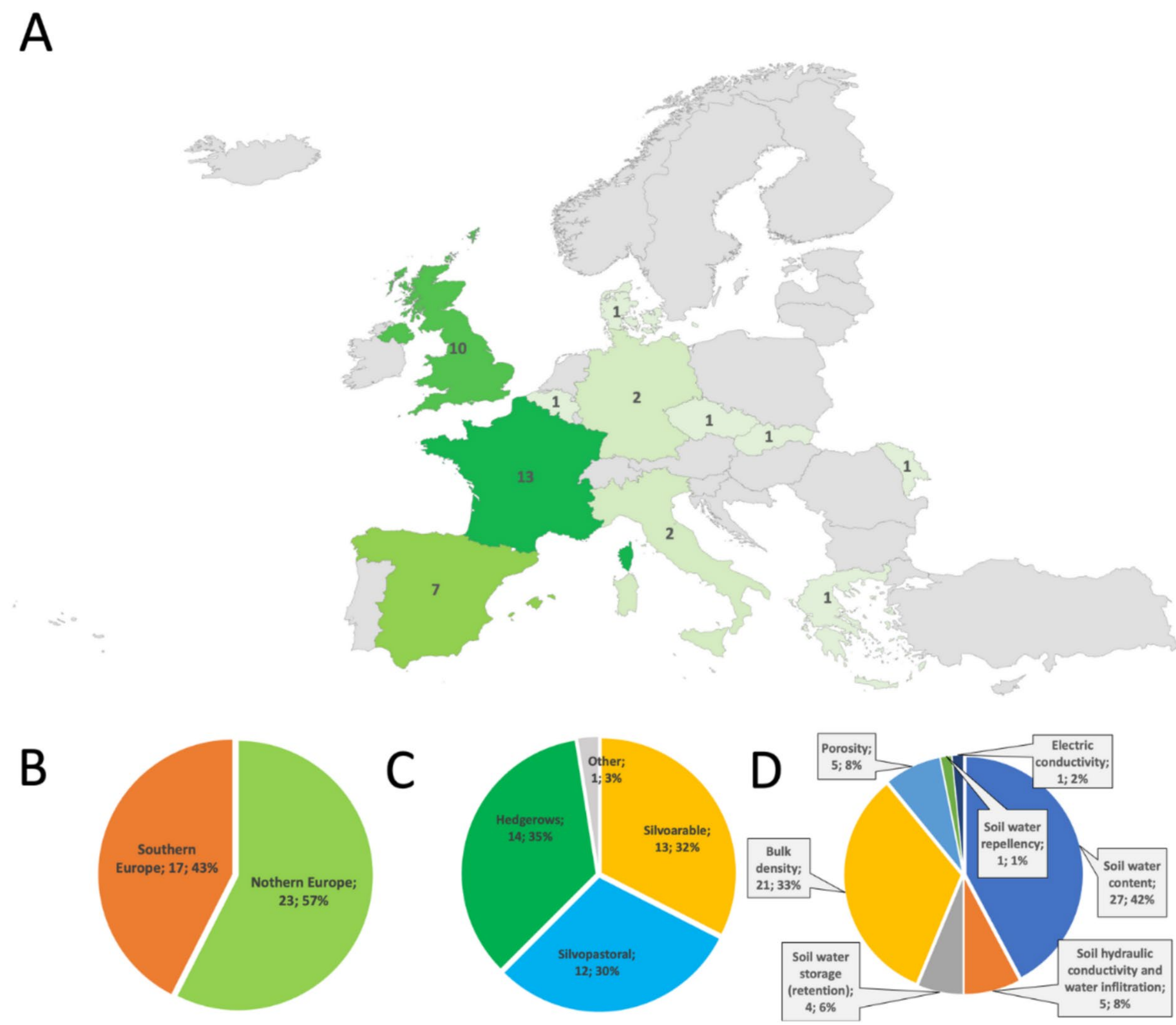


Fig. 2 Geographic and categorical overview. **A** Geographic distribution of included studies by country (darker green = more studies). **B** Share of studies in Northern vs Southern Europe. **C** Proportion of studies by agroforestry system type. **D** Frequency of investigated hydrophysical soil properties. Colours in the pie charts are independent of the map shading

Among the silvoarable systems in Southern Europe, integration of woody components led to HPSP improvements. Positive changes in HPSP were observed especially in the tree rows of the alley cropping systems. Quantitative changes included particularly increased soil water content (Clivot et al. 2020; Inurreta-Aguirre et al. 2022; Mettauer et al. 2023) and improved infiltration capacity (Mettauer et al. 2023). The improvement of HPSP can be attributed to the enhancement of physical soil properties: bulk density decrease (Cardinael et al. 2015, 2017) or soil structure improvement (Mahieu et al. 2016; Mettauer et al. 2023), that can potentially lead to soil compaction decrease and porosity increase (Cardinael et al. 2015; Mahieu et al. 2016).

Even young alley cropping systems (< 5 years old) can develop deep fine roots, contributing to soil water use optimization (O'Connor et al. 2023). However, the increased water uptake by young trees can intensify soil drying effects (Clivot et al. 2020; Mettauer et al. 2023), also in deep soil layers (O'Connor et al. 2023). Decreased soil moisture in tree rows, compared to interrows or monocropping systems, was observed in the early stages after

