Overview of evidence on agroforestry's role in biodiversity conservation and climate change mitigation and adaptation in low- and middle-income countries

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Conceptualisation: KB, MA, GNS, JE, PS, SS; Methodology: JE, SKDS, LE, EJW, SS, JP, AS; Investigation (screening and data extraction): EJW, SKDS, MA, KB; Investigation (Conducting searches and retrieving articles): LE, SKDS, EJW; Investigation (developing and applying AI-based models): AS, JP; Investigation (data analysis and visualization): SKDS, EJW, JE, SS; Writing – Original Draft: SKDS, SS, LE, EJW; Writing – Review & Editing: All authors; Project lead: SS; Project administration: EJW, SKDS, LE; Funding acquisition: JP, SS.

Conflict of interest

The authors declare they have no conflict of interests.

Abstract

Agroforestry has been promoted as one solution to make agriculture more ecologically sustainable. While research has examined its effects on biodiversity and on climate change mitigation and adaptation separately, comprehensive reviews linking these outcomes remain lacking. This review fills that gap. We searched six academic databases in June 2025, retrieving 12,175 unique records. Screening against pre-defined criteria yielded 258 studies reporting at least one biodiversity and one climate outcome.

Findings reveal a strong concentration of studies on soil biota and plants in agrosilviculture systems with short-term, observational designs. When biodiversity is studied alongside climate change adaptation, outcomes cluster around soil nutrients and chemical properties, with very few studies addressing ecosystem process, such as nutrient cycling and ecosystem regulation. Studies on biodiversity and mitigation are centred around soil carbon. Overall, fruit trees are more common than timber trees, though, continental differences in system characteristics exist. There is a significant knowledge gap for studies on vertebrates and long-term studies. Further, the evidence comes from a few countries leaving significant geographical gaps.

The review underlines how current research falls short on capturing the complexity and ecological resilience of agroforestry systems. Cross-taxa, system-level perspectives offer valuable insights into the synergies between biodiversity and climate mitigation and can help to identify win-win situations for managing production landscapes. We provide the findings as an interactive database enabling stakeholders to explore the evidence by outcome and context, and discuss how to improve the global relevance of agroforestry research and help avoid overly narrow development pathways.

Keywords

Evidence synthesis, species diversity, species richness, community composition, carbon sequestration, systematic mapping

1 Introduction

Agricultural practices are the largest drivers of biodiversity loss globally, primarily through the conversion of natural ecosystems into farmland (Dudley and Alexander, 2017). This transformation often involves clearing forests and grasslands, significantly reducing the area available for wildlife and plant species. The intensive practices used within agriculture, such as monoculture plantations and the heavy use of agrochemicals, not only exacerbates this decline in species biodiversity, but also the effects of climate change as well (Campbell et al., 2017; Dudley and Alexander, 2017; FAO, 2023). For example, the reliance on synthetic fertilizers releases substantial amounts of nitrous oxide (N_2O) into the atmosphere, a potent greenhouse gases (GHG) that contributes to global warming (Tubiello et al., 2013). Furthermore, cultivating land-use for food production often involves increased water usage, which intensifies the impact of climate-driven drought disturbances, especially in drought-prone areas (Campbell et al., 2017; Pfister et al., 2011). Practices such as continuous tillage also disrupt soil structure, leading to soil compaction and reduced porosity. Such compacted soils are more vulnerable to erosion by wind and water, which removes the organic layer that supports plant growth (Borrelli et al., 2020). This depletion reduces soil capacity in retaining moisture and nutrients, creating a feedback cycle of degradation that undermines long-term agricultural sustainability and amplifies the ecological challenges posed by climate change (Borrelli et al., 2020; Lal, 2009). These processes link agricultural practices to both climate change mitigation (through GHG emissions and carbon loss) and adaptation (through reduced resilience to climate extremes). Agroforestry, the integration of trees and shrubs into agricultural landscapes, is increasingly recognized by policymakers as a transformative approach to enhance sustainability, biodiversity, and climate resilience in agricultural systems (Jose, 2009; Mbow et al., 2014). However, mixed tree-crop-animal (polyculture) systems have been practiced by Indigenous peoples for many thousands of years (Maezumi et al., 2018) and are still practised today. Particularly in low- and middle-income countries (LMICs), where agricultural systems face mounting challenges from climate change, biodiversity loss, and resource constraints, agroforestry offers a promising strategy for fostering resilient and sustainable agricultural practices.

The integration of diverse tree and shrub species in agroforestry systems propagates a greater variety of ecological interactions and fosters a more complex ecosystem. This diversification of agricultural lands creates various habitats and niches for a wide range of organisms, including beneficial insects, birds, and soil microorganisms, which play essential roles in providing ecological services (Udawatta et al., 2019). For instance, the presence of flowering plants within agroforestry systems attracts pollinators, such as bees and butterflies, which are crucial for the reproduction of many crops and wild plants (Bentrup et al., 2019; Centeno-Alvarado et al., 2023). Additionally, these systems support a diverse array of predatory insects and birds that help control pest populations naturally, thereby reducing the need for intensive agricultural practices such as spraying chemical pesticides (Pumariño et al., 2015). As such, diversifying agriculture systems through the integration of trees and shrubs not only aids in conserving local species richness and diversity but also increases the functional diversity of local species and the ecosystem services they provide (Philpott et al., 2009). Maintaining such ecosystem services is essential to supporting the resilience of the agri-ecosystems to climate-related disturbances (Hisano et al., 2018).

Implementing agroforestry can directly mitigate climate change by increasing carbon (C) sequestration, and thereby, contributing to the net reduction of GHG (Lorenz and Lal, 2014; Zomer et al., 2016). This carbon is accumulated and stored in the soil as soil organic carbon (SOC), resulting from the stable production of leaf litter and root decomposition. This not only enables long-term carbon storage but also enhances leaf litter quality and quantity (Laganière et al., 2010), particularly as trees can access nutrients from deeper soil layers and bring them to the surface through leaf litter and root exudates. This process also enriches the topsoil with essential nutrients, benefiting companion crops and reducing the need for fertilizers, as such, fostering a diverse microbial community that further enhances soil health and fertility (Laganière et al., 2010; Veen et al., 2019).

Furthermore, integrating trees within agricultural systems enhances the adaptive capacity of agri-ecosystems, improving their resilience to climate variability and extreme weather events and contributing to yield stability. For example, increasing the depth and complexity of the rooting structure can both decrease soil erosion and increase soil water retention, which is crucial for dampening the effects of drought (Fahad et al., 2022). The accumulation of leaf litter and shading from the tree canopy creates a microclimate buffering effect within the soil and understorey, which both buffer the adverse impacts of climatic extremes on crop growth and reduce water loss through evaporation (De Carvalho et al., 2021; Svoma et al., 2016). Similarly, trees and shrubs in agroforestry systems may act as windbreaks, which reduce wind speed and crop damage caused by high-velocity winds (Chang et al., 2021). Collectively, these multifaceted benefits illustrate that integrating trees within agricultural landscapes supports ecological health and enhances the overall sustainability and productivity of farming systems, ultimately fostering food security in the face of climate change. By promoting biodiversity and creating a more resilient agricultural framework, agroforestry emerges as a vital strategy for adapting to and mitigating the impacts of an increasingly unpredictable climate.

However, evidence linking biodiversity outcomes in agroforestry systems with both climate change mitigation and adaptation remains fragmented. Previously research has been published on the effects of agroforestry on biodiversity, ecosystem services and human well-being (Brown et al., 2018; Castle et al., 2021) as well as its effects on climate change mitigation (Dmuchowski et al., 2024). Here we fill this knowledge gap by systematically mapping evidence on agroforestry interventions that have simultaneously measured biodiversity and climate outcomes. We show that the evidence base is severely limited and provide an interactive database for practitioners and policy makers of the studies conducted so far.

2 Agroforestry typology

According to Atangana et al. (2014), agroforestry systems and practices are often used interchangeably, making their distinction somewhat unclear. Both terms generally refer to forms of land use that integrate trees with crops and/or livestock. Atangana et al. (2014) identified more than 100 agroforestry systems globally, which are defined as particular land-use systems characterized by the environment, plant species and their arrangement, management practices, and socio-economic functions, with around 30 agroforestry practices identified. Major agroforestry practices or technologies in the humid tropics, as outlined by Atangana et al. (2014), include: homegardens, perennial crop-based systems, shifting cultivation, alley cropping, improved and rotational tree fallows. Additional important systems in the humid tropics include multilayered tree gardens, multipurpose trees integrated into croplands, and combinations of plantations with crops. Terminology of agroforestry has been expanded by researchers to include systems such as agrosilvicultural systems, woodlots, boundary plantings, live fences, and multistrata agroforests (Feliciano et al., 2018).

Difference in categorization of agroforestry systems have been observed between Brown et al. (2018) and Feliciano et al. (2018) studies (Table 1). Based on Brown et al. (2018) classification certain agroforestry subtypes, e.g. improved fallow was classified under agrosilviculture. In contrast, Feliciano et al. (2018) categorized such agroforestry practices as one main type of their seven reclassified systems. Similarly, while shelterbelts were grouped by Feliciano et al. (2018) as subtypes under boundary agroforestry systems, Brown et al. (2018) mentioned such practices both under agrosilviculture (to protect farmlands) and silvopasture (to protect farmlands and animals).

Table 1. Classification of agroforestry systems and agroforestry practices.

General agroforestry systems	Specific agroforestry practices	Source
Agrisilviculture[1]	Parklands, intercropping, Taungya	Feliciano et al., 2018
Silvopasture		
Boundary planting	Shelterbelt, live fence	
Improved fallows		
Shadow systems	Cocoa-based agroforestry, tea-based agroforestry, coffee-based agroforestry	
Homegardens	Homegardens, multistrata agroforests	
Woodlots	Woodlots, fast growing trees	
Agrosilviculture/ silvoarable	Multipurpose trees (trees integrated in crop fields) hedgerows, shelterbelts, and windbreak systems alley-cropping systems improved or rotational fallow riparian buffer strips	Brown et al., 2018
Silvopasture	Multipurpose trees (trees/shrubs on pasture), meadow orchards hedgerows, shelterbelts, and windbreak systems	
Agrosilvipasture	Integrated production of animals (meat and dairy), crops, and wood/fuelwood	

[1] Synonymous to agrosilviculture.

We follow Brown et al. (2018) due to its clear categorization of agroforestry systems based on their structure and functional integration within agricultural landscapes. While Feliciano et al. (2018) group systems such as shelterbelts and live fences under boundary planting, we opted for the Brown et al. (2018) framework to highlight the functional diversity of agroforestry interventions. The inclusion of systems like parklands and boundary planting under agrosilviculture and silvopasture reflects their functionality in supporting crop and animal production respectively. The Brown et al. (2018) framework thus aligns with the multifunctionality emphasized in the review objectives.

In addition, the three systems align with FAO's 2022 framework, providing a robust and widely recognized classification scheme for agroforestry systems. The three main types of agroforestry systems and subtypes (agrosilviculture, silvopasture, and agrosilvipasture) considered in review are presented in Table 2. Many of the practices listed under the subtypes are interchangeable among the three main agroforestry systems. For instance, practices such as shelterbelts, live fence, windbreak, parklands and home gardens can be appropriately classified within agrosilviculture, silvopasture, or agrosilvipasture systems, depending on their specific application and context. Further, to describe the integration of crops with trees, the literature uses the synonymous terms “agrisilviculture” (Feliciano et al., 2018) and “agrosilviculture” (Brown et al., 2018). For consistency, we have opted to use the term agrosilviculture throughout this review.

Table 2. Main types and subtypes of agroforestry systems considered in this review.

Main type of agroforestry systems	[1]Subtype of agroforestry systems
Agrosilviculture	Multipurpose trees in annual or perennial crop fields, hedgerows, shelterbelts, live fence, and windbreak systems to protect farmlands, alley-cropping, improved or rotational fallow, riparian buffer strips, parklands, intercropping, cocoa/coffee/tea-based agroforestry, homegardens, multistrata agroforests, woodlots
Silvopasture	Multipurpose trees and shrub on pastureland, hedgerows, shelterbelts, live fence, and windbreak systems to protect farmlands and animals, meadow orchards
Agrosilvipasture	Integrated production of animals (meat and dairy), crops, and wood/fuelwood

[1]Adapted from Brown et al., 2018 and Feliciano et al., 2018

3 Conceptual framework

The diagram illustrates agroforestry as an intervention combining three practices: agrosilviculture, silvopasture, and agrosilvopasture. These practices lead to intermediate outcomes that ultimately enhance biodiversity, mitigate climate change, and support adaptation strategies compared to business-as-usual scenarios. For instance, agrosilviculture (integrating crops and trees) contributes to climate change mitigation by increasing aboveground and belowground biomass and carbon storage in biomass, improving soil organic matter (SOM). Such practices contribute to a net reduction in GHG emissions, even though, in some contexts, they may be associated with increased nitrous oxide (N_2O) and, to a lesser extent, methane (CH_4) emissions (Berhanu et al., 2023; Gross et al., 2022). The presence of trees with crops controls erosion (Durojaiye et al., 2024; Fahad et al., 2022; Liu et al., 2018; Ngaba et al., 2024) and supports ecosystems with more diverse flora and fauna compared to monocropping (Marsden et al., 2020; Ngaba et al., 2024; Udawatta et al., 2019).

Silvopasture, a system integrating trees with livestock grazing, enhances soil carbon and nitrogen (N) levels through livestock manure (Gautam et al., 2009; Yaebiyo et al., 2024), leading to improved soil health compared to open pastures (Orefice et al., 2017; Pent and Fike, 2021). In addition to promoting biodiversity and increasing carbon sequestration (Kremer, 2021), silvopasture strengthens livestock resilience by offering diverse and sustainable fodder sources, including tree leaves, pods, and fruits, which reduce reliance on external feed during times of scarcity (Dibala et al., 2021). Furthermore, it supports forage production as well as meat and milk production, thereby providing co-benefits such as income generation (Nichols et al., 2021; Udawatta et al., 2019). Land use change from pasture/grassland to agrosilvipasture systems (combining trees, crops, and livestock) contributes to climate change mitigation by increasing soil organic carbon (SOC) stocks (De Stefano and Jacobson, 2017). All three share several key outcomes, such as enhancing SOC sequestration, improving biodiversity through diverse flora and fauna, reducing soil and wind erosion, and supporting climate change mitigation and adaptation strategies. These common outcomes highlight the cross-cutting benefits of agroforestry systems, demonstrating their capacity to address environmental sustainability and resilience in a variety of contexts.

