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A Systematic Review of Ongoing Research and Future Perspectives in Nature Based Solution (NbS) in Agriculture

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Abstract: Nature-based Solutions (NbS) are becoming more popular in the current time to address the complex issues of climate change, biodiversity loss and food security in agro-ecosystems. In this systematic review, we synthesize existing empirical research on NbS in agriculture, focusing on their effectiveness, implementation difficulties, and potential for upscaling. Employing a rigorous methodology aligned with PRISMA 2020 criteria, we screened 2,900 records from Web of Science, Scopus, and Google Scholar. We included 83 studies (65 empirical, 10 meta-analyses, and eight policy documents) after quality assessment. The analysis demonstrates that NbS practices make a considerable contribution to carbon sequestration, with reported rates ranging from 1.8 to 133 Mg C ha^{-1}, depending on the practice and setting. Substantial benefits in biodiversity, including increases in pollinator populations and soil microbial richness, are also routinely seen. Economically, NbS provides significant returns on investment, with specific practices earning over £4 for every £1 invested and short payback times. Despite these benefits, widespread adoption is limited by a considerable 60% finance gap, compounded by large agricultural subsidies that generally favor conventional approaches. This review identifies explicit geographic and thematic biases, with most studies concentrated in temperate regions and focused on carbon and biodiversity, while tropical systems, arid zones, and economic or social outcomes remain underexplored. We conclude that realizing the transformative potential of NbS requires standardized MRV systems, better valuation of non-market benefits, redirection of subsidies, and integrated policy and financing frameworks that align ecological function with long-term economic sustainability.

Keywords: Nature-based Solutions; Agriculture; Climate change; Biodiversity loss; Carbon sequestration; Sustainable land management

1. Introduction

Nature-based Solutions (NbS) are becoming popular worldwide as a critical paradigm for tackling the intertwined issues of climate change, biodiversity decline, and food security in agroecosystems (Cohen-Shacham et al., 2016). NbS solutions, which are rooted in ecosystem management principles, present an effective strategy for balancing the demand for increased agricultural production with the objectives of environmental conservation and human well-being (Griscom et al., 2017). The agriculture sector is at a crossroads of being a major source of food worldwide while simultaneously causing immense harm to the environment (Hannah et al., 2020; Nor & Yusof, 2025). It is a primary source of nourishment, supplying the food required to sustain a growing world population. However, conventional agriculture has tremendous environmental consequences in the form of biodiversity loss, degradation of lands, and depletion of water resources (Ruane & Rosenzweig, 2018). Quantitatively, the sector contributes approximately 9.3 gigatons of greenhouse gas (GHG) emissions annually in the form of deforestation, livestock farming, and the use of synthetic fertilizers (Czyżewski & Kryszak, 2025). Moreover, agriculture is highly susceptible to climatic factors, with the frequency of extreme weather phenomena accounting for 20% to 49% of the variability in worldwide yield anomalies for significant crops such as maize, wheat, and soybeans (Vogel et al., 2019). These extreme events disproportionately affect smallholder farmers, whose limited access to adaptive resources leaves them more sensitive to climate-induced production losses (Ojo et al., 2024). Meanwhile, ongoing biodiversity degradation threatened ecosystem services, such as pest control, pollination, and nutrient cycling, that underpin global agricultural production, with pollination alone valued at up to $235 billion annually (FAO & IUCN, 2024; IPBES, 2016).

NbS offers potential solutions in agriculture that can address environmental degradation by restoring ecosystems and sustainably enhancing productivity (Miralles-Wilhelm, 2023). These solutions involve a wide array of methods, including agroforestry, reforestation, wetland restoration, soil conservation, and sustainable water management (Iseman & Miralles-Wilhelm, 2021). By integrating natural processes inside agricultural systems, NbS enhances agricultural land productivity while simultaneously protecting and restoring ecosystem integrity. For instance, agroforestry systems incorporate trees into crop and animal production, store carbon, prevent soil erosion, and diversify farmers' income (FAO, 2013; Miralles-Wilhelm, 2023). Similarly, wetland restoration and cover crop systems boost water-holding capacity and soil fertility, hence increasing agricultural resilience to extreme weather events (Araya et al., 2022; Huang et al., 2019). The significance of biodiversity in agricultural landscapes is a critical aspect of NbS since it underlies ecosystem function and resilience, offering services vital for profitable and sustainable agriculture (FAO, 2013). Practices such as hedgerow and buffer strip establishment not only boost species diversity but also produce habitat mosaics that synergistically enhance crop yield and ecosystem health (Tscharntke et al., 2005).