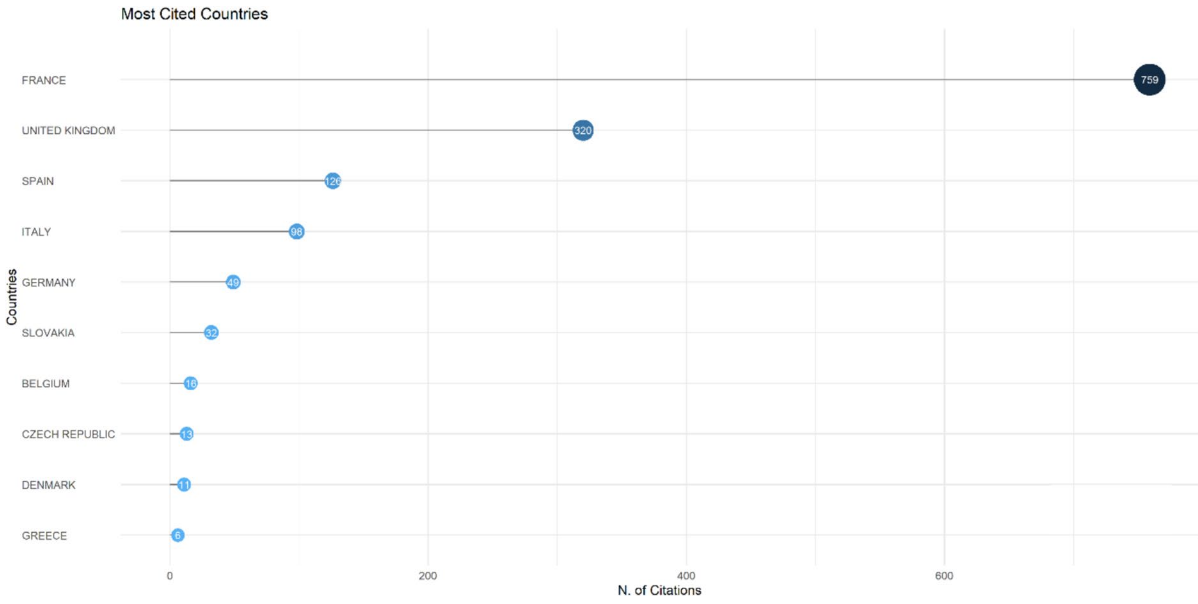


Fig. 3 Most cited countries. Total citation counts by authors' affiliation country for the included records (bubble size scales with citations)

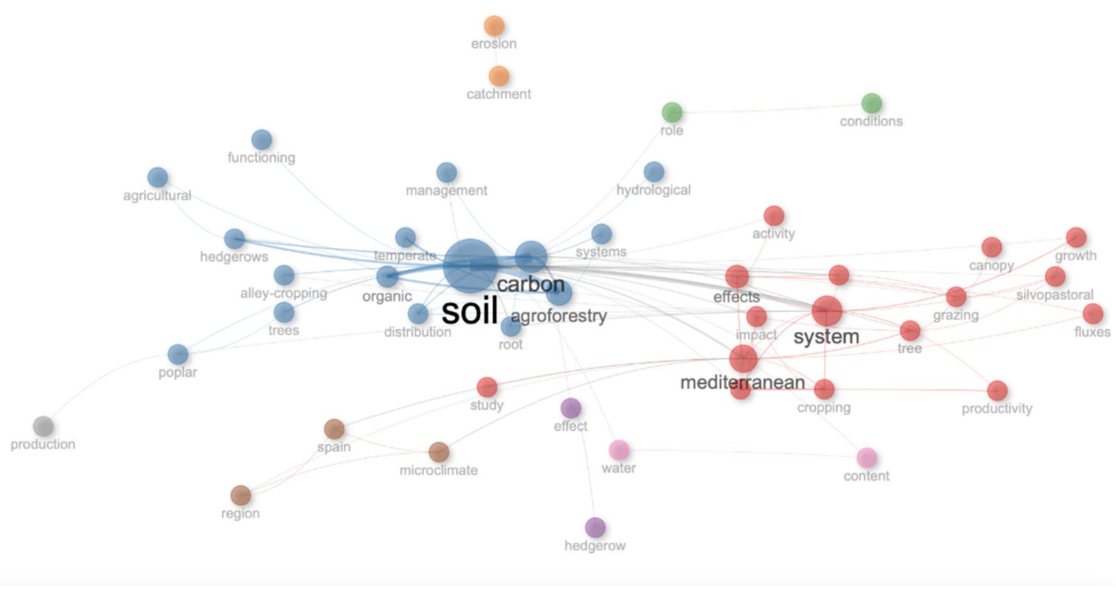


Fig. 4 Keyword/title co-occurrence network. Co-occurrence network of authors' keywords and title terms from the included studies (node size = term frequency; edge thickness = co-occurrence strength). 'Carbon' appears because many papers list SOC/carbon in their metadata; SOC was not a target variable of the hydrophysical synthesis

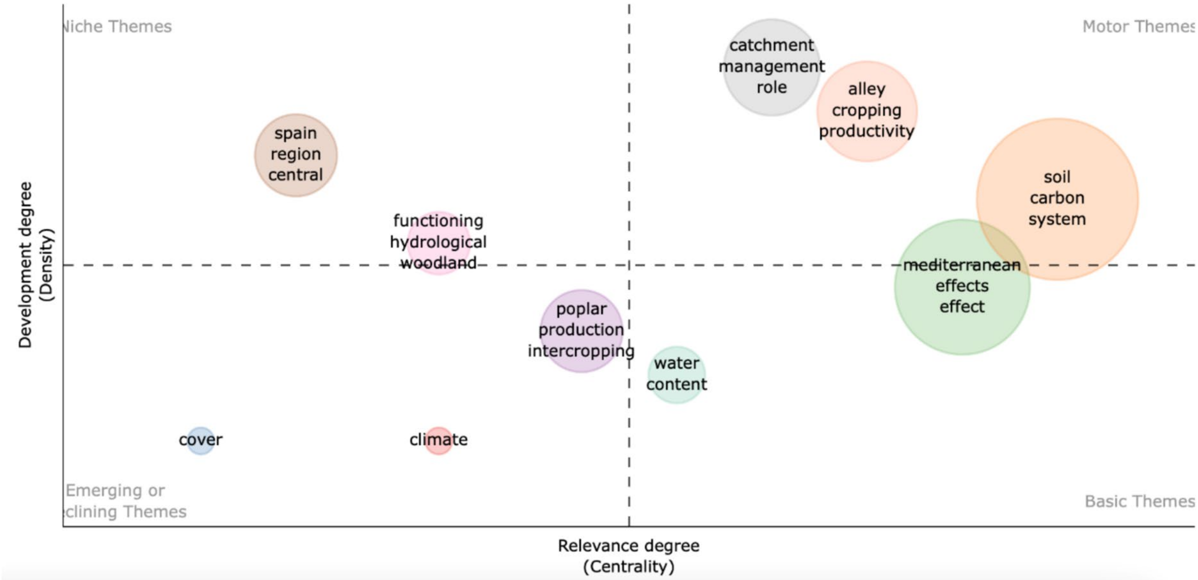


Fig. 5 Thematic map. Thematic map derived from co-word analysis (axes: centrality and density) identifying motor, basic, niche, and emerging/declining themes; clusters are labelled by their most representative terms