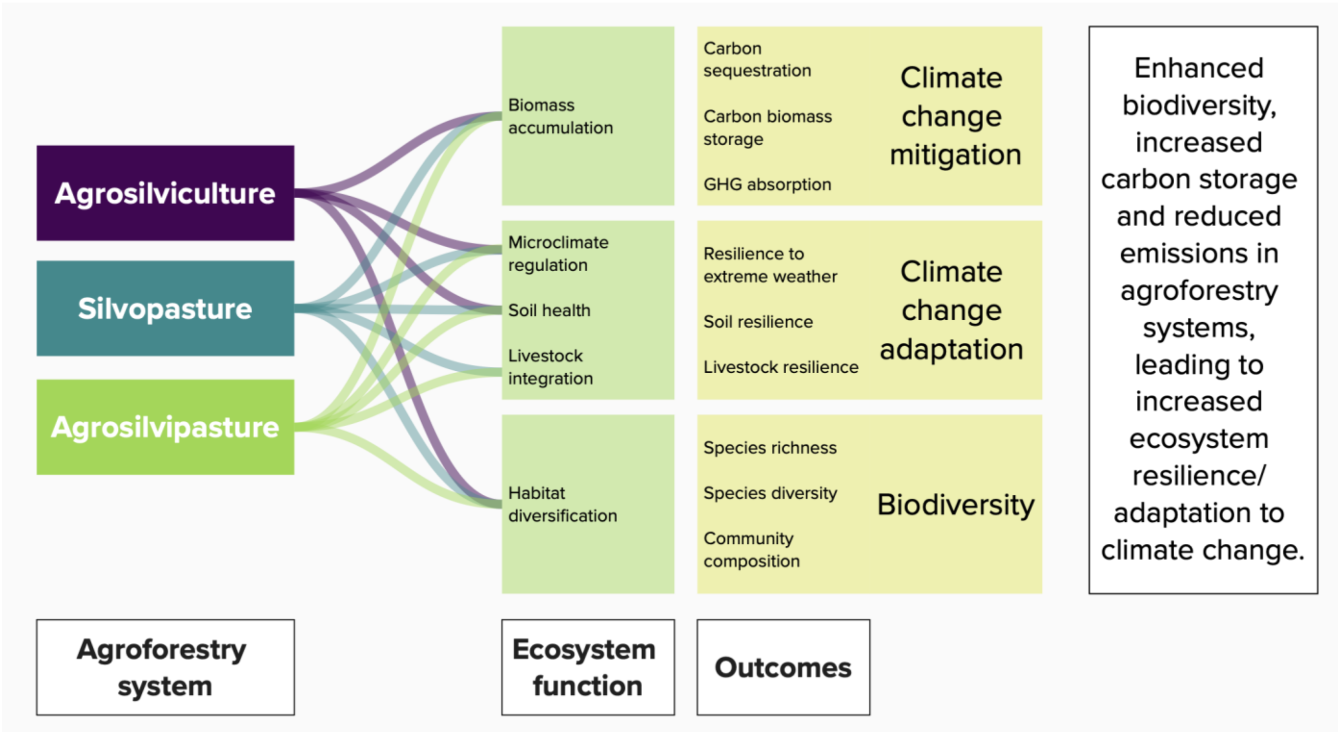

Figure 1. Schematic pathway to show how the three main agroforestry types: agrosilviculture (yellow), silvopasture (orange), agrosilvipasture (green), may impact on biodiversity, climate change mitigation and climate change adaptation. The ecosystem functions under each agroforestry type include biomass accumulations (include aboveground and belowground biomass), microclimatic regulations (increase humidity, reduce extreme heat, temperature fluctuation, protect farmland from wind and soil erosion), soil health (improve soil structure, soil fertility, water filtration, reduce water stress), livestock integration (high quality forage, manure addition) and habitat diversification (improved conditions for flora and fauna diversity). Note that livestock integration, is linked with only silvopasture and agrosilvipasture.

4 Methods

4.1 Protocol

This systematic map was conducted following an updated, published protocol (Begum et al., 2025) and according to the Collaboration for Environmental Evidence guidelines for systematic reviews and maps (Collaboration for Environmental Evidence, 2022). We report the review conduct against the ROSES reporting standards (S1) (Haddaway et al., 2018). We made the following deviations to the published protocol: 1) we deemed that tree basal area, soil bulk density, soil pH would not be eligible as a single measure of CCM/A and at least two must be reported; 2) we extracted data independently and simultaneously from 20 studies and compared consistency before moving to single person data extraction, instead of a second reviewer double checking at least 20% of the articles; and 3) we did not complete citation chasing owing to lack of funded time.

4.2 Research question and question components

The objective of this systematic map is to identify the evidence on the effects of agroforestry on biodiversity, climate change mitigation and climate change adaptation outcomes in low- and middle-income countries (LMICs). The research question is:

What is the evidence base investigating the impacts of agroforestry interventions on biodiversity and climate change mitigation and/or climate change adaptation in LMICs?

The research question is defined by following question elements:

Population: Agricultural systems in LMICs.

Intervention: Agrosilviculture (trees with crops), silvopasture (trees with livestock grazing), agrosilvipasture (trees, crops and livestock)

Comparator: Temporal control, spatial control, comparison with another intervention, or comparison with another level of the same intervention.

Outcomes: Biodiversity (Species richness, species diversity and individual abundance, relative abundance/evenness, community composition, beta diversity); climate change mitigation (Greenhouse gases (GHG), emissions, SOC sequestration, carbon storage in biomass); and Climate change adaptation (soil attributes such as moisture and mineral content, soil stability, shade, fodder to livestock.

4.3 Searches

Searches were developed and conducted by an information specialist (LE). Six databases (including Web of Science Core Collection, Scopus, CAB Abstracts, CAB Global health and ProQuest Agricola) were searched 26 June 2025, based on the search strategy provided in Annex A which was amended to match the syntax of each resource. Due to the capacity of the team, we searched in English language only.

15 organizational websites were searched for grey literature on 26 June 2025 (Annex B).

- Web of Science Core Collection, including:
  - Science Citation Index Expanded (SCI-EXPANDED) 1970-present
  - Social Sciences Citation Index (SSCI) 1970-present
  - Arts & Humanities Citation Index (AHCI) 1975-present
  - Emerging Sources Citation Index (ESCI) 2015-present
  - Conference Proceedings Citation Index – Science (CPCI-S) 1990-present
  - Conference Proceedings Citation Index – Social Science & Humanities (CPCI-SSH) 1990-present
- Scopus (1960-present)
- CAB Abstracts (EBSCO) (1973-present)
- CAB Global Health
- ProQuest Dissertations & Theses (1637–present)
- ProQuest Agricola (1970-present)

4.4 Screening

Articles were screened against eligibility criteria (Annex C) based on the question elements. Consistency checking at the title and abstract stage was undertaken between two reviews (EJD, SKDS) – we first screened 250 studies and then 50 studies. Consistency measured with the Kappa statistic was low (0.33, 0.456 respectively). Because the proportion of includes is low, there needs to be extremely high agreement to achieve kappa > 0.6 (Li et al., 2023). In our case, we had disagreement on two of the fifty studies. We reviewed the conflicts and found that the studies we disagreed on were not eligible, meaning that there was a high level of agreement on included studies. After clarifying further our shared understanding of the inclusion criteria, we decided to move to single-screening.

We reduced manual efforts during title and abstract screening using classifier and recommender-based machine learning (AI) approaches. The subset of 2500 manually screened records from database searches was used to train an AI (ML classifier) model which returned a set of studies to be screened at full text. We checked the model and agreed a threshold for inclusion at 0.22 following screening of two subsets of 200 records with different likelihoods of eligibility. The model was then run on the remaining set of records. After applying the inclusion threshold of 0.22 to the modelled records, 7800 studies were screened manually at title and abstract.

4.5 Data extraction and synthesis

Eligible articles were subjected to data coding (allocation of predefined categorical labels) and meta-data extraction (descriptive information) using Covidence software ("Covidence systematic review software," 2025). We revised the template following the interim report for clarity and efficiency. Two review authors (EJD, SKDS) then extracted data from 20 studies in duplicate and cross-checked data for consistency. During this process we discussed construct validity and gained a shared understanding, and following this data were extracted by a single review author. Any uncertainties were discussed between the core review team (EJD, SKDS, SS).

We extracted data on the study location, agroforestry type (agrosilviculture, silvopasture, agrosilvipasture) and subtype (e.g. intercropping, homegarden, parkland, woodlot), outcomes reported, and details of study length and soil sample depth. We extracted information about the crops, animals farmed, and agroforestry trees used in interventions. We categorised crop trees such as cacao, coffee, banana (Musa spp.) and rubber as either crops or agroforestry trees depending on how they were used in the study. Crop data were grouped into broad categories such as cereal, legume, fruit and vegetable to allow a broad overview of the data. We did not extract quantitative outcome data. Since the purpose of this project was to map the evidence base, we did not conduct critical appraisal of the articles. Furthermore, authors did not participate in decisions regarding articles they had authored to ensure procedural independence.

We produced a narrative summary of the findings and a database of the included studies. The narrative summary describes the study characteristics, studied systems and reported outcomes. We complemented the narrative with visualisations to explore patterns across the evidence base and across groups, based on, for example, geographical region, agroforestry types, and types of outcomes.

5 Review findings

Our database and grey literature searches resulted in 27,906 records, which was reduced to 12,175 after duplicate removal (Figure S1). Two thousand nine hundred records were screened and the decisions used to train a Natural Language Processing (NLP) model. After the model was applied, 7,800 records were screened at title abstract level with 1,443 records progressing to full text screening. Of those, 1,369 were located and 258 included in the final review. The most common reasons for exclusion at full text were Climate Change Adaptation/ Climate Change Mitigation (CCA/CCM) outcome not being reported, ineligible comparator, non-English language and biodiversity outcome not being reported. The full set of articles included is available as a supplementary file (S2) and as an interactive database https://tinyurl.com/agroforestryevidenceatlas with various filters to identify specific evidence. Articles excluded and their exclusion reasons are also included in the supplementary file (S2). The data for the review findings is available as a supplementary file (S3).

5.1 Temporal and geographical distribution of studies

Relatively few studies were published before 2012 (Figure S2). Since then, the number of studies has steadily grown although year to year variation exists. This growth corresponds to general publication trends across disciplines.

The geographical distribution of the studies varied across continents and countries (Figure 2). Asia had the greatest number of studies (n= 104), followed by South America (n=61) and Africa (n=68). North and Central America had the fewest studies (n=25). In Africa, studies were found from 15 countries, of which Ethiopia and Cameroon had the highest number of studies, 23 and 13 respectively. In Asia, China, Indonesia and India had considerably more studies than any of the other countries. In North and Central America, Mexico had the most studies, whereas Central American countries had 1-4 studies each and Cuba one. Brazil had overall the greatest number of studies as well as by the greatest number of studies in South America (n=34). In terms of agroecological zones, humid lowland tropics had by far the greatest number of studies followed by studies on land with severe soil limitations (Figures 2 and S3).

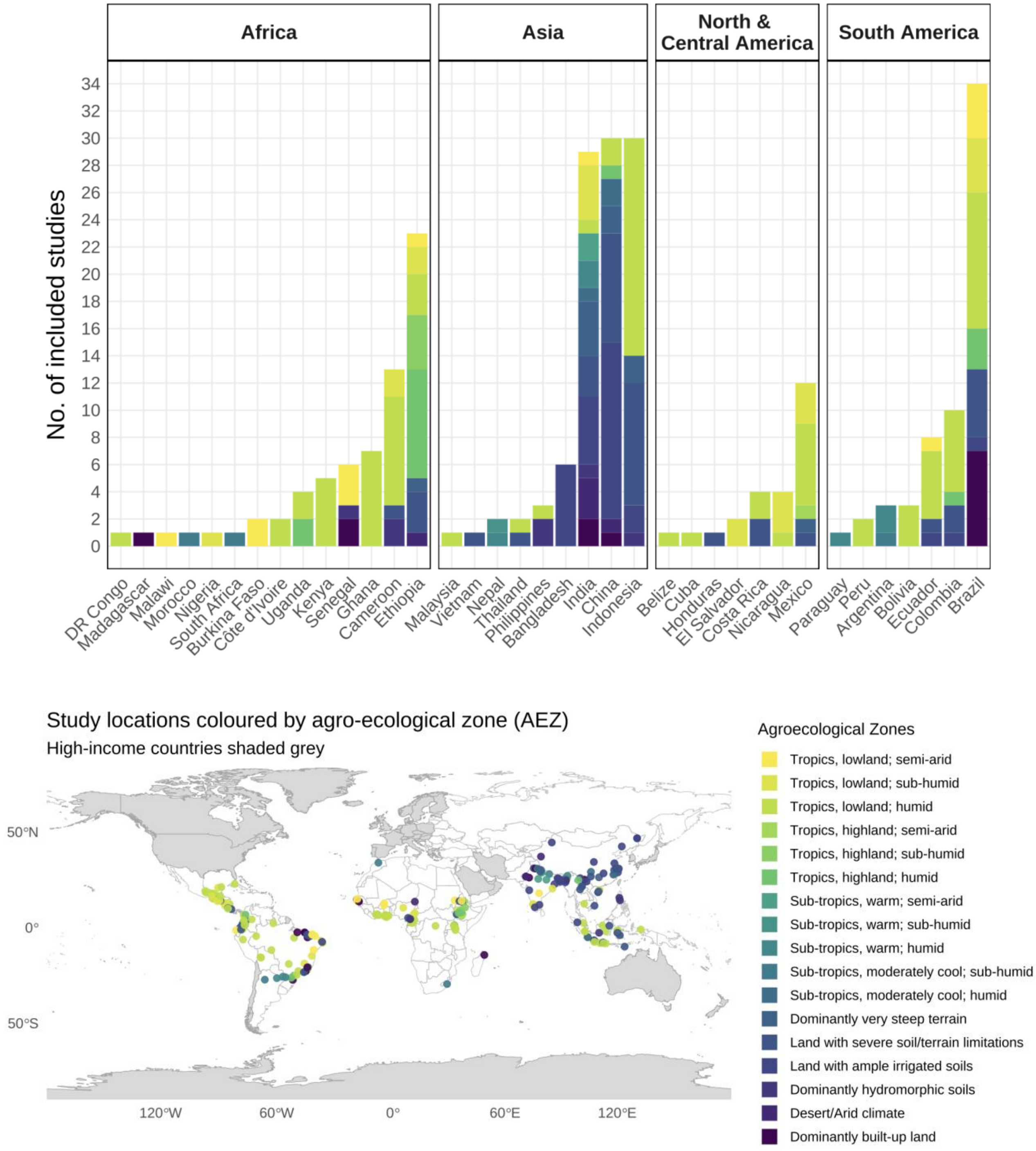

Figure 2. Geographical distribution of the studies across agroecological zones (AEZ). Countries and continents in grey were excluded from the review as the review focused on LMICs.