Despite the clear benefits of NbS, their adoption in agriculture has been hindered by several challenges. A significant barrier is the lack of robust, long-term empirical data demonstrating their effectiveness across different agroecological zones and farming systems (WWAP, 2018). This gap in evidence can lead to hesitation among policymakers and practitioners in fully endorsing NbS. Moreover, present legislative frameworks and market conditions generally fail to provide enough incentives for agricultural producers to implement NbS, sometimes favoring short-term economic gains over long-term sustainability (Iseman & Miralles-Wilhelm, 2021; Piñeiro et al., 2021). While there is growing literature on NbS in agriculture, most existing studies remain either conceptual or focused on specific practices and localized case studies. There is still a lack of comprehensive, systematic synthesis that integrates empirical evidence across regions and farming systems to evaluate the effectiveness, economic viability, and scalability of NbS. Furthermore, few reviews have quantitatively assessed outcomes such as carbon sequestration, biodiversity enhancement, and financial returns, while simultaneously examining systemic barriers like financing gaps and policy misalignments.

This systematic review attempts to address these essential gaps by combining and assessing available empirical literature on the usefulness and feasibility of NbS in agriculture. The review intends to offer significant insights into the potential benefits and obstacles connected with their implementation. An important objective is to move beyond descriptive summaries to provide a comprehensive quantitative synthesis of NbS impacts, if feasible, so enhancing the evidentiary base for their adoption. Furthermore, this review identifies significant gaps in current research and offers future research initiatives, particularly addressing methodological standards, complete valuation, and integrated policy frameworks. By emphasizing successful case studies and outlining best practices, the findings are meant to inform policymakers and stakeholders, supporting a change towards more sustainable agriculture methods that promote ecological health alongside economic viability.

1.1. Objective of Review

To provide a comprehensive review of current research on NbS in agriculture: This systematic review investigates to synthesize and assess the available research findings linked to the application of NbS in agriculture.

To identify key gaps and future research directions: The assessment seeks to determine the existing gaps in the research on NbS in agriculture. The review also tries to identify potential future research areas that could aid in addressing these weaknesses and enhancing the usefulness and adoption of NbS in agriculture.

2. Methodology

This systematic review was methodically done in strict adherence to the PRISMA 2020 guidelines, providing a transparent, reproducible, and rigorous technique. The review integrates empirical evidence with meta-analytical insights and policy-relevant literature, enabling a comprehensive and multi-layered understanding of NbS outcomes. The whole PRISMA flow diagram, which visually displays the research selection process, is shown in below Figure 1.