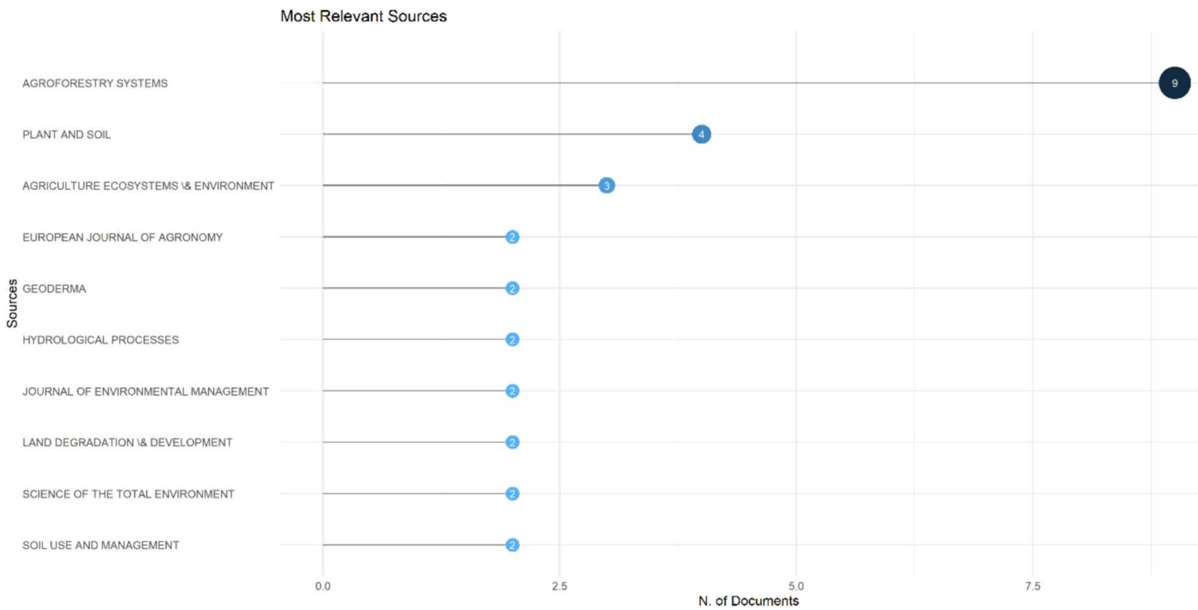


Fig. 6 Most relevant sources. Journals hosting the included records, shown as number of documents per source

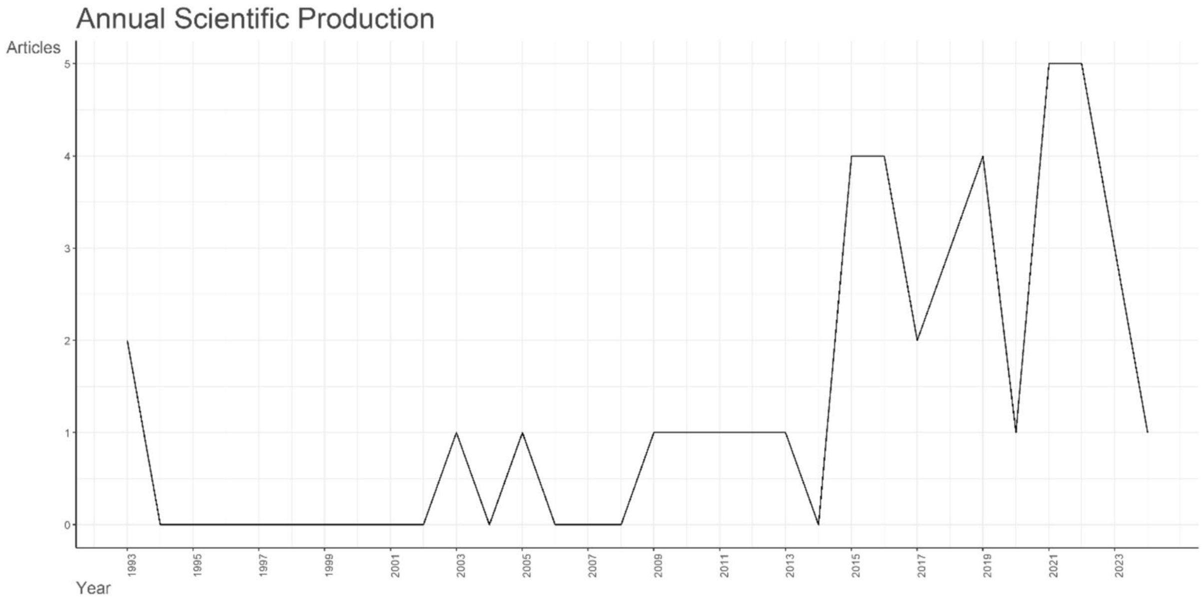


Fig. 7 Annual scientific production. Number of included publications per year

system establishment (Clivot et al. 2020) or during summer periods with prevalent dry conditions (O'Connor et al. 2023). Eventually, over time, the same systems contributed to higher soil water content (Clivot et al. 2020).

Effects of hedgerows/shelterbelts in agroforestry systems on HPSP

Research on hedgerow systems in Northern Europe represent the largest set of studies with a total of 10 papers and a distinct clustering in the UK (Fig. 2). They demonstrated that hedgerow systems affect hydrophysical soil properties by influencing soil moisture distribution (Holden et al. 2019; Van Den Berge et al. 2021; Dlamini et al. 2022) and by increasing hydraulic conductivity (Kovář et al. 2011; Holden et al. 2019). Hedgerows reduced bulk density (Holden et al. 2019; Ford et al. 2019; Wallace et al. 2021; Van Den Berge et al. 2021; Biffi et al. 2022) and surface compaction (Holden et al. 2019; Wallace et al. 2021) compared to adjacent pasture or arable fields. These changes led to improved soil structure and water movement, mitigating surface runoff and erosion due to increased porosity and higher infiltration rates (Kovář et al. 2011; Holden et al. 2019; Wallace et al. 2021; Van Den Berge et al. 2021).

Enhancements in water movement and storage in hedgerow systems were also evident in the promotion of micropore flow over macropore flow (Holden et al. 2019). Positive effects on hydrophysical soil properties were spatially localized around the hedgerow areas or their immediate vicinity, decreasing with the distance from the woody component (Ford et al. 2019; Wallace et al. 2021; Van Den Berge et al. 2021). Hence, the integration of linear or borderline woody vegetation enhances hydrophysical soil functions and leads to improved soil water management of the system.