5.2 Study design, outcomes and attributes of agroforestry systems studied

Most of the 258 included studies reported observational data (n = 176) on existing agroforestry systems, while 82 had an experimental design where agroforestry interventions and comparators were set up and monitored (Figure 3). Most of the studies reported quantitative data only (n = 247), while three reported qualitative data and seven studies reported both data types. Most studies measured outcomes at one time point only (n = 238), while fewer studies reported multiple outcomes measured over time 1-5 years (n = 11), 6-10 years (n = 3), and over 10 years (n = 2). The length of time that agroforestry systems were established prior to measurements being taken was unclear in 125 studies, in particular, the observational studies were unclear in this respect. Agroforestry systems in 23 studies were established for less than 5 years prior to measurements being recorded, while in 81 studies they were established for more than 10 years and the remaining 25 studies were established up to 10 years.

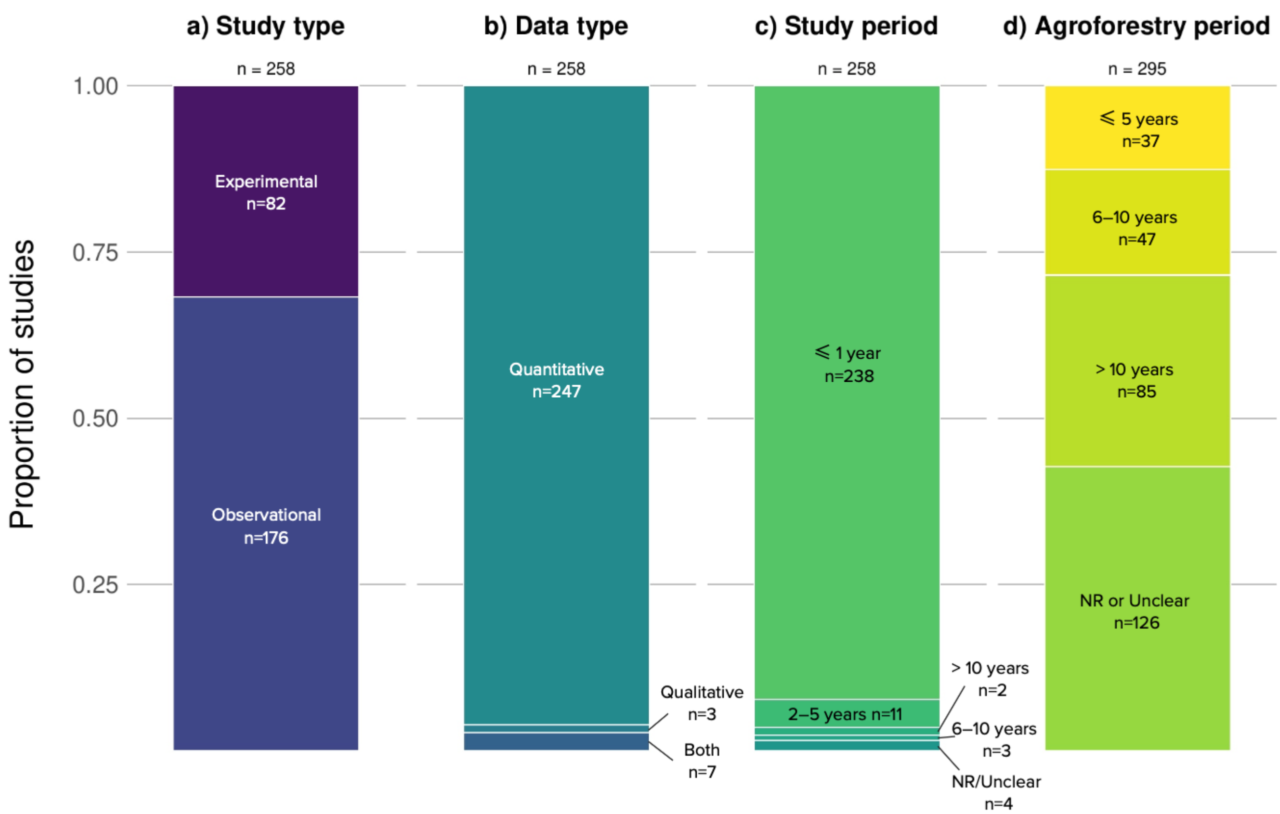

Figure 3. Study characteristics. Only studies reporting a data point are included in the figure. Also, agroforestry period includes data from both comparators and interventions when two or more agroforestry types were compared to each other.

We recorded both the agroforestry type and subtype for interventions and comparators. For interventions, studies involved agrosilviculture (n = 196), silvopasture (n = 23), agrosilvipasture (n = 8) or compared one or more agroforestry type (n = 28), while three studies did not clearly report agroforestry type (Figures 4 and S4). Shadow systems and intercropping were the most common subtypes in agrosilviculture systems whereas scattered trees and intercropping were common in silvopasture systems. Different subtypes were relatively equally distributed under agrosilvipasture systems.

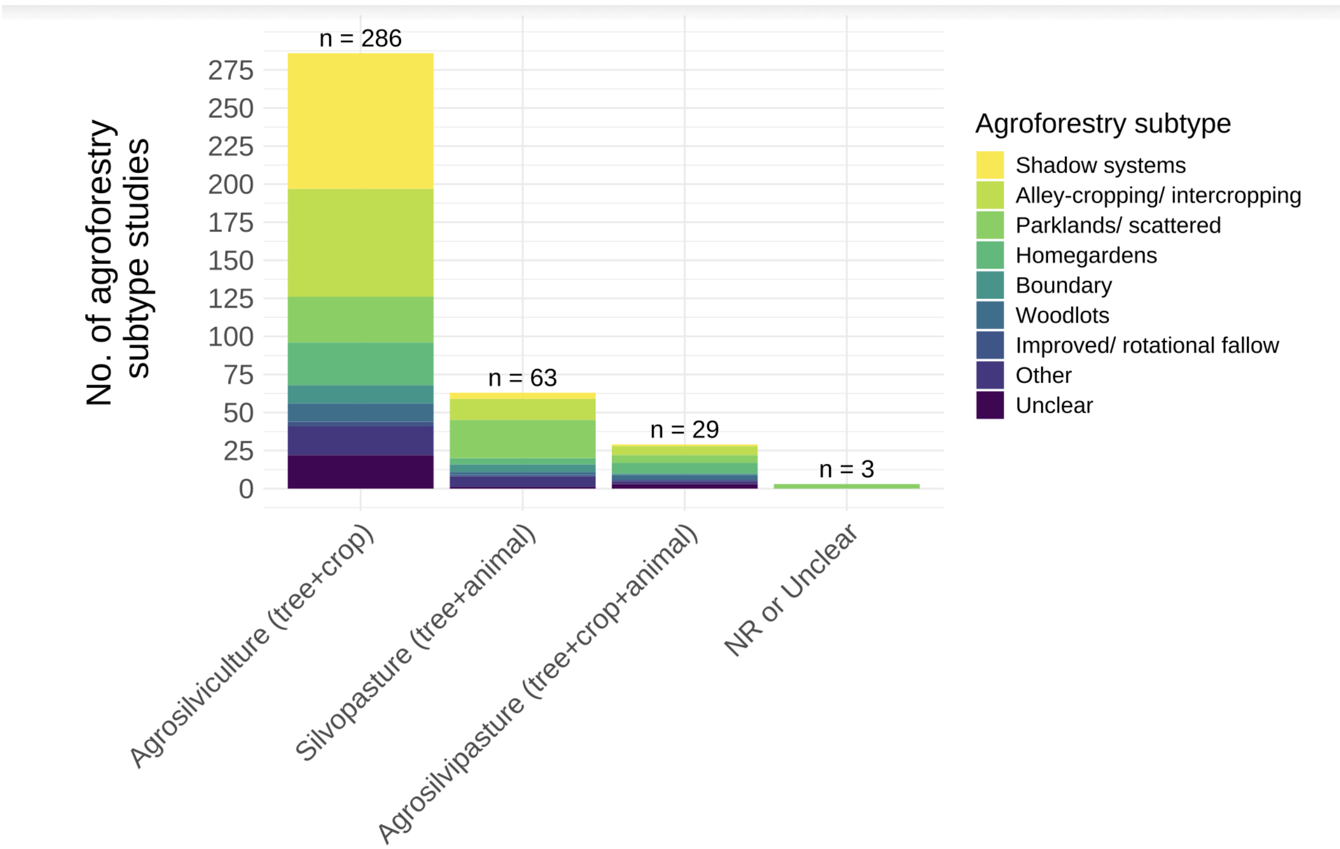

Figure 4. Agroforestry types and subtypes in the included studies. For studies that compared between different types/subtypes, we have included each as an instance here, hence the numbers totalling more than the number of studies in this systematic map.

5.3 Crops and trees used in the agroforestry interventions

The most common crops in the agroforestry system studied were cereals (n = 163), legumes (n=86) and fruit crops (defined as fruits that are grown in the understory below tree species) (n = 80) (Table 3).

Table 3. The most reported crops in studies by categories.

#	Top 10 crop categories (n)
1	Cereal (163)
2	Legume (86)
3	Fruit crops (80)
4	Vegetable (70)
5	Root/tuber (61)
6	Coffee (58)
7	Grass (55)
8	Cacao (50)
9	Medicinal herb (27)
10	Spice (26)

At continental level, maize was the most common crop in Africa and North and Central America as well as the second most common crop in South America (Table 4). Grasses were the most common crops in South America, mainly grown for livestock feed. In Asia, spices and beans were the two most common crops. Coffee and beans were among the top five crops in each continent.

Table 4. Top 5 most common crops across studies in this systematic map (per continent).

STUDY CONTINENT	Top 1	Top 2	Top 3	Top 4	Top 5
Africa	Maize (26)	Cacao (20)	Coffee (20)	Legume (beans) (13)	Medicinal herbs (11)
Asia	Spices (24)	Legume (beans) (21)	Coffee (16)	Medicinal herbs (16)	Grasses (15)
North America (includes Central America)	Maize (11)	Grasses (7)	Coffee (6)	Cacao (5)	Legume (beans) (5)
South America	Grasses (32)	Maize (26)	Legume (beans) (19)	Coffee (16)	Cacao (14)

The most reported tree genus in the Americas was *Mangifera*, which includes the common mango (Table 5). In Asia, four of the top 5 agroforestry species were fruit trees: *Cordia* species, *Psidium spp*. (guava), *Cocos nucifera* (coconut) and *Artocarpus spp.* which includes breadfruit and jackfruit. In contrast, only two of the most common tree genera were fruit trees in Africa: *Musa spp.* (banana) was the most common tree species along with C*itrus spp.* and *Eucalyptus spp*.

Table 5. Top 5 most common agroforestry tree genera across included studies (per continent).

STUDY CONTINENT	Top 1	Top 2	Top 3	Top 4	Top 5
Africa	*Musa* (20)	*Citrus* (19)	*Eucalyptus* (19)	*Albizia* (17)	*Erythrina* (15)
Asia	*Cordia* (23)	*Psidium* (19)	*Acacia* (16)	*Cocos* (15)	*Artocarpus* (13)
North America (includes Central America)	*Mangifera* (7)	*Artocarpus* (6)	*Ficus* (6)	*Acacia* (4)	*Coffea* (4)
South America	*Mangifera* (22)	*Gliricidia* (17)	*Carica* (10)	*Elaeis* (9)	*Citrus* (8)

When looking at the co-occurrence of tree genera and crops, fruit trees are overall more common than timber trees (Figure 5). *Citrus spp.*, *Persea spp.* (avocado) and *Musa spp.* (banana) were the most reported trees with different crops followed by *Psidium spp.* (guava) and fruit trees from genus *Artocarpus*, which includes jackfruit and breadfruit. Coffee was cultivated with variety of trees, most often with *Persea spp.* and *Cordia spp.* followed by *Musa spp.* and *Inga spp*. Cereals were most reported with *Musa spp.* and *Persea spp*. Root and tuber vegetables were cultivated both with timber, e.g. *Swietenia spp.* (mahogany) and fruit trees, e.g. *Musa spp.* and C*itrus spp*. When fruits were included as crops (i.e. grown in the understory), they were most often cultivated with *Inga spp.*, a fast-growing legume trees commonly used in alley-cropping.