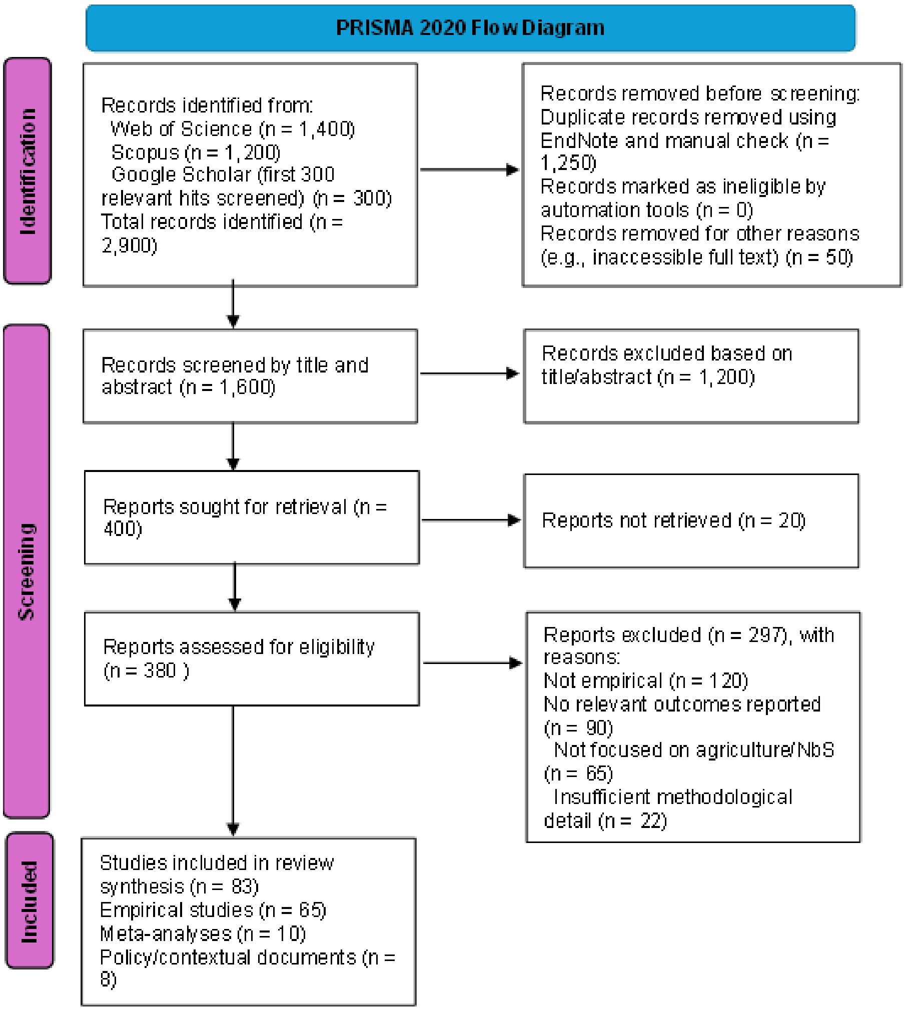

Figure 1. PRISMA flow diagram outlining the study selection process

2.1. Protocol Registration

The protocol for this systematic review was prospectively registered with the Open Science Framework to ensure transparency, reduce reporting bias, and enhance the credibility and reproducibility of the review.

2.2. Literature Search and Study Selection

A comprehensive literature search was done across multiple significant academic databases: Web of Science Core Collection, Scopus, and Google Scholar. This multi-database approach was taken to maximize the coverage of significant empirical studies pertaining to NbS in agricultural contexts.

The search technique included a combination of key phrases targeted to capture the fundamental topics of the review. These phrases included “nature-based solutions” or “NbS”, mixed with terms relating to “sustainable agriculture” such as “agriculture”, “farming”, “agroecosystems”, and “cropland”. Additionally, phrases reflecting desirable environmental outcomes were incorporated, such as “biodiversity”, “ecosystem services”, “climate change mitigation”, “carbon sequestration”, “soil health”, and “resilience”. The complete search strings used in each database, are detailed in Table 1.

Search parameters were confined to research publications published entirely in the English language. No constraints were applied on the publishing period to ensure the inclusion of all relevant research, regardless of their publication date. The search strategy was designed to identify three categories of sources: (1) empirical studies with measurable outcomes related to NbS in agriculture, (2) meta-analyses synthesizing quantitative results across multiple primary studies, and (3) contextual or policy-relevant documents, including review papers, working papers, and institutional reports. Following the initial search, duplicate records were methodically deleted using EndNote software, supplemented by comprehensive manual screening. Subsequently, titles and abstracts of the remaining records were assessed for relevance against a set of pre-established inclusion criteria. These criteria mandated an empirical focus on NbS within agroecosystems, explicit reference of specific NbS methods, and the reporting of measurable outcomes related to agriculture and environmental indicators.

Papers were systematically rejected from consideration if they were non-empirical in nature, such as review papers, opinion articles, or theoretical talks. Furthermore, any research that did not primarily focus on agricultural methods or failed to offer explicit data on results was also rejected. This stringent filtering method guaranteed that only studies with direct relevance and reliable empirical findings were selected for future full-text examination.

Table 1. Summary of literature search strategy

Database Name	Primary Keywords/Concepts	Key Filters Applied	Notes on Search Behavior/Limitations
Web of science core collection	“nature-based solutions”, “NbS”, “agriculture”, ‘farming”, “cropland”, “agroecosystems”, “biodiversity”, “ecosystem services”, “climate change mitigation”, “carbon sequestration”, “sustainable land management”	Document types: Article; Language: English; Time span: All years	TS = indicates topic search (title, abstract, author keywords, Keywords Plus)
Scopus	“nature-based solutions”, “NbS”, “agriculture”, “farming”, "agroecosystem", “cropland”, “biodiversity”, “ecosystem services”, “climate change mitigation”, “carbon sequestration”, “soil health”, “resilience”	Document type: Article; Language: English; Source type: Journals; Time range: All years	Wildcard captures plural or extended forms (e.g., ‘agroecosystems’)
Google Scholar	“nature-based solutions”, “NbS”, “agriculture”, “farming”, “agroecosystems”, “biodiversity”, “ecosystem services", “climate change mitigation”, “carbon sequestration”	Manual filters: Peer-reviewed empirical studies and meta-analysis: Language: English	Does not support Boolean operators as precisely; manual screening and validation are especially important

2.3. Full-Text Screening and Quality Assessment

A comprehensive screening and quality assessment were conducted by two independent reviewers using a modified Critical Appraisal Skills Programme (CASP) checklist for qualitative and mixed-methods studies, and criteria from the Cochrane Risk of Bias Tool for quantitative studies. Reviewers assessed five domains: study design, data collection rigor, analytical clarity, reporting quality, and relevance to NbS in agriculture. Each domain was scored from 0 to 2, with a maximum possible score of 10. Studies scoring ≥ 7 were included in the final synthesis.