A similar situation was observed in a set of hedgerow-focused studies from Southern Europe, with Spain and France leading the research. Improvements of HPSP included higher infiltration rates (Richet et al. 2017), decreased bulk density (Walter et al. 2003; Kokkora et al. 2022), an increase of soil porosity near the hedgerow (Viaud et al. 2005), and an increase of soil water content (Sánchez et al. 2010; Sánchez and McCollin 2015). These changes facilitate better water retention and suggest improvements in soil structure (Walter et al. 2003; Viaud et al. 2005; Sánchez et al. 2010; Richet et al. 2017; Wiesmeier et al. 2018).

Discussion

This systematic review highlights the role of woody vegetation in EAFS in influencing HPSP. The findings underscore the significant contribution of agroforestry systems to improving soil functions and resilience, with notable implications for sustainable agricultural practices in changing climate. This section synthesizes the key outcomes of the review, discusses the variability of the results across different agroforestry systems, and identifies research gaps and future directions.

Enhancements of HPSP and underlying mechanisms

The integration of woody vegetation in agroforestry systems has been shown to enhance several hydrophysical soil properties. Findings across multiple studies consistently included increases in hydraulic conductivity and porosity and decreases in bulk density, suggesting improved soil structure and water retention (Kovář et al. 2011; Holden et al. 2019; Ford et al. 2019; Wallace et al. 2021; Kokkora et al. 2022). These changes facilitate better infiltration rates and water retention, crucial for mitigating drought impacts and enhancing soil water storage (Campi et al. 2009; Richet et al. 2017; Murphy et al. 2021; Van Den Berge et al. 2021). For instance, hedgerows and shelterbelts were particularly effective in increasing soil hydraulic conductivity and reducing surface runoff, as observed in both Northern and Southern Europe (Sánchez et al. 2010; Lunka and Patil 2016; Van Den Berge et al. 2021). Similar findings have been reported from studies in temperate zone, in both silvoarable (Seobi et al. 2005; Akdemir et al. 2016) and silvopastoral systems (Kumar et al. 2008, 2012).

These patterns are consistent with several reinforcing mechanistic pathways. Improvements in HPSP under agroforestry arise from:

1. Organic matter inputs from litterfall, rhizodeposition and root turnover promote aggregation and increase meso-/macroporosity, supporting higher infiltration, (saturated) hydraulic conductivity and water retention (Yazdanpanah et al. 2016).
2. Soil fauna activity and bioturbation (e.g., earthworms) and root-derived biopores enhance macropore continuity and preferential flow paths (Blouin et al. 2013).
3. Canopy- and barrier-driven microclimate moderation (reduced wind, lower surface temperatures, shading, litter cover) diminishes evaporation and surface sealing, while interception/throughfall/stemflow locally redistribute water and influence infiltration (Levia and Germer 2015)
4. Root activity, including radial growth, turnover and hydraulic redistribution, alters pore architecture and water-potential gradients, improving access to deeper water and buffering short-term deficits (Bleby et al. 2010)

Although SOC/OM was not a target variable in our synthesis, its functional role as a driver of aggregate stability and porosity within these pathways is acknowledged (Bronick and Lal 2005).

In European alley cropping systems, deeper fine root development was associated with depth-dependent soil water patterns, indicating altered vertical distribution and improved access to deeper water (O'Connor et al. 2023). These observations are consistent with the broader concept of hydraulic lift, where woody vegetation can draw water up from deeper layers and ameliorate shallow-rooted crops (e.g. Joffre and Rambal 1993). Studies outside Europe further extend the knowledge with seasonal variation. For example, roots of perennial agroforestry features mitigate spring waterlogging utilizing water before the interrow crops (Sahin et al. 2016; Alagele et al. 2020). Increased infiltration and porosity enable the agroforestry woody features to store more water during heavy rains. Subsequently, during hot summers, this supply can be lifted by trees for shallow rooting crops, thus, reducing plant stress (Anderson et al. 2009).

EAFS, particularly hedgerows and shelterbelts are effective in reducing runoff and erosion (Kovář et al. 2011; Holden et al. 2019; Wallace et al. 2021; Van Den Berge et al. 2021). A Review by Pavlidis and Tsihrintzis (2018), comprised of more than 2000 papers, shows potential reduction of N and P losses from 20% up to 100% by agroforestry systems. Moreover, reduction of pesticide losses amounted to as much as 90%. Woody component of agroforestry systems therefore reduces mobility of fertilizers and pesticides and subsequently improves water quality.

Trees in EAFS also have detrimental impacts on HPSP. Woody vegetation in young EAFS can initially decrease soil water content, before fine roots gradually explore deeper soil layers (Clivot et al. 2020). Competitive interactions are a subject to a complex of climatic and edaphic conditions. Competition for water between the trees and crops is more pronounced in areas with insufficient precipitation during cropping season (Kho 2000) and is strongly dependent upon the agroforestry system spatial arrangement (Jose and Gordon 2008; Quinkenstein et al. 2009). Moreover, depth of water table, hardly ever considered in studies, can have a significant bearing on the intensity of water competition. To the extent that when trees have access to the water table, it can result to reduced groundwater recharge with minimal competition for water resources (White et al. 2002).

Variability in system/tree feature performance

The magnitude and variability of effects on HPSP in EAFS varied with tree species, their age, planting configuration, management and local soil and climatic conditions (Campi et al. 2009; Holden et al. 2019; Clivot et al. 2020; Siegwart et al. 2023; Candel-Pérez et al. 2024). Within individual studies, configurations effects have been observed—for instance, in a silvopastoral case study, clumped tree arrangements were associated with higher infiltration rates and lower bulk density compared to evenly spaced systems (Lunka and Patil 2016). Similarly, Mediterranean dehesas displayed enhanced water retention under tree canopies compared to open areas, highlighting the heterogeneous effects within a single system (Joffre and Rambal 1993). Mediterranean systems also reported significant role of tree age (O'Connor et al. 2023), species composition (Rolo et al. 2019), pasture management (Candel-Pérez et al. 2024; Sanna et al. 2021), spatial arrangement of woody vegetation (Kokkora et al. 2022; Sanna et al. 2021), and pruning/management of roots (O'Connor et al. 2023). On the contrary, these factors were neither considered nor covered in Northern European systems. The focus was on comparing two contrasting types of land use, namely mono-cropping versus agroforestry, with the inclusion of soil hydrophysical properties alongside the primary objective of the study (such as assessment of soil carbon, CO_2 flux).

Moreover, competition for water between trees and crops in alley cropping systems occasionally led to reduced crop yields, despite improvements in soil water content (Inurreta-Aguirre et al. 2022). This trade-off underscores the need for strategic management practices, such as root pruning or optimized tree density, to balance competition and facilitation effects (Sánchez et al. 2010).