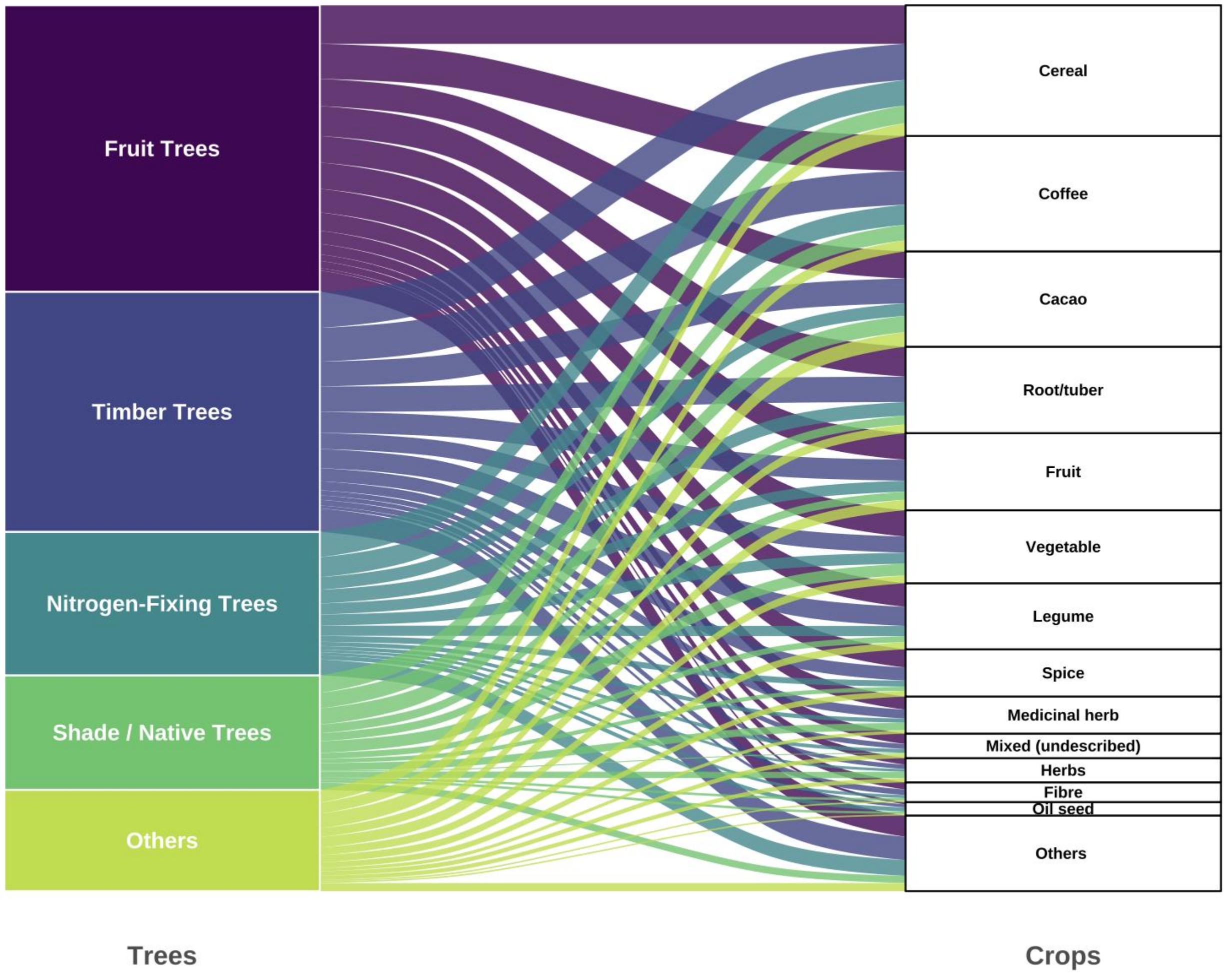

Figure 5. Sankey diagram showing the co-occurrence of tree and crop groupings in agroforestry systems across the reviewed studies. Note: only the most dominant tree and crop groupings represented (smaller groupings are represented as others)

5.4 Studied outcomes, taxa, and their combinations

Figure 6 provides an overview of the studied outcomes across the three outcome domains. Species richness and diversity, soil carbon, soil nutrient and chemical properties were the most studied outcomes. At the other end of the scale, soil degradation, ecosystem processes, and carbon fluxes were the least studied outcomes.

Figure 6. Overview of the studied biodiversity (yellow) and climate change mitigation (green) and adaptation (blue) outcomes.

Plants were by far the most studied taxa (122 studies in total) (Figures 7 and S5). Soil invertebrates (n=54), bacteria (n=50) and fungi (n=46) as well as invertebrates above soil (n=39) were also commonly studied. In contrast, protists, above-soil fungi, mammals, amphibians and birds were all rarely studied (n≤5). The biodiversity measures of species richness (n=97) and diversity (n=89), relative (n=59) and individual abundance (n=11) were most reported for plants (Figures 7 and S6). Community composition (beta diversity) was commonly reported for soil bacteria (n=29) and soil fungi (n=22) whereas abundance of key species was commonly reported for soil fungi (n=12) and soil invertebrates (n=14).

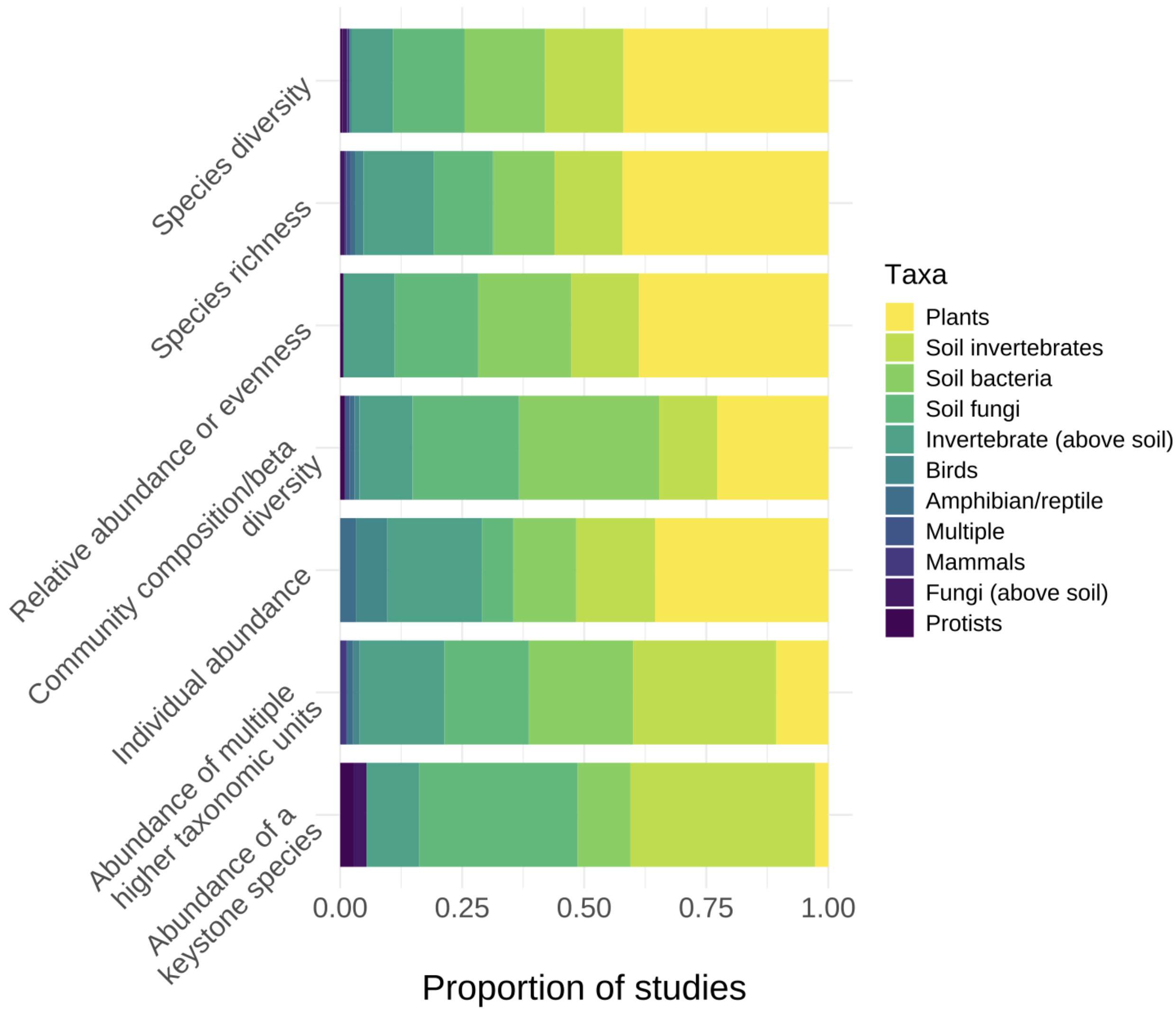

Figure 7. Proportional bar chart showing relative distribution of biodiversity outcomes reported across different taxonomic groups.

Overall, there were studies on almost all biodiversity outcomes in relation to each agroforestry sub-type (Figure 8). Species richness and diversity were commonly measured in relation to shadow systems (65 and 54 studies respectively) and intercropping (58 and 58 studies respectively). Different abundance indicators were less measured, but their distribution was more even across the sub-types. Abundance of higher taxonomic units was the most common abundance measure (60 studies in total).

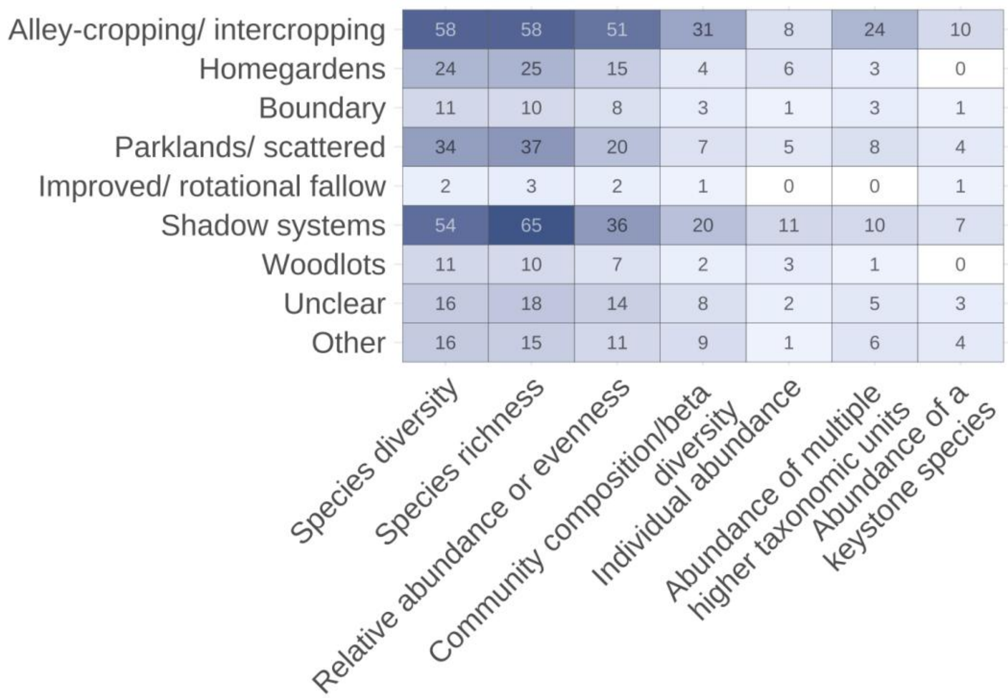

Figure 8. Heatmap presenting the biodiversity outcomes reported across different agroforestry sub-types.

Climate mitigation and adaptation outcomes were commonly measured together (n=189, Figure S7). Climate mitigation alone was measured in 49 studies and adaptation in 20 studies. Soil carbon, soil nutrients and soil chemical properties were the most measured mitigation and adaptation outcomes, and the majority of these studies were conducted in the lowland humid tropics (S8 and S9).

Of biodiversity outcomes, species diversity, richness and relative abundance were the most commonly measured across all mitigation measures (Figure 9a). Different abundance indicators were less often measured in relation to mitigation whereas studies measuring community composition together with a mitigation measure ranged from two studies on total biomass to 35 studies on soil carbon. At the indicator level, species diversity and richness were most often measured together with soil carbon (88 and 83 studies respectfully) and total/ecosystem carbon (56 and 57 studies respectfully). Soil carbon and soil organic matter were the mitigation measures most often measured together with abundance indicators.

Biodiversity measurement in combination with climate adaptation indicators shows a different pattern (Figure 9b). Across studies, soil chemical properties and soil nutrients were most often measured in combination with biodiversity outcomes. Soil degradation, litter and nutrient cycling, and biotic stress and ecosystem regulation were adaptation indicators that were rarely measured together with biodiversity outcomes. Similarly to climate mitigation, species richness, diversity, and relative abundance outcomes were measured more often than abundance indicators.

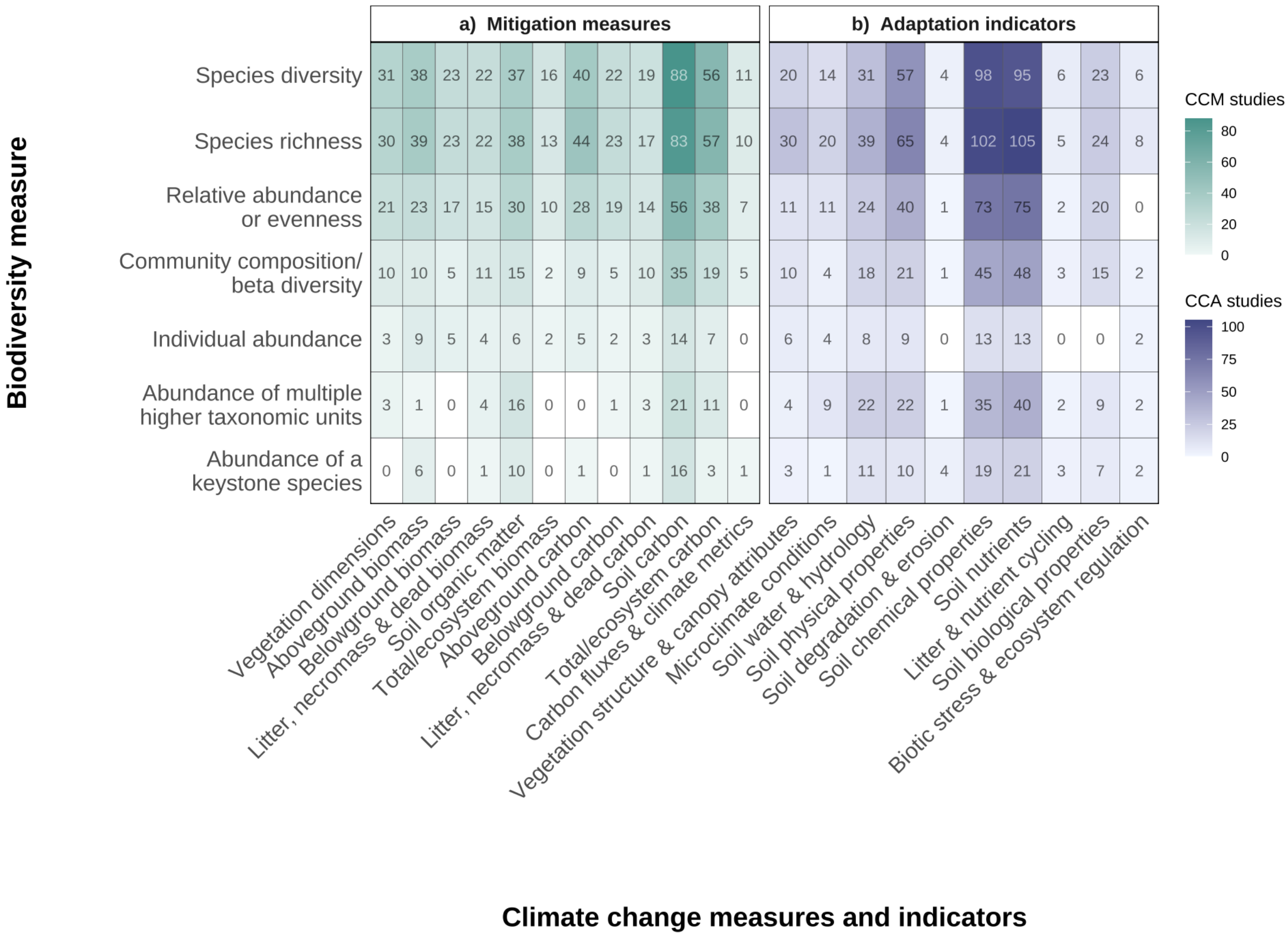

Figure 9. Heatmap showing number of studies measuring biodiversity outcomes and climate change mitigation measures (a) and adaptation indicators (b).