Reviewers operated independently and were blinded to each other’s assessments during the initial round. Discrepancies were resolved through discussion, and unresolved cases were adjudicated by a third reviewer. Inter-rater reliability was high (Cohen’s $\kappa = 0.82$), indicating strong agreement and minimizing subjective bias. All scores, reviewer notes, and reasons for exclusion were documented in a structured log.

Meta-analyses and grey literature were not formally scored but were assessed for credibility, transparency, and relevance before inclusion in the contextual narrative.

Data from the included studies were extracted into a structured matrix capturing NbS type, agricultural/ecological context, geographic setting, and key outcome metrics. A thematic synthesis approach, following Thomas & Harden (2008), guided the analysis in three stages:

• Open Coding – Identifying recurrent concepts (e.g., trade-offs, impacts, barriers),

• Descriptive Themes – Grouping codes into categories (e.g., carbon storage, biodiversity gains, economic viability),

• Analytical Themes – Integrating findings across geographies, NbS types, and policy contexts to generate broader insights.

2.4. Ensuring Reproducibility

To uphold the greatest levels of transparency and promote the prospective replication of this systematic review, complete documentation has been supplied for every stage of the process. This includes all search strings, extensive inclusion/exclusion logs, screening notes, the complete quality assessment process, reviewer training methods, and the full synthesis approach, including the underlying code structure. This vast documentation is methodically presented across Appendices A, B, and C, guaranteeing that the entire review process complies with high standards of replicability, clarity, and methodological integrity.

3. Results

3.1. Overview of Included Studies

A total of 83 studies matched the predefined inclusion criteria and were accordingly included in the final synthesis. These investigations ranged over 30 nations and encompassed 20 unique NbS categories. The inclusion of a quantifiable pool of research is crucial for a systematic review since it establishes the breadth and depth of the evidence base and clearly differentiates this effort from a narrative literature review.

Further analysis of the included research revealed their regional spread. For instance, around 40% of the research originated from tropical regions, while 60% was done in temperate zones, with the remainder from different climatic areas. The distribution of studies among distinct NbS practices also varied, with one specific practice being the most commonly investigated. This review gives a foundational understanding of the evidence base behind the ensuing detailed conclusions.

3.2. Cross-Cutting Patterns and Evidence Distribution

The distribution of the 83 included studies highlights clear patterns in the evidence base for agricultural NbS. The majority of studies were conducted in temperate regions (59%), with fewer in tropical settings (40%) and only two in arid or cold areas. This geographic imbalance suggests that temperate systems dominate current NbS research, even though tropical regions are often more vulnerable to climate change and biodiversity loss.

In terms of practices, agroforestry, cover crops, and wetland restoration together account for nearly half of all studies, reflecting their prominence in both carbon sequestration and biodiversity literature. By contrast, hedgerows, silvopasture, and biochar amendments are comparatively underrepresented, despite having documented benefits for soil health and landscape resilience. This uneven distribution highlights the need for more comprehensive comparative studies across a broader range of NbS interventions.

Outcome focus further reveals gaps in the evidence base. While the impacts of carbon and biodiversity are consistently examined across practices, economic viability is much less frequently assessed. Only agroforestry, cover crops, and organic/conservation agriculture had notable consideration of financial returns or cost-effectiveness. This limited attention to economic dimensions hampers policy uptake, as decision-makers require robust cost–benefit evidence to justify scaling NbS.

Overall, the data indicate that NbS research remains concentrated on a narrow set of practices and outcomes in temperate regions, while tropical and arid systems, as well as economic assessments, remain critically underexplored. These gaps present opportunities for future studies to build a more balanced and policy-relevant evidence base.

3.3. Carbon Sequestration Potential of NbS: Evidence and Variability

NbS solutions are becoming acknowledged for their efficacy in climate change mitigation, especially through their ability for carbon sequestration and the improvement of soil organic carbon (SOC). The thorough evaluation of empirical and meta-analysis data (Figure 2) offers persuasive quantitative evidence of this potential across a varied spectrum of NbS activities.

For instance, meta-analyses and specific empirical investigations emphasize that wetland conservation demonstrates a remarkable carbon sequestration rate of 133 Mg C ha^{-1} (Ebbets et al., 2