Research gaps and future directions

Despite these promising findings, several gaps persist in the current body of literature:

1. Most studies predominantly focus on topsoil (0–30 cm depth), with limited data on subsoil properties (below 50 cm) (Wallace et al. 2021). In addition, the set of articles is heavily dominated by short-term studies, with seasonal monitoring or frequency of a few times per year, instead of comprehensive continuous monitoring. Considering the importance of deep rooting woody perennials in agroforestry, and addressing the seasonal variability, future research should extend to deeper soil profiles and continuous monitoring.
2. There is a notable geographic and climatic bias in existing studies. Most agroforestry research is accomplished in Western Europe, whereas agroforestry systems in Central and Eastern Europe remain underrepresented (Fig. 2). The tree effects depend on resource availability and differ in specific climate-edaphic environments. Local specificities also govern crop's response (Kho 2000). There are also very limited resources available for a comprehensive understanding of silvoarable agroforestry systems under Northern European conditions. This gap limits the generalizability of our findings in European climatic context.
3. In terms of local resource availability, apart from two studies (Cardinael et al. 2015; Lunka & Patil 2016), the set completely lacked information on groundwater levels, as arguably the main limiting factor for water resource use.
4. Methodological heterogeneity and inconsistencies, such as variations in sampling depths and measurement techniques, complicate cross-study comparisons. Standardized protocols for assessing hydrophysical soil properties in agroforestry systems would enhance the robustness and comparability of future studies (Holden et al. 2019).

5. The role of tree species diversity and planting density in moderating soil–water dynamics remains poorly understood. Incorporating these variables into experimental designs could provide insights into optimizing agroforestry systems for both productivity and soil health.
6. The hydraulic lift phenomenon in the specific climate-soil-contexts of Northern Europe remains largely untested; none of the studies included in our review directly measured hydraulic redistribution. The mechanism and its importance in dryland environments is well covered in tropical environments (Scholz et al. 2002; Neumann and Cardon 2012) and moderately explained in Mediterranean systems (Kurz-Besson et al. 2006).
7. Presented studies almost exclusively included agricultural monocropping control, while there was only one comparative study with forested system (Candel-Pérez et al. 2024). In terms of assessing the overall water dynamics of agroforestry systems and their performance in comparison to ecosystems that are closer to nature than agro-ecosystems, it is imperative to consider pointing future research into the direction of forested controls.

Implications for practice

The findings of this review emphasize the potential of agroforestry systems to address soil functions losses and water scarcity in the Mediterranean regions (Sánchez et al. 2010; Wallace et al. 2021). Practices incorporating perennial woody features into agricultural landscapes can significantly enhance ecosystem services whilst mitigating negative impacts of agriculture (Udawatta and Gantzer 2022). Sound management of the woody component modifies water movement and use, also in consideration of below-ground competition between trees and crops (Quinkenstein et al. 2009; Nerlich et al. 2013). Tailored management practices that consider local climatic, edaphic, and socio-economic conditions ensure successful steering of the both beneficial and detrimental hydro-physical effects. The validated practices in EAFS include root pruning and optimized tree densities which mitigate competition for water while maximizing the hydraulic benefits of deep-rooted trees (Inurreta-Aguirre et al. 2022).

Conclusion

This review demonstrates that agroforestry systems in Europe can significantly improve hydrophysical soil properties, with diverse effects depending on system type, age, tree species, and management practices. One of the linkages with direct implications for practice are strategic interventions that promote desirable effects, such as root pruning and optimising tree density. Despite the enhancement in comprehension of the impacts on HPSP resulting from the presented studies, they do not encompass the complete spatial and temporal variability of EAFS. The paucity of comparative studies incorporating silvicultural controls and monitoring reflecting these spatial and temporal aspects is a key knowledge gap that should be addressed in future research. Such in-depth studies would be highly valuable, yielding fundamental understanding of the existing patterns and interdependencies between agroforestry and soil properties across different environmental zones. Addressing the identified research gaps through long-term and multidisciplinary studies will be crucial for advancing the understanding and implementation of agroforestry systems. Such efforts will serve to strengthen the role of sustainable solutions in soil and water management in agricultural landscapes.

Author contributions A.M.M. created the review concept and was the main person responsible for the management of the systematic review, data analysis, and interpretation. She wrote the main manuscript text. T.V. was the main reviewer in the screening process and contributed to data analysis and interpretation. P.Z. was a reviewer in the screening process, contributed to data analysis and interpretation and prepared bibliographic figures. J.V. was a reviewer in the screening process and revised the work. Š.N. was a reviewer in the screening process and contributed to data analysis. V.V. was an expert supervisor over the whole process. All authors reviewed the manuscript.

Funding Specific university research and departmental resources of Mendel University in Brno, Faculty of Forestry and Wood Technology.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Akdemir E, Anderson SH, Udawatta RP (2016) Influence of agroforestry buffers on soil hydraulic properties relative to row crop management. Soil Sci 181:368–376. https://doi.org/10.1097/SS.0000000000000170

Alagele SM, Anderson SH, Udawatta RP (2020) Agroforestry, grass, biofuel crop, and row-crop management effects on soil water dynamics for claypan landscapes. Soil Sci Soc Am J 84:203–219. https://doi.org/10.1002/saj2.20026

Anderson SH, Udawatta RP, Seobi T, Garrett HE (2009) Soil water content and infiltration in agroforestry buffer strips. Agroforest Syst 75:5–16. https://doi.org/10.1007/s10457-008-9128-3

Aria M, Cuccurullo C (2017) Bibliometrix: an R-tool for comprehensive science mapping analysis. J Informetr 11:959–975. https://doi.org/10.1016/j.joi.2017.08.007

Bakker G, Heinen M, Gooren HPA et al (2019) Hydrofysische gegevens van de bodem in de basisregistratie ondergrond (BRO) en het bodemkundig informatie systeem (BIS): Update 2018

Biffi S, Chapman PJ, Grayson RP, Ziv G (2022) Soil carbon sequestration potential of planting hedgerows in agricultural landscapes. J Environ Manage 307:114484. https://doi.org/10.1016/j.jenvman.2022.114484

Blanco H, Lal R (2023) Soil Conservation and Management. Springer Nature Switzerland, Cham

Bleby TM, McLerone AJ, Jackson RB (2010) Water uptake and hydraulic redistribution across large woody root systems to 20 m depth. Plant Cell Environ 33:2132–2148. https://doi.org/10.1111/j.1365-3040.2010.02212.x