6 Discussion

6.1 Patterns and gaps in the evidence base

This systematic map provides an overview of agroforestry studies measuring both climate and biodiversity outcomes. It shows that overall, the evidence base is relatively large with 258 included studies that have been published since 2005. However, the picture that emerges from our findings is that there are significant gaps in the evidence base. Although we found studies on all continents, the evidence comes from a relatively small number of countries and is heavily concentrated in humid, lowland tropics. Further, the evidence clusters around soil biota and plants in agrosilviculture, particularly shaded systems and intercropping. There is a significant knowledge gap for studies on mammals, birds, amphibians and reptiles. In terms of biodiversity measures, species richness and diversity were the most measured and there is a knowledge gap on broader biodiversity measures. Further, studies on climate change adaptation clustered around soil nutrients and chemical properties with very few studies focusing on ecosystem processes, such as nutrient cycling and ecosystem regulation. Similarly, studies on mitigation were heavily centred around soil carbon.

Taken together, we have an evidence base that mainly focuses on soil health and soil carbon in a few tree-crop systems mostly in humid, lowland tropics. The focus on shaded systems and intercropping is unsurprising, as these systems are commonly used in cultivation of agricultural commodities, such as coffee, cocoa and banana, and have potential to improve environmental sustainability of large-scale production (Becker et al., 2025), notwithstanding historical or current land use change. Less research attention has been given to homegardens, improved fallows and boundary trees although these increase structural complexity within landscapes, which is beneficial for biodiversity and provision of ecosystem services (Santos et al., 2019). These are also systems that may improve smallholder resilience may create further social co-benefits (Aryal et al., 2022; Manaye et al., 2021; Reang et al., 2021).

Very little of the evidence base focuses on ecosystem level impacts, such as carbon fluxes or ecosystem regulation. This methodological gap is significant, as system-level metrics provide a more holistic view of the net mitigation impact by integrating all sources and sinks of GHGs (Smith et al., 2014). Future research should prioritize multi-pool carbon accounting frameworks and adopt longitudinal system-level assessments, which align more closely with IPCC guidelines for comprehensive land-use carbon accounting (Intergovernmental Panel On Climate Change, 2022). Similarly, the evidence base was focused on small number of taxa with very few studies on impacts of agroforestry interventions on vertebrates. Impacts of agroforestry systems on vertebrates have been studied separately (e.g. Silva et al., 2020; Yashmita-Ulman et al., 2021). However, considering the current biodiversity crisis and the potential of climate change to exacerbate extinctions (Urban, 2024), research that examines both outcomes simultaneously at ecosystem level is urgently needed.

Species richness and diversity dominated measured biodiversity outcomes. While useful, these limited metrics fall short of capturing the complexity and ecological resilience of agroforestry systems. Biodiversity, in its full scope, includes many measures beyond species richness, for example, species distribution and abundance, community composition, species traits, and functional diversity (Navarro et al., 2017; Pereira et al., 2013). All these are critical to understanding ecosystem functioning and stability. For example, Häger and Avalos (2017) studied the impact of trait dominance, species diversity, and trait variation on carbon storage in the soils and vegetation of twenty agroforestry systems in Costa Rica. They found that both dominant traits and species complementarity played a role in determining carbon storage. Moving from simple measures to holistic measurement of ecosystem functions and responses is important to identify causal relationships and feedback loops.

Further, studies across multiple taxa can help to identify win-win scenarios across biodiversity and climate change outcomes. For example, Kessler et al. (2012) assessed species richness across four groups of plants and eight groups of animals in tropical agroforestry landscapes in Indonesia. They linked biodiversity across these groups to both above-ground and below-ground carbon stocks. By standardizing species richness across 12 focal taxa, the study illustrated how different organisms contribute uniquely to ecosystem functioning and carbon dynamics. This kind of cross-taxa, system-level perspective offers valuable insights into the synergies between biodiversity and climate mitigation and can help to identify win-win situations for managing production landscapes.

6.2 Methodological constraints in agroforestry studies

Most studies were observational, short-term, and conducted in well-established systems. This has important implications for assessing impacts of agroforestry interventions. The short-term nature of studies is problematic because they do not capture the dynamic nature of agroforestry systems over time or their long-term ecological impacts. Given that many benefits of agroforestry, such as carbon sequestration, emerge over years or decades, this represents a significant constraint on the ability of studies to draw robust conclusions.

Observational studies are sensitive for biases that can arise from research design (e.g. selection bias) and/or confounding factors. Furthermore, the lack of baseline data when short term studies are undertaken in already established systems means that the true effect of the intervention cannot be determined due to lack of information about pre-existing differences. Observational studies with Control-Intervention (CI) design are dominant in environmental research and Before-After Control-Intervention (BACI) designs remain rare (e.g. Christie et al., 2019; Haddaway et al., 2025). Over the years, there have been several calls to improve practices to allow evaluation of impacts (e.g. Christie et al., 2019; Ferraro and Pattanayak, 2006; Griscom et al., 2025; Parker et al., 2019; Sills et al., 2017). These have ranged from implementing small-scale pilot initiatives with experimental (or quasi-experimental) design (Ferraro and Pattanayak, 2006) to larger scale, landscape level experiments to accelerate learning (Griscom et al., 2025). What all these calls have common is intentionality in project design. Incorporating impact evaluation in project planning will help to generate rigorous evidence needed for decision making. Furthermore, when well conducted, impact evaluations help to identify important contextual factors that are key for successful implementation and longevity of programme impacts.

6.3 Limitations

The evidence base was limited in several ways. Agroforestry interventions were poorly described in many studies. Furthermore, many studies alluded to recording outcomes that were not reported so could not be included in the final review. There was also a notable geographical bias in the distribution of studies, with some regions and agroecological zones underrepresented, limiting the generalizability of the findings. Temporal limitations were common, as most studies reported outcomes at a single timepoint.

Despite following a published protocol and using standard methods for conduct and reporting of systematic maps, our review methodology has some limitations. Due to resource constraints, most of the screening and data extraction was conducted by a single reviewer. However, we checked for consistency at each stage and discussed issues within the review team throughout, to minimise the likelihood of inaccuracies. Due to time constraints, we did not complete citation chasing to find additional records. Also, we searched only in English and therefore, most likely have missed some articles published in other languages. However, as we had a comprehensive search strategy and the searches were conducted only at the end of June 2025, we do not believe that we have missed a substantial number of articles.

We chose not to include comparisons with forest or monoculture plantations as we were interested in agroforestry specifically as an agricultural intervention. We recognise that comparing agroforestry to forest ecosystems, especially natural and secondary forests, is valuable from biodiversity conservation and climate change mitigation perspective, but this was outside the scope of our work.

7 Conclusions

To strengthen the evidence base needed to inform agroforestry policy and practice, we have four recommendations for future research. 1) Researchers should improve monitoring and reporting. Current deficiencies and variability in monitoring and reporting hinder collating information about effectiveness of agroforestry interventions. Using standardised indicators for biodiversity monitoring would support achievement of policy goals under the Kunming-Montreal Global Biodiversity Framework. 2) Long-term studies, ideally extending over decadal timescales, are needed to capture ecosystem processes and to assess agroforestry outcomes under changing environmental conditions, as short-term studies are insufficient for evaluating biodiversity and climate change mitigation or adaptation benefits. 3) Projects should be intentionally designed to allow impact evaluation and identification of important contextual factors. 4) Finally, the evidence base should be broadened to include less-studied taxa, regions and systems. Expanding taxonomic and geographic coverage, and increasing research on silvopastoral and agrosilvopastoral systems would improve the global relevance of agroforestry research and help avoid overly narrow development pathways.

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9 Supplementary files

1. S1. ROSES form for systematic maps
2. S2. Included articles and excluded full texts with reason for exclusion
3. S3. Extracted raw data

Annex A. The search string used for the search of academic databases (syntax shown for Web of Science)

Line	Search String	Hits
#1	TOPIC Agroforest* OR “agro forest*” OR agro-forest* OR agriforest* OR “agri forest*” OR agrisilv* OR “agri silv*” OR agri-silv* OR agrosilv* OR “agro silv*” OR agro-silv* OR “silvi-arable” OR silviarable OR silvoarable OR “silvo-arable” OR silvopast* OR “silvo past*” OR silvo-past* OR silvipast* OR “silvi past*” OR “silvi-past*” OR alleycrop* OR “alley crop*” OR “alley coppice” OR “meadow orchard*” OR windbreak* OR “wind break*” OR “forest garden*” OR “tree garden*” OR shelterbelt* OR “shelter belt*” OR “shade-grown” OR “liv* fence*” OR “liv*-snow-fence" OR “boundary plant*” OR “multipurpose tree*” OR “multi-purpose tree*” OR “improved fallow” OR “rotational fallow” OR “shifting cultivation” OR “tree fallow” OR “fertiliser tree*” OR “master tree grower*” OR “mixed farm*” OR “scatter tree*” OR taungya OR (shade NEAR/4 tree*) OR ((agroecolog* OR agronom* OR “agro ecolog*” OR agricult* OR farm* OR crop* OR intercrop* OR arable OR fodder OR livestock* OR pastur* OR homegarden* OR "kitchen garden*” OR “home garden*” OR “integrated production”) AND (forest* OR tree* OR wood* OR orchard* OR parkland* OR shrub* OR hedge-crop* OR “hedge crop*” OR hedgerow* OR “hedge row*” OR multi-strata OR “multi strata” OR multistrata))	185,241
#2	TOPIC biodivers* OR bio-divers* OR “bio divers*” OR “biological diversity” OR agrobiodivers* OR agro-biodivers* OR “agro biodivers*” OR abundance OR richness OR “species composition” OR “community composition” OR “community similarity” OR “community structure” OR “species assemblage” OR beta-diversity OR “beta diversity”	972,164

	OR ((species OR ecosystem* OR habitat OR flora* OR fauna* OR biota OR biotic OR herbivor* OR predator* OR detritivore* OR pollinat* OR saproxylic OR insectivore*) NEAR/15 divers*) OR (soil NEAR/2 (microbiota OR macrobiota OR micro-org* OR microorg* OR biot*))	
#3	TOPIC “climate change” OR “climate proof*” OR ((adapt* OR resilien* OR risk* OR mitigat* OR respons* OR sustainab*) NEAR/15 (climate OR agricultur* OR farm* OR drought OR flood* OR soil OR water OR rain* OR heat OR "surface runoff" OR evapotranspiration OR frost* OR temperature* OR weather OR cold OR “sea level” OR sea-level OR storm* OR precipitation OR thermal OR microclimat* OR ecosystem*)) OR ((agroecosystem OR ecological OR livestock OR crop*) NEAR/6 resilien*) OR (climat* NEAR/15 “crop diversi*”) OR (“greenhouse gas*” OR GHG* OR "low-carbon development" OR "emission* reduction" OR “low* emission*” OR “carbon emission*” OR "carbon-emission" OR CH4 OR N2O OR “methane emission*” OR “nitrous oxide emission*” OR “carbon dioxide emission*” OR “CO2 emission*” OR “non-carbon dioxide emission*” OR “carbon storage” OR “C storage” OR “aboveground biomass” OR “above-ground biomass” OR “aboveground plant biomass” OR “above-ground plant biomass” OR “aboveground C” OR “above-ground C” OR “belowground plant biomass” OR “below-ground plant biomass” OR “belowground biomass” OR “below-ground biomass” OR “belowground C” OR “below-ground C” OR “biomass carbon” OR “soil organic carbon” OR “soil C storage” OR “carbon stock” OR “C stock” OR sequestration)	 1,751,795
#4	TOPIC/AFFILIATION LMIC* OR “low-income countr*” OR “middle-income countr*” OR Asia* OR Africa* OR afghanistan* OR algeria* OR angola* OR antigua* OR barbuda* OR argentin*a* OR aruba* OR azerbaijan* OR bahrain* OR bangladesh* OR barbados OR barbadian OR belize* OR hondura* OR benin OR beninese OR bhutan* OR bolivia* OR botswana* OR batswana* OR matswana* OR brazil* OR brasil* OR “burkina faso” OR “burkina fasso” OR burkinabe OR “upper volta*” OR burund* OR ulundi OR “cabo verde” OR “cape verde*” OR cambodia* OR kampuchea* OR “khmer republic” OR cameroon* OR cameron OR cameroun OR “central african republic” OR “ubangi shari” OR chad OR chadian OR chile OR chilean OR china OR chinese OR colombia* OR comoros OR comorian OR “comoro islands” OR “iles comores” OR mayotte OR majoran OR “democratic republic of the congo” OR “democratic republic congo” OR congo OR congolese OR zaire OR “costa rica*” OR “cote d’ivoire” OR “cote d’ ivoire” OR “cote divoire” OR “cote d ivoire” OR “ivory coast” OR ivorian OR cuba OR cuban OR djibouti* OR “french Somaliland” OR dominica* OR “dominican	 6,424,155

	republic” OR ecuador* OR egypt* OR “united arab republic” OR UAE OR “el salvador*” OR “equatorial guinea” OR “spanish guinea” OR guinean OR eritrea* OR eswatini OR “swazi swati” OR swamis OR swaziland OR ethiopia* OR fiji OR fijian OR gabon OR gabonese OR “gabonese republic” OR gambia* OR ghana* OR grenada* OR guam OR guamanian OR guatemala* OR guinea* OR “guinea Bissau” OR guyana* OR “british guiana*” OR haiti* OR hispaniola* OR india OR indian OR indonesia* OR timor OR timorese OR iran OR iranian OR iraq OR iraqi OR jamaica* OR jordan OR jordanian OR kenya* OR “democratic people’s republic of korea” OR “north korea*” OR korea* OR kyrgyzstan* OR kirghizia OR kirgizstan* OR “kyrgyz republic” OR kirghiz OR laos OR "lao pdr" OR “lao people’s democratic republic” OR laotian OR lebanon OR lebanese OR “lebanese republic” OR lesotho OR basotho OR mesotho OR basutoland OR liberia* OR libya* OR “libyan arab Jamahiriya” OR macau OR maganese OR macao OR madagasca* OR malagasy OR malawi* OR nyasaland OR malaysia* OR “malay federation” OR “malaya federation” OR maldives OR maldivian OR “indian ocean islands” OR “indian ocean” OR mali OR malian OR micronesia* OR “federated states of Micronesia” OR kiribati OR “marshall islands” OR nauru* OR “northern mariana islands” OR palau* OR tuvalu* OR mauritania* OR mauritius OR mauritian OR mexico OR mexican OR mongolia* OR morocc* OR ifni OR mozambi* OR “portuguese east Africa” OR myanmar OR burma OR myanmar OR namibia* OR nepal* OR “netherlands Antilles” OR nicaragua* OR niger OR nigerien OR nigeria OR nigerian OR oman* OR muscat OR pakistan* OR panama* OR “papua new guinea” OR “new guinea” OR paraguay* OR peru OR peruvian OR philippin* OR philipin* OR phillipin* OR phillippin* OR filipino OR “puerto rico” OR “puerto rican” OR rwanda* OR ruanda* OR samoa* OR “pacific islands” OR “pacific islander*” OR polynesia* OR “samoan islands” OR “navigator island” OR “navigator islands” OR “sao tome and principe” OR “sao tomean” OR santomea OR “saudi arabia*” OR senegal* OR seychelles OR seychellois OR “sierra leone*” OR melanesia* OR “solomon island*” OR “solomon islander*” OR “norfolk island” OR “norfolk islander*” OR somali* OR “south africa*” OR “south sudan*” OR “sri lanka*” OR ceylon OR “saint kitts and nevis” OR kintian OR nevisia OR “st. kitts and nevis” OR “saint lucia*” OR “st. Lucia*” OR “saint vincent and the grenadines” OR “saint Vincent” OR “st. Vincent” OR grenadines OR “saint vincentians” OR vincentians OR sudan* OR suriname* OR surinam OR “dutch Guiana” OR “netherlands Guiana” OR syria* OR “syrian arab republic” OR tajikistan* OR tadjikistan* OR tadzhikistan* OR tadzhik* OR tanzania* OR tanganyika* OR thailand OR thai OR siam* OR “timor leste” OR “east timor*” OR togo OR togolese OR “togolese republic” OR tonga* OR “trinidad and Tobago” OR trinidad OR tobago OR trinidadian OR tobagonians OR tunisia* OR turkmenistan* OR turkmen OR uganda* OR uruguay* OR uzbekistan* OR uzbek OR vanuatu OR "new hebrides" OR venezuela* OR vietnam* OR “viet nam” OR Zaire OR zambia* OR zimbabwe* OR “northern Rhodesia” OR “global south” OR “africa south of the sahara” OR “sub-saharan” OR subsaharan OR “central Africa” OR “africa, northern” OR “north Africa” OR “northern Africa” OR maghreb OR maghrib OR sahara OR “africa, southern” OR “southern Africa” OR “africa, eastern” OR MENA OR “Western Sahara” OR “east Africa” OR “eastern Africa” OR “africa, western” OR “west Africa” OR “western Africa” OR “west indies” OR “indian ocean islands” OR caribbean OR “central America” OR “latin America” OR “south and central America” OR “south america" OR "asia, central" OR "central asia" OR "asia, northern" OR "north*	

	asia" OR "northern asia" OR “south* asia*” OR “asia, southeastern” OR “south eastern asia” OR “southeast asia” OR “south east asia” OR “asia, western” OR “western asia” OR “developing countr*” OR “developing nation*” OR “developing population*” OR “developing world” OR “less developed countr*” OR “less developed nation*” OR “less developed population*” OR “less developed world” OR “lesser developed countr*” OR “lesser developed nation*” OR “lesser developed population*” OR “lesser developed world” OR “under developed countr*” OR “under developed nation*” OR “under developed population*” OR “under developed world” OR “underdeveloped countr*” OR “underdeveloped nation*” OR “underdeveloped population*” OR “underdeveloped world” OR “middle income countr*” OR “middle income nation*” OR “middle income population*” OR “low income countr*” OR “low income nation*” OR “low income population*” OR “lower income countr*” OR “lower income nation*” OR “lower income population*” OR “underserved countr*” OR “underserved nation*” OR “underserved population*” OR “underserved world” OR “under-served countr*” OR “under-served nation*” OR “under-served population*” OR “under-served world” OR “deprived countr*” OR “deprived nation*” OR “deprived population*” OR “deprived world” OR “poor countr*” OR “poor nation*” OR “poor population*” OR “poor world” OR “poorer countr*” OR “poorer nation*” OR “poorer population*” OR “poorer world” OR “developing econom*” OR “less developed econom*” OR “lesser developed econom*” OR “under developed econom*” OR “underdeveloped econom*” OR “middle income econom*” OR “low income econom*” OR “lower income econom*” OR “low gdp” OR “low gnp” OR “low gross domestic” OR “low gross national” OR “lower gdp” OR “lower gnp” OR “lower gross domestic” OR “lower gross national” OR “third world” OR “lami countr*” OR “transitional countr*” OR “emerging econom*” OR “emerging nation*” OR “emerging market*” OR “least developed countr*”	
#5	#1 AND #2 AND #3 AND #4	5,495
#6	Limit #5 to 2005-2025	5,486

Annex B. Grey literature sources

Fifteen organizational or institutional repositories were searched manually and using built-in search tools:

Organisation name	**URL**
AgEcon	https://ageconsearch.umn.edu/?ln=en.
British Ecological Society (BES)	https://www.britishecologicalsociety.org
Center for International Forestry Research (CIFOR) & World Agroforestry (ICRAF)	https://cifor-icraf.org
CGSpace, a repository of CGIAR (The consortium of international Agricultural Research Centres)	https://cgspace.cgiar.org/home

EASAC Environment Programme	https://easac.eu/programmes/environment
Food and Agriculture Organization (FAO)	https://www.fao.org/home/en
International Food Policy Research Institute (IFPRI)	https://www.ifpri.org/
International Fund for Agricultural Development (IFAD)	https://www.ifad.org/en/
International Livestock Research Institute (ILRI)	https://ilri.org
Joint Nature Conservation Committee (JNCC)	https://jncc.gov.uk
National Environment Research Council (NERC)	https://nerc.ukri.org
The Alliance of Biodiversity International and the International Center for Tropical Agriculture (CIAT)	https://alliancebioversityciat.org
The Nature Conservancy	https://www.nature.org/enus
World Bank	https://www.worldbank.org/en/home
Worldwide Fund for Nature	https://www.wwf.org.uk

Annex C. Criteria to assess eligibility of studies at title-abstract and full text screening stage.

Inclusion criteria	**Exclusion criteria**
Population	
Agricultural systems in LMICs, the latter as defined by the World Bank categories (*World Bank Country and Lending Groups – World Bank Data Help Desk*, 2023). We define agricultural systems as areas undergoing cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products. Commercial, smallholder and subsistence agriculture settings are all eligible.	Non- LMICs, non-agricultural systems. Aquaculture, and other non-land-based systems. Cultivation of trees (i.e. plantations) / forestry as the primary crop system. Settings that are not clearly or intentionally agricultural e.g. rangelands, large savannahs, natural forests where planting/grazing is minimal.
Intervention	
Articles must have agroforestry as an intervention, which we define as 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. This includes where grazing animals have been deliberately moved to forested areas for silvopasture. Some commonly used systems and terms used to describe agroforestry interventions include (but are not limited to) hedgerows, shelterbelts, live fences, windbreaks, alley-cropping, improved or rotational fallow, riparian buffer strips, parklands, intercropping, woodlots, homegardens, meadow orchards, or forest fallows. These terms may need to appear in combination with other descriptors to confirm that deliberate agroforestry was undertaken. Studies will fall into one of the three broad agroforestry types (see Box 1 for detailed rationale): 1. Agrosilviculture: Integrating trees with crops 2. Silvopasture: Combining trees with livestock grazing 3. Agrosilvipasture: Trees integrated with both crops and livestock as a system	Articles that do not focus on agroforestry (as defined here) as an intervention being studied.
Comparator	
Articles must contain at least one of the following controls or comparators:	Articles that do not contain any of the listed controls or comparators.

Temporal control (i.e. “before” the intervention began in a plot, also known as “baseline”); Spatial control (e.g. a similar plot where no intervention was applied); Comparison with another intervention (e.g. improved fallow plot vs boundary trees plot); Comparison with another level of the same intervention (e.g. plot with high shaded (> 80% cover) vs a plot with low shaded (< 40% cover) area). We included studies comparing similar agroforestry systems where the only difference was tree species or tree ages.	Studies where the comparator is a forest plantation/monoculture of the shade- providing tree in the agroforestry system.
Biodiversity outcomes	
Articles must report data on biodiversity, measured as one or more of the following: -Species richness, species diversity, individual abundance, relative abundance/ evenness, community composition.	Articles that do not report any measure of biodiversity. Articles reporting only biodiversity of planted species, or of crop species only. Articles reporting climate outcomes only will be excluded.
Climate change adaptation and mitigation outcomes	
Articles must report data on either climate change mitigation or climate adaptation, or both these outcomes Climate change mitigation, measured as: Biomass accumulation, tree basal area, carbon storage, carbon sequestration, GHG (specifically, CH_4, N_2O) emissions reduction, SOC sequestration, carbon storage in biomass, carbon storage in leaf litter. We include studies describing CCM-related components (e.g., carbon stock) even if they do not explicitly state their relevance to CCM. Carbon stock data alone is sufficient for inclusion under CCM. Climate change adaptation, described as adaptations improve agri-ecosystem resilience to climate variability and extreme weather events, and reported as/ measured as: Wind erosion, soil erosion, microclimate regulation, soil fertility, soil salinity, water conservation, soil moisture retention, soil microbial diversity, soil surface temperature, soil pH, soil N, Ca^{2+}, Mg^{2+},K^{+},Na^{+}, Al^{3+}, soil	Articles that do not report data on either climate change mitigation or climate change adaptation (i.e. articles reporting biodiversity outcomes only will be excluded). The following outcomes are not sufficient as a single measure of CCM/A and at least two must be reported: tree basal area, soil bulk density, soil pH Tree density is not eligible as an outcome measure.

bulk density, soil compaction, water regulation, soil resilience, soil stability, drought tolerance, frost damage, livestock resilience, fodder for livestock, shade provision, pest and disease outbreak, habitat for pollinators and wildlife. Other soil health parameters are eligible. We include studies describing CCA-related components (e.g., soil conservation, erosion control, SOM data as indicator of CCA) even if they do not explicitly state their relevance to CCA. Where studies report a measure of climate change adaptation not listed here, the review team (which includes subject experts) will consider, discuss and add the measure to this list if deemed appropriate.	
Study type	
Articles containing primary, empirical, quantitative and qualitative data. Studies must include practical evidence derived from field implementation or direct empirical observations, or in the case of qualitative data, peoples' first-hand opinions, perspectives or lived experiences. For example, eligible qualitative data would constitute direct quotes by a farmer, describing their subjective view on whether an agroforestry intervention has impacted one of the eligible outcomes. This qualitative data must have been collected as intentional research, i.e. with a clearly defined research objective and methodological description to the research.	Articles that do not contain any primary data. Articles that report only modelling data (that contain no eligible empirical observation data). Articles reporting anecdotal observations. Opinion pieces, theoretical articles, editorials, or purely conceptual works. Review articles, secondary analyses and meta-analyses that lack empirical data. Qualitative works that do not have a defined research objective or method e.g. storytelling/narratives.
Timeframe	
Articles published between 2005-2025. Where no publishing information is given, the article should have been made available/ or study conducted within this timeframe.	Articles published prior to 2005

Supplementary figures

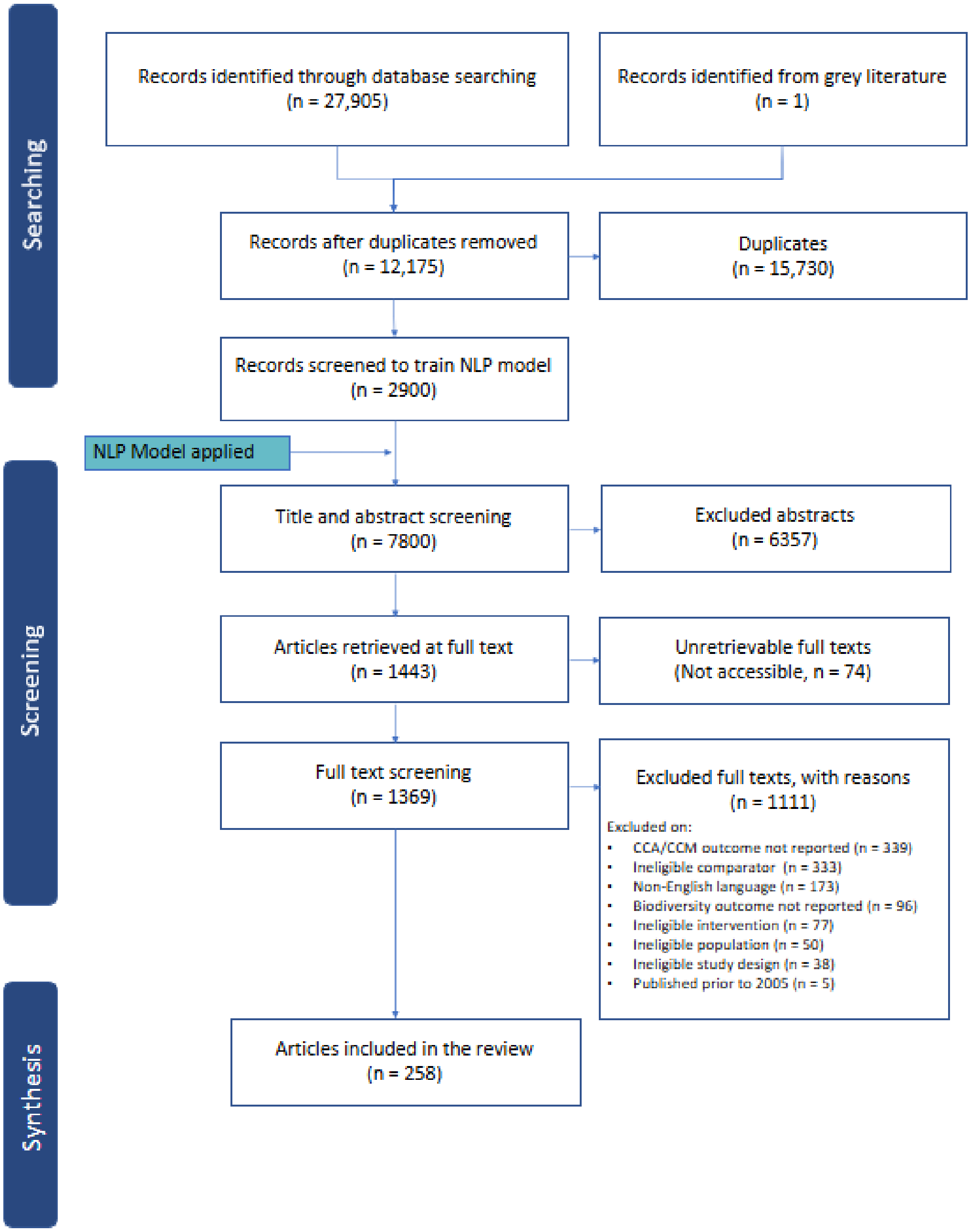

Figure S1. Number of articles included at different stages of the review process.