Blouin M, Hodson ME, Delgado EA et al (2013) A review of earthworm impact on soil function and ecosystem services. Eur J Soil Sci 64:161–182. https://doi.org/10.1111/ejss.12025

Bridges EM, Oldeman LR (1999) Global assessment of human-induced soil degradation. Arid Soil Res Rehabil 13:319–325. https://doi.org/10.1080/089030699263212

Bronick CJ, Lal R (2005) Soil structure and management: a review. Geoderma 124:3–22. https://doi.org/10.1016/j.geoderma.2004.03.005

Campi P, Palumbo AD, Mastrorilli M (2009) Effects of tree windbreak on microclimate and wheat productivity in a Mediterranean environment. Eur J Agron 30:220–227. https://doi.org/10.1016/j.eja.2008.10.004

Candel-Pérez D, Lucas-Borja ME, Plaza-Álvarez PA et al (2024) Effects of grazing on soil properties in mediterranean forests (Central-Eastern Spain). J Environ Manage 354:120316. https://doi.org/10.1016/j.jenvman.2024.120316

Cardinael R, Chevallier T, Barthès BG et al (2015) Impact of alley cropping agroforestry on stocks, forms and spatial distribution of soil organic carbon—a case study in a Mediterranean context. Geoderma 259:288–299. https://doi.org/10.1016/j.geoderma.2015.06.015

Cardinael R, Chevallier T, Cambou A et al (2017) Increased soil organic carbon stocks under agroforestry: a survey of six different sites in France. Agric Ecosyst Environ 236:243–255. https://doi.org/10.1016/j.agee.2016.12.011

Cardoso EJBN, Vasconcellos RLF, Bini D et al (2013) Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Sci Agric 70:274–289. https://doi.org/10.1590/S0103-90162013000400009

Carroll ZL, Carroll ZL, Bird SB et al (2004) Can tree shelterbelts on agricultural land reduce flood risk? Soil Use Manag 20:357–359. https://doi.org/10.1079/SUM2004266

Clivot H, Petitjean C, Marron N et al (2020) Early effects of temperate agroforestry practices on soil organic matter and microbial enzyme activity. Plant Soil 453:189–207. https://doi.org/10.1007/s11104-019-04320-6

Cubera E, Moreno G (2007) Effect of land-use on soil water dynamic in dehesas of Central-Western Spain. Catena (Amst) 71:298–308. https://doi.org/10.1016/j.catena.2007.01.005

Delgado A, Gómez JA (2016) The soil. Physical, chemical and biological properties. In: Principles of Agronomy for Sustainable Agriculture. Springer International Publishing, Cham, pp 15–26

Dexter AR (2004) Soil physical quality. Geoderma 120:201–214. https://doi.org/10.1016/j.geoderma.2003.09.004

Dlamini JC, Cardenas LM, Tesfamariam EH et al (2022) Soil N_2O and CH_4 emissions from fodder maize production with and without riparian buffer strips of differing vegetation. Plant Soil 477:297–318. https://doi.org/10.1007/s11104-022-05426-0

Fagerholm N, Torralba M, Burgess PJ, Plieninger T (2016) A systematic map of ecosystem services assessments around European agroforestry. Ecol Indic 62:47–65. https://doi.org/10.1016/j.ecolind.2015.11.016

FAO, ITPS (2015) Status of the world's soil resources (SWSR)—main report. Rome, Italy: Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils

Fernández ME, Gyenge J, Licata J et al (2008) Belowground interactions for water between trees and grasses in a

temperate semiarid agroforestry system. Agroforest Syst 74:185–197. https://doi.org/10.1007/s10457-008-9119-4
Ferreiro-Domínguez N, Rigueiro-Rodríguez A, Rial-Lovera KE et al (2016) Effect of grazing on carbon sequestration and tree growth that is developed in a silvopastoral system under wild cherry (*Prunus avium* L.). CATENA 142:11–20. https://doi.org/10.1016/j.catena.2016.02.002
Ford H, Healey JR, Webb B et al (2019) How do hedgerows influence soil organic carbon stock in livestock-grazed pasture? Soil Use Manage 35:576–584. https://doi.org/10.1111/sum.12517
Gordon AM, Jose S (2008) Applying ecological knowledge to agroforestry design: a synthesis. pp 301–306
Grover D, Mishra AK, Rani P et al (2024) Soil management in sustainable agriculture: principles and techniques. Technological approaches for climate smart agriculture. Springer International Publishing, Cham, pp 41–77
Hatfield JL, Dold C (2019) Water-use efficiency: advances and challenges in a changing climate. Front Plant Sci 10:103. https://doi.org/10.3389/fpls.2019.00103
Hirota I, Sakuratani T, Sato T et al (2004) A split-root apparatus for examining the effects of hydraulic lift by trees on the water status of neighbouring crops. Agroforest Syst 60:181–187. https://doi.org/10.1023/B:AGFO.0000013293.77907.64
Holden J, Grayson RP, Berdeni D et al (2019) The role of hedgerows in soil functioning within agricultural landscapes. Agric Ecosyst Environ 273:1–12. https://doi.org/10.1016/j.agee.2018.11.027
Inurreta-Aguirre HD, Lauri P-É, Dupraz C, Gosme M (2022) Impact of shade and tree root pruning on soil water content and crop yield of winter cereals in a Mediterranean alley cropping system. Agrofor Syst 96:747–757. https://doi.org/10.1007/s10457-022-00736-9
Ivezić V, Yu Y, Werf W (2021) Crop yields in European agroforestry systems: a meta-analysis. Front Sustain Food Syst. https://doi.org/10.3389/fsufs.2021.606631
Joffre R, Rambal S (1993) How tree cover influences the water balance of Mediterranean rangelands. Ecology 74:570–582. https://doi.org/10.2307/1939317
Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. Agroforest Syst 76:1–10. https://doi.org/10.1007/s10457-009-9229-7
Jose S, Gillespie AR, Pallardy SG (2004) Interspecific interactions in temperate agroforestry. Agroforest Syst 61–62:237–255. https://doi.org/10.1023/B:AGFO.0000029002.85273.9b
Jose S, Gordon AM (2008) Ecological Knowledge and Agroforestry Design: An Introduction. pp 3–9
Kho RM (2000) A general tree-environment-crop interaction equation for predictive understanding of agroforestry systems. Agric Ecosyst Environ 80:87–100. https://doi.org/10.1016/S0167-8809(00)00136-5
Kokkora MI, Vrahnakis M, Kleftoyanni V (2022) Soil quality characteristics of traditional agroforestry systems in Mouzaki area, central Greece. Agroforest Syst 96:857–871. https://doi.org/10.1007/s10457-022-00746-7
Kovář P, Vaššová D, Hrabalíková M (2011) Mitigation of surface runoff and erosion impacts on catchment by stone hedgerows. Soil Water Res 6:153–164. https://doi.org/10.17221/31/2011-SWR
Kumar S, Anderson SH, Bricknell LG et al (2008) Soil hydraulic properties influenced by agroforestry and grass buffers for grazed pasture systems. J Soil Water Conserv 63:224–232. https://doi.org/10.2489/jswc.63.4.224
Kumar Y, Manojkumar S, Behera L (2022) Tree root dynamics: An essential tool to combat root competition in agroforestry. Ecol Environ Conserv 28:S371–S376. https://doi.org/10.53550/EEC.2022.v28i04s.057
Kumar BM, Singh AK, Dhyani SK (2012) South Asian Agroforestry: Traditions, Transformations, and Prospects. pp 359–389
Kurz-Besson C, Otieno D, Lobo do Vale R et al (2006) Hydraulic lift in cork oak trees in a savannah-type Mediterranean ecosystem and its contribution to the local water balance. Plant Soil 282:361–378. https://doi.org/10.1007/s11104-006-0005-4
Lehmann LM, Smith J, Westaway S et al (2020) Productivity and economic evaluation of agroforestry systems for sustainable production of food and non-food products. Sustainability 12:5429. https://doi.org/10.3390/su12135429
Levia DF, Germer S (2015) A review of stemflow generation dynamics and stemflow-environment interactions in forests and shrublands. Rev Geophys 53:673–714. https://doi.org/10.1002/2015RG000479
Ludwig F, Dawson TE, de Kroon H et al (2003) Hydraulic lift in *Acacia tortilis* trees on an East African savanna. Oecologia 134:293–300. https://doi.org/10.1007/s00442-002-1119-x
Lunka P, Patil SD (2016) Impact of tree planting configuration and grazing restriction on canopy interception and soil hydrological properties: implications for flood mitigation in silvopastoral systems. Hydrol Process 30:945–958. https://doi.org/10.1002/hyp.10630
Mahieu S, Metay A, Brunel B, Dufour L (2016) Nitrogen fluxes in chickpea grown in Mediterranean agroforestry systems. Agroforest Syst 90:313–324. https://doi.org/10.1007/s10457-015-9856-0
Majaura M, Böhm C, Freese D (2024) The influence of trees on crop yields in temperate zone alley cropping systems: a review. Sustainability 16:3301. https://doi.org/10.3390/su16083301
Manevski K, Jakobsen M, Kongsted AG et al (2019) Effect of poplar trees on nitrogen and water balance in outdoor pig production—a case study in Denmark. Sci Total Environ 646:1448–1458. https://doi.org/10.1016/j.scitotenv.2018.07.376
Mayer S, Wiesmeier M, Sakamoto E et al (2022) Soil organic carbon sequestration in temperate agroforestry systems—a meta-analysis. Agric Ecosyst Environ 323:107689. https://doi.org/10.1016/j.agee.2021.107689
McAdam JH, Burgess PJ, Graves AR et al (2008) Classifications and functions of agroforestry systems in Europe. Agroforestry in Europe. Springer, Netherlands, Dordrecht, pp 21–41
Medinski TV, Freese D, Böhm C (2015) Soil CO_2 flux in an alley-cropping system composed of black locust and poplar trees, Germany. Agroforest Syst 89:267–277. https://doi.org/10.1007/s10457-014-9764-8
Mettauer R, Thoumazeau A, Le Gall S et al (2023) Soil health in temperate agroforestry: influence of tree species and

position in the field. Arch Agron Soil Sci 69:1781–1800. https://doi.org/10.1080/03650340.2022.2116013

Metzger MJ, Bunce RGH, Jongman RHG et al (2005) A climatic stratification of the environment of Europe. Glob Ecol Biogeogr 14:549–563. https://doi.org/10.1111/j.1466-822X.2005.00190.x

Moreno Marcos G, Obrador JJ, García E et al (2007) Driving competitive and facilitative interactions in oak dehesas through management practices. Agroforest Syst 70:25–40. https://doi.org/10.1007/s10457-007-9036-y

Murphy TR, Hanley ME, Ellis JS, Lunt PH (2021) Native woodland establishment improves soil hydrological functioning in upland pastoral catchments. Land Degrad Dev 32:1034–1045. https://doi.org/10.1002/ldr.3762

Nerlich K, Graeff-Hönninger S, Claupein W (2013) Agroforestry in Europe: a review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. Agroforest Syst 87:475–492. https://doi.org/10.1007/s10457-012-9560-2

Neumann RB, Cardon ZG (2012) The magnitude of hydraulic redistribution by plant roots: a review and synthesis of empirical and modeling studies. New Phytol 194:337–352. https://doi.org/10.1111/j.1469-8137.2012.04088.x

O'Connor C, Zeller B, Choma C et al (2023) Trees in temperate alley-cropping systems develop deep fine roots 5 years after plantation: what are the consequences on soil resources? Agric Ecosyst Environ 345:108339. https://doi.org/10.1016/j.agee.2022.108339

Page MJ, McKenzie JE, Bossuyt PM et al (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. https://doi.org/10.1136/bmj.n71

Pavlidis G, Tsihrintzis VA (2018) Environmental benefits and control of pollution to surface water and groundwater by agroforestry systems: a review. Water Resour Manage 32:1–29. https://doi.org/10.1007/s11269-017-1805-4

Priori S, Barbetti R, Meini L et al (2019) Towards economic land evaluation at the farm scale based on soil physical-hydrological features and ecosystem services. Water (Basel) 11:1527. https://doi.org/10.3390/w11081527

Quinkenstein A, Wöllecke J, Böhm C et al (2009) Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environ Sci Policy 12:1112–1121. https://doi.org/10.1016/j.envsci.2009.08.008

Rees RM, Griffiths BS, McVittie A (2018) Sustainable intensification of agriculture: impacts on sustainable soil management, pp 7–16

Richet J-B, Ouvry J-F, Saunier M (2017) The role of vegetative barriers such as fascines and dense shrub hedges in catchment management to reduce runoff and erosion effects: experimental evidence of efficiency, and conditions of use. Ecol Eng 103:455–469. https://doi.org/10.1016/j.ecoleng.2016.08.008