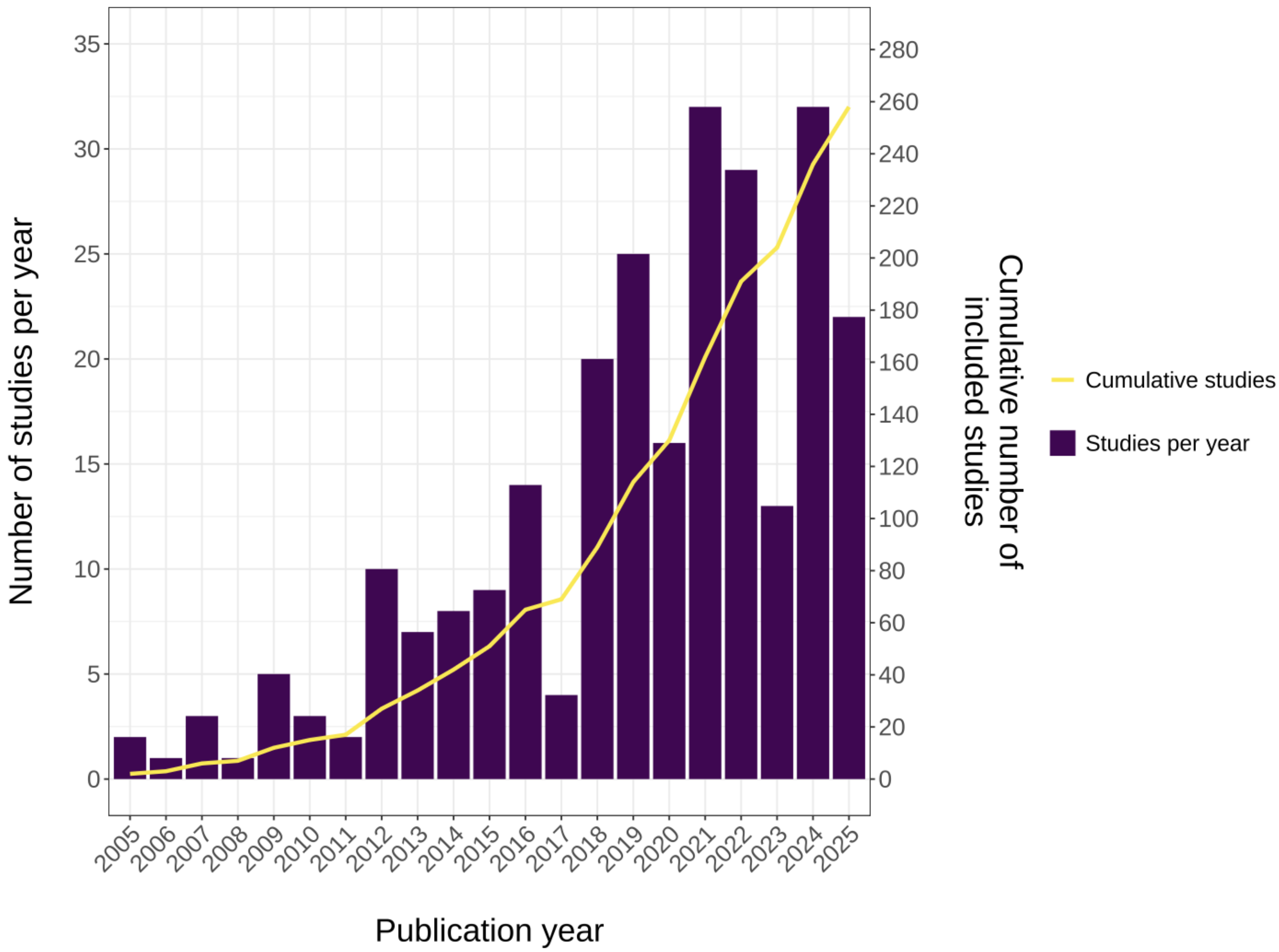

Figure S2. Studies published per year and cumulatively since 2005.

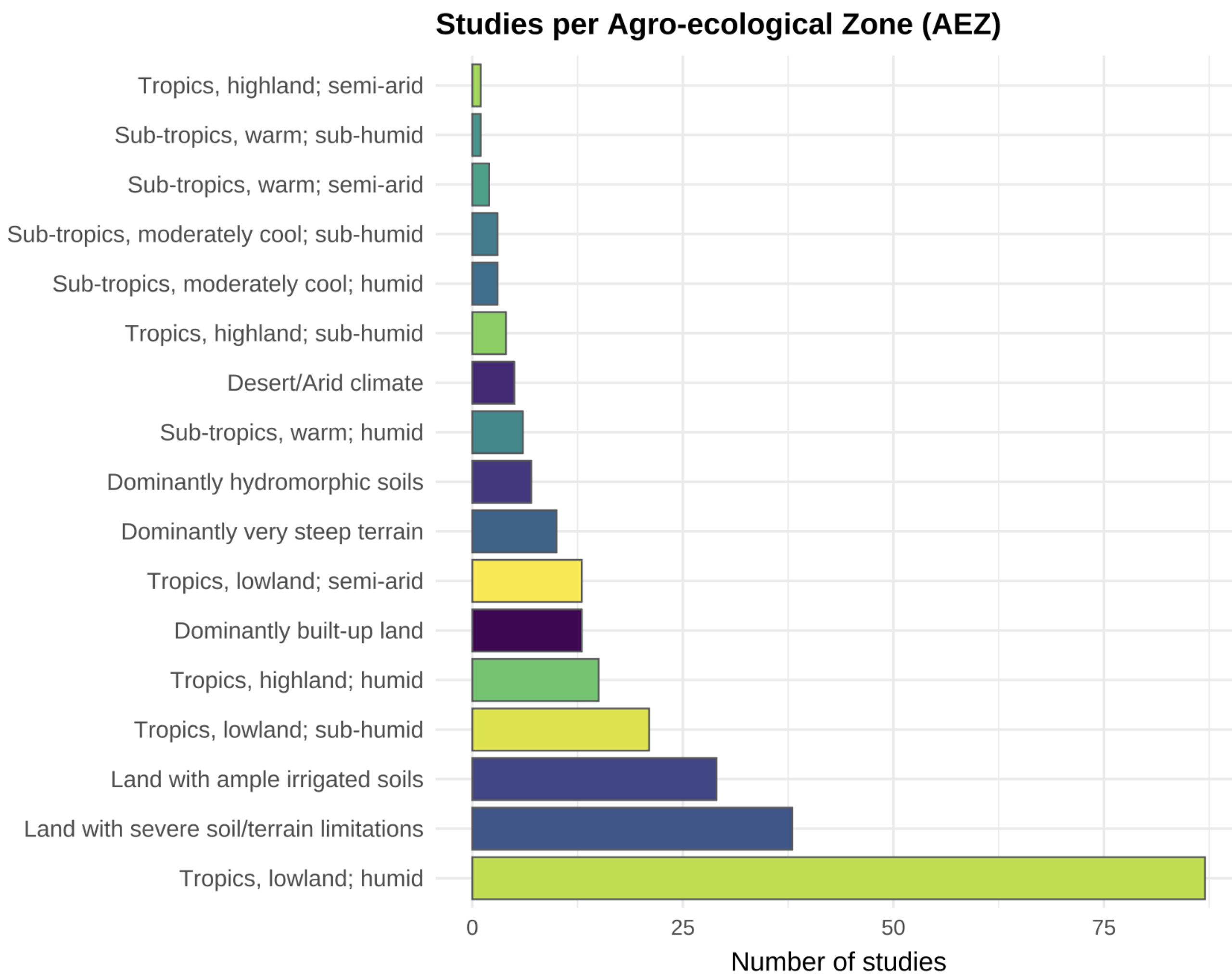

Figure S3. Studies per agroecological zone.

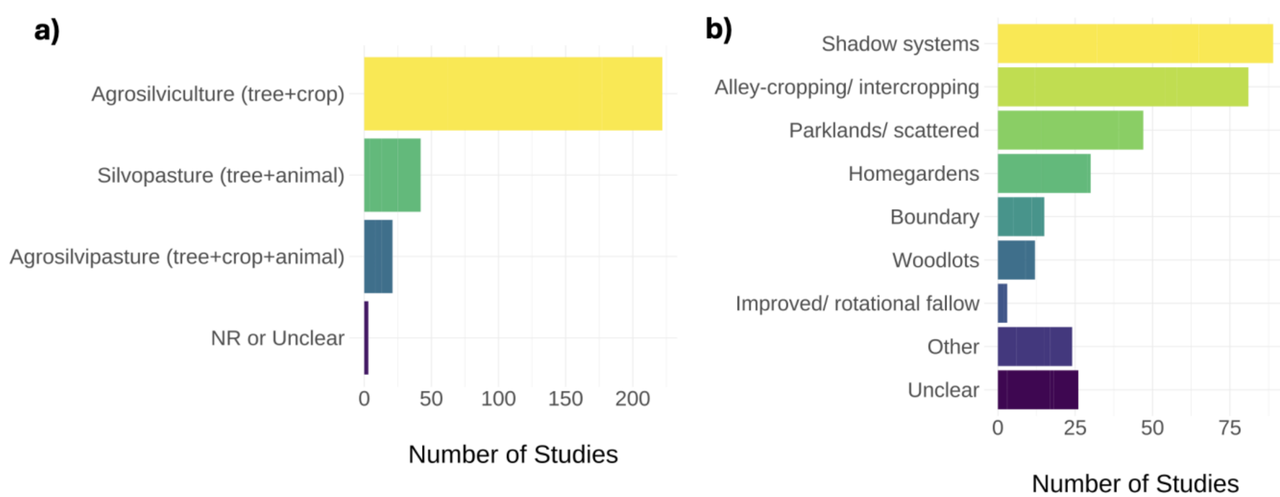

Figure S4. Agroforestry a) type and b) subtype.

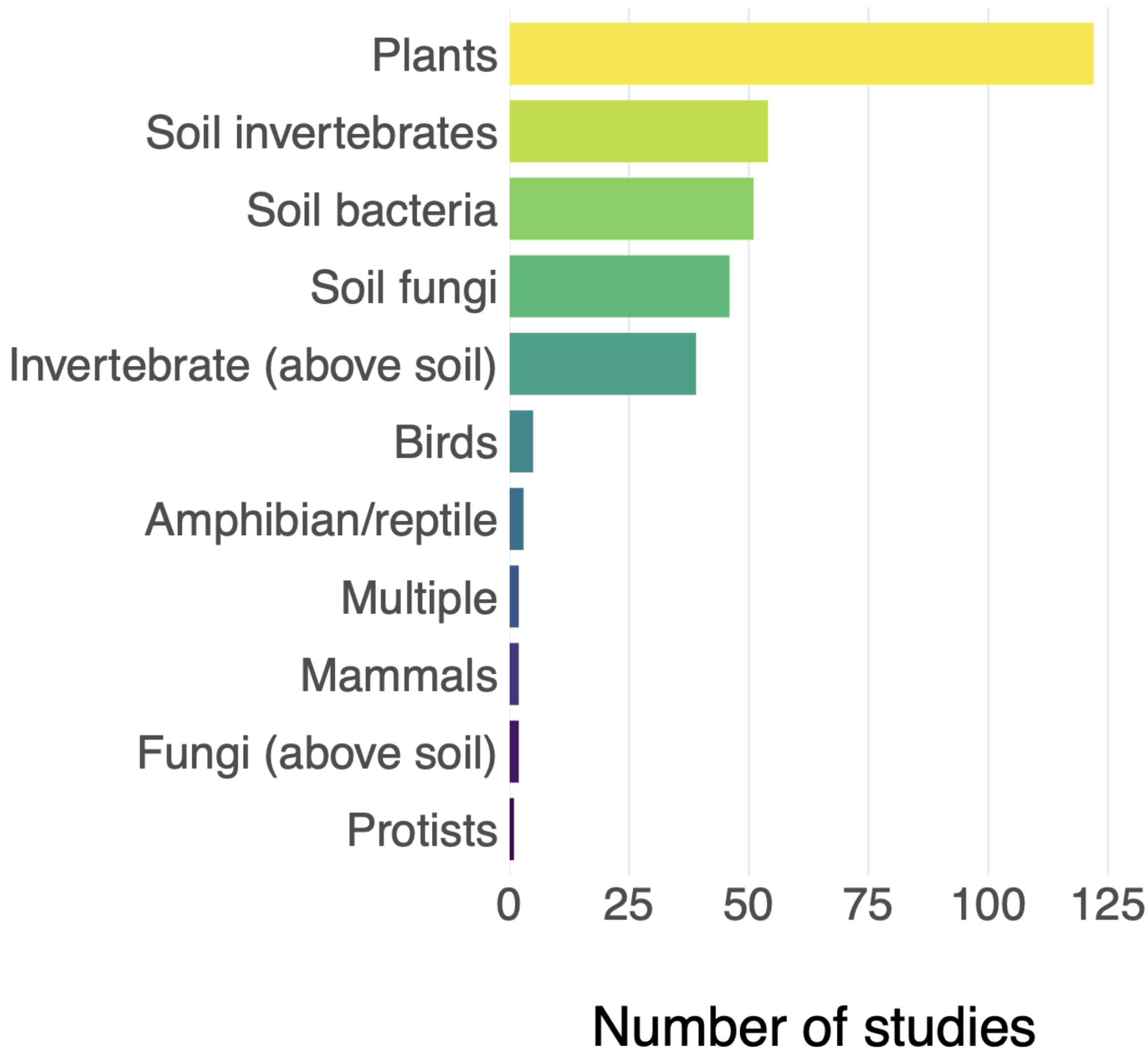

Figure S5. Taxonomic groups studied.

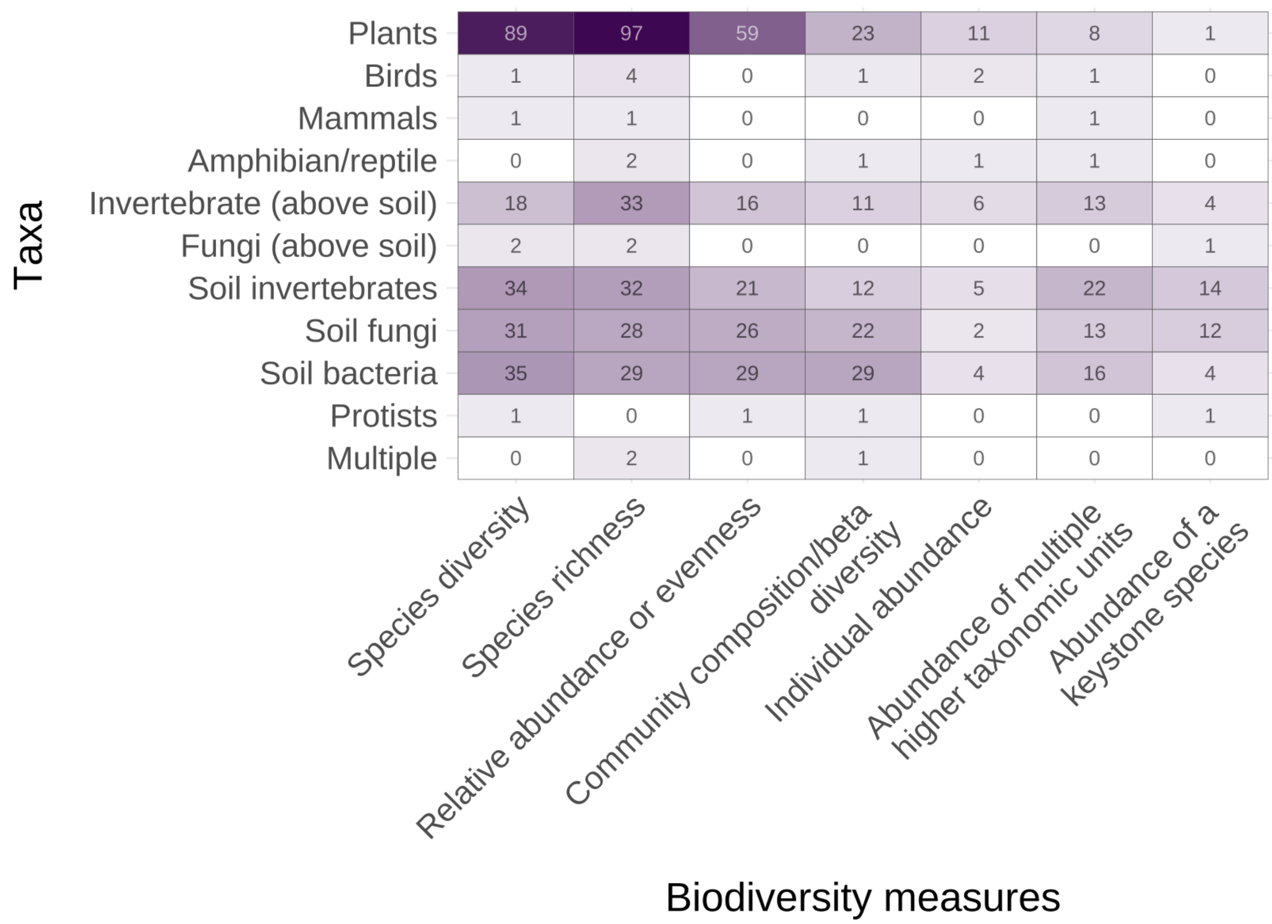

Figure S6. Number of studies for different biodiversity outcomes across taxonomic groups.

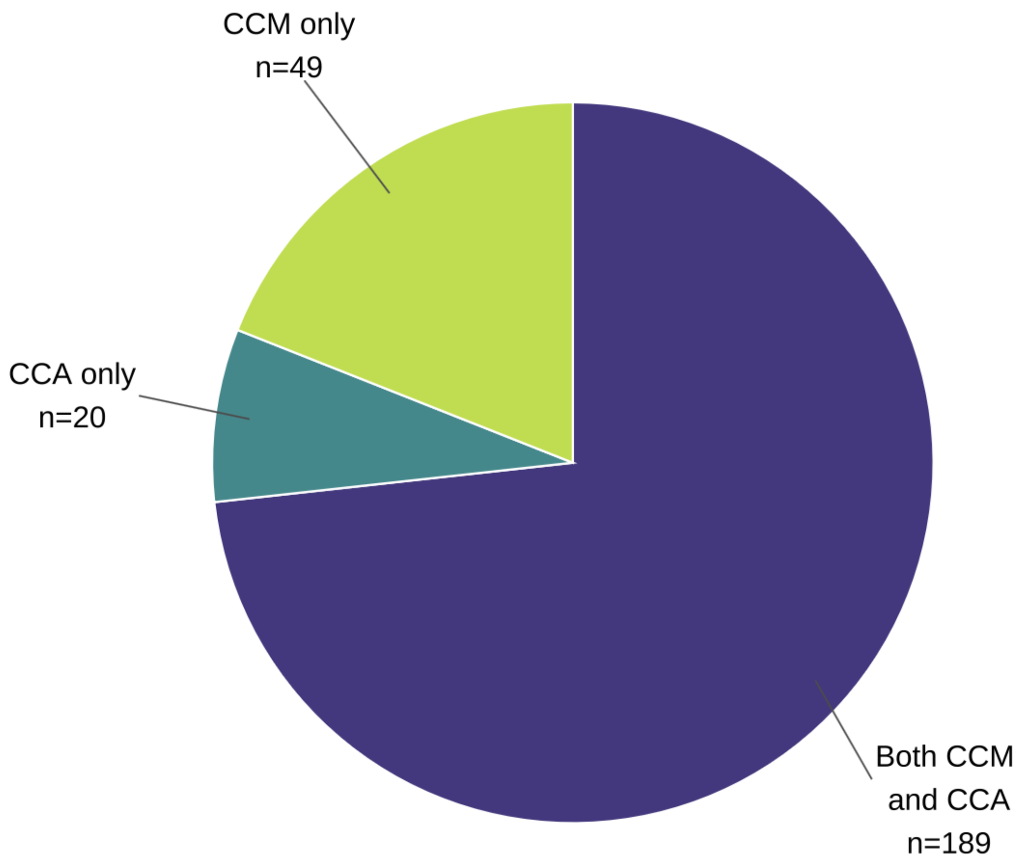

Figure S7. Distribution of studies measuring climate change mitigation (CCM), adaptation (CCA) or both.

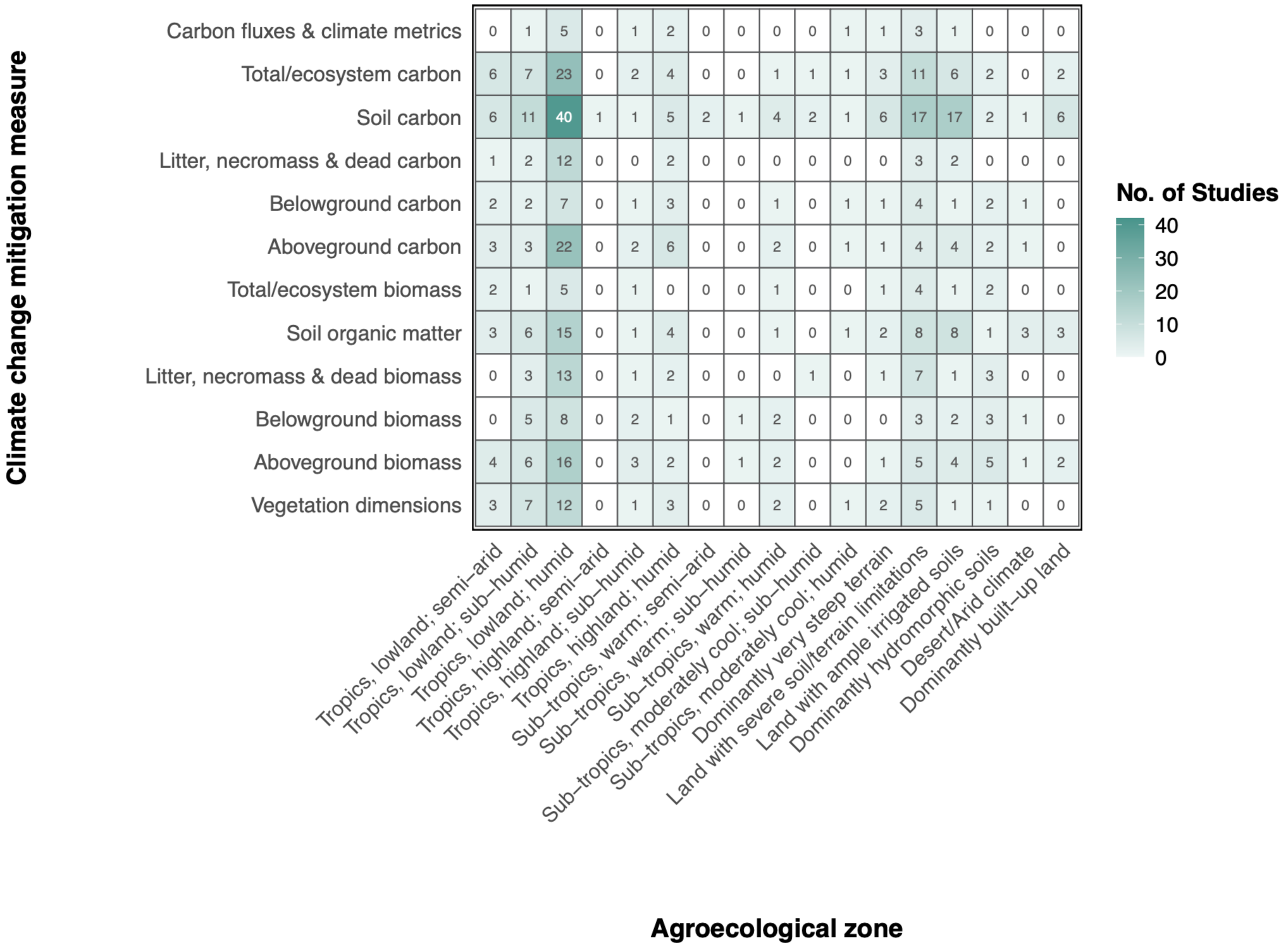

Figure S8. Number of studies measuring climate change mitigation outcomes per agroecological zone.

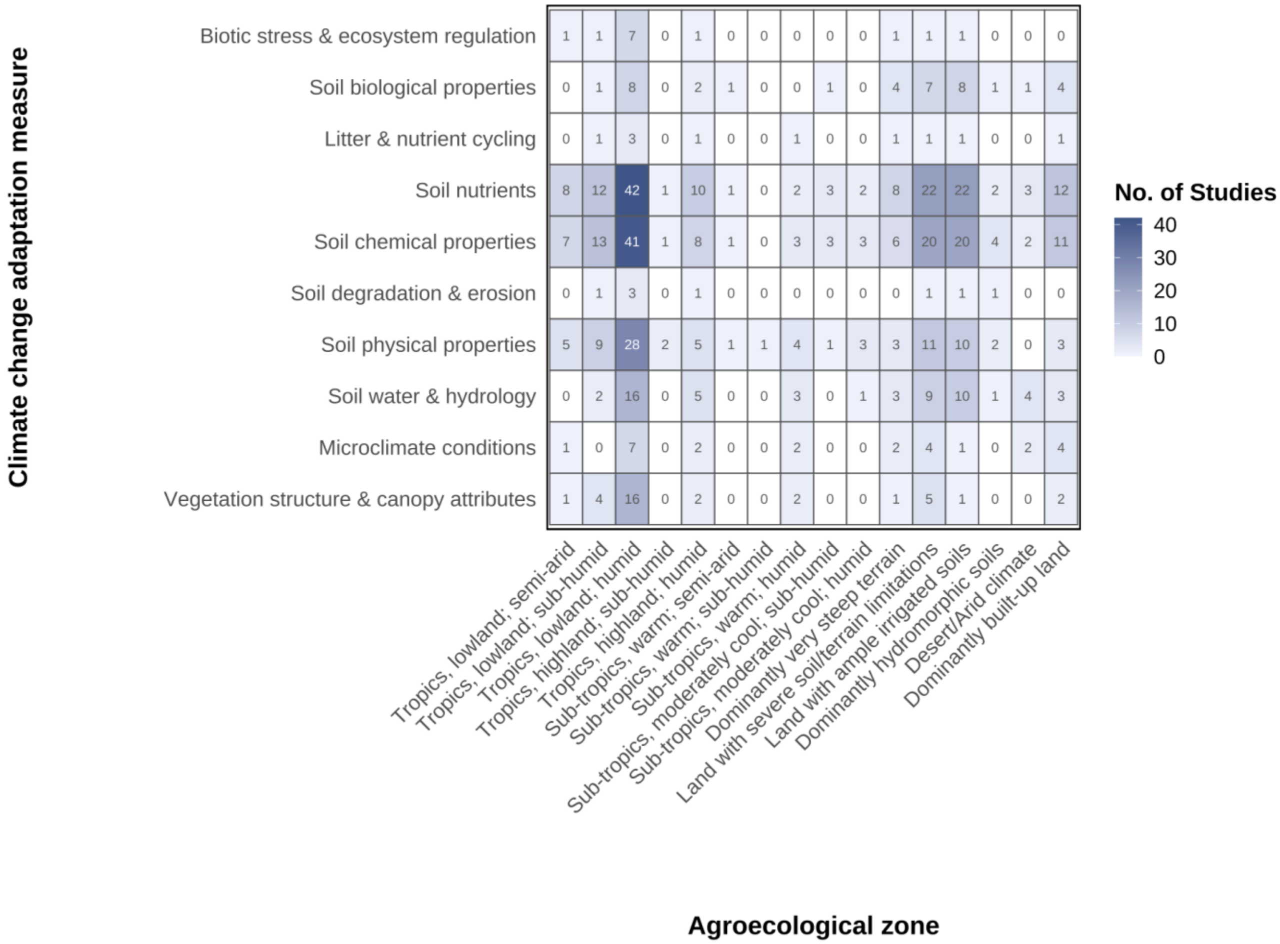

Figure S9. Number of studies measuring climate change adaptation outcomes per agroecological zone.