Rigueiro-Rodróguez A, McAdam J, Mosquera-Losada MR (2009) Agroforestry in Europe. Springer, Netherlands, Dordrecht

Rolo V, Moreno G (2019) Shrub encroachment and climate change increase the exposure to drought of Mediterranean wood-pastures. Sci Total Environ 660:550–558. https://doi.org/10.1016/j.scitotenv.2019.01.029

Sahin H, Anderson SH, Udawatta RP (2016) Water infiltration and soil water content in claypan soils influenced by agroforestry and grass buffers compared to row crop management. Agroforest Syst 90:839–860. https://doi.org/10.1007/s10457-016-9899-x

Sánchez IA, McCollin D (2015) A comparison of microclimate and environmental modification produced by hedgerows and dehesa in the Mediterranean region: a study in the Guadarrama region, Spain. Landsc Urban Plan 143:230–237. https://doi.org/10.1016/j.landurbplan.2015.07.002

Sánchez IA, Lassaletta L, McCollin D, Bunce RGH (2010) The effect of hedgerow loss on microclimate in the Mediterranean region: an investigation in Central Spain. Agroforest Syst 78:13–25. https://doi.org/10.1007/s10457-009-9224-z

Sanna F, Campesi G, Deligios P et al (2021) Combined effects of microenvironment and land use on C fluxes in a Mediterranean agro-silvopastoral system. Eur J Agron 130:126348. https://doi.org/10.1016/j.eja.2021.126348

Sassenrath GF, Davis K, Sassenrath-Cole A, Riding N (2018) Exploring the physical, chemical and biological components of soil: improving soil health for better productive capacity. Kansas Agric Exp Stat Res Rep. https://doi.org/10.4148/2378-5977.7577

Schnabel S, Dahlgren RA, Moreno-Marcos G (2013) Soil and Water Dynamics. pp 91–121

Scholz FG, Bucci SJ, Goldstein G et al (2002) Hydraulic redistribution of soil water by neotropical savanna trees. Tree Physiol 22:603–612. https://doi.org/10.1093/treephys/22.9.603

Seobi T, Anderson SH, Udawatta RP, Gantzer CJ (2005) Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. Soil Sci Soc Am J 69:893–901. https://doi.org/10.2136/sssaj2004.0280

Siegwart L, Bertrand I, Roupsard O, Jourdan C (2023) Contribution of tree and crop roots to soil carbon stocks in a sub-sahelian agroforestry parkland in Senegal. Agric Ecosyst Environ 352:108524. https://doi.org/10.1016/j.agee.2023.108524

Staton T, Breeze TD, Walters RJ et al (2022) Productivity, biodiversity trade-offs, and farm income in an agroforestry versus an arable system. Ecol Econ 191:107214. https://doi.org/10.1016/j.ecolecon.2021.107214

Stoate C, Báldi A, Beja P et al (2009) Ecological impacts of early 21st century agricultural change in Europe—a review. J Environ Manage 91:22–46. https://doi.org/10.1016/j.jenvman.2009.07.005

Thiesmeier A, Zander P (2023) Can agroforestry compete? A scoping review of the economic performance of agroforestry practices in Europe and North America. For Policy Econ 150:102939. https://doi.org/10.1016/j.forpol.2023.102939

Thompson SE, Harman CJ, Heine P, Katul GG (2010) Vegetation-infiltration relationships across climatic and soil type gradients. J Geophys Res Biogeosci. https://doi.org/10.1029/2009JG001134

Torralba M, Fagerholm N, Burgess PJ et al (2016) Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. Agric Ecosyst Environ 230:150–161. https://doi.org/10.1016/j.agee.2016.06.002

Udawatta RP, Gantzer CJ (2022) Soil and water ecosystem services of agroforestry. J Soil Water Conserv 77:5A-11A. https://doi.org/10.2489/jswc.2022.1028A

Upson MA, Burgess PJ, Morison JIL (2016) Soil carbon changes after establishing woodland and agroforestry trees in a grazed pasture. Geoderma 283:10–20. https://doi.org/10.1016/j.geoderma.2016.07.002

Uribe C, Inclán R, Hernando L et al (2015) Grazing, tilling and canopy effects on carbon dioxide fluxes in a Spanish dehesa. Agroforest Syst 89:305–318. https://doi.org/10.1007/s10457-014-9767-5

Van Den Berge S, Vangansbeke P, Baeten L et al (2021) Soil carbon of hedgerows and 'ghost' hedgerows. Agroforest Syst 95:1087–1103. https://doi.org/10.1007/s10457-021-00634-6

Viaud V, Durand P, Merot P et al (2005) Modeling the impact of the spatial structure of a hedge network on the hydrology of a small catchment in a temperate climate. Agric Water Manag 74:135–163. https://doi.org/10.1016/j.agwat.2004.11.010

Wairiu M, Mullins CE, Campbell CD (1993) Soil physical factors affecting the growth of sycamore (*Acer pseudoplatanus* L.) in a silvopastoral system on a stony upland soil in North–East Scotland. Agroforest Syst 24:295–306. https://doi.org/10.1007/BF00705628

Wallace EE, McShane G, Tych W et al (2021) The effect of hedgerow wild-margins on topsoil hydraulic properties, and overland-flow incidence, magnitude and water-quality. Hydrol Process. https://doi.org/10.1002/hyp.14098

Walter C, Merot P, Layer B, Dutin G (2003) The effect of hedgerows on soil organic carbon storage in hillslopes. Soil Use Manag 19:201–207. https://doi.org/10.1111/j.1475-2743.2003.tb00305.x

White DA, Dunin FX, Turner NC et al (2002) Water use by contour-planted belts of trees comprised of four eucalyptus species. Agric Water Manag 53:133–152. https://doi.org/10.1016/S0378-3774(01)00161-5

Wiesmeier M, Lungu M, Cerbari V et al (2018) Rebuilding soil carbon in degraded steppe soils of eastern Europe: the importance of windbreaks and improved cropland management. Land Degrad Dev 29:875–883. https://doi.org/10.1002/ldr.2902

Yazdanpanah N, Mahmoodabadi M, Cerdà A (2016) The impact of organic amendments on soil hydrology, structure and microbial respiration in semiarid lands. Geoderma 266:58–65. https://doi.org/10.1016/j.geoderma.2015.11.032

Zhu X, Liu W, Chen J et al (2020) Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: a review of evidence and processes. Plant Soil 453:45–86. https://doi.org/10.1007/s11104-019-04377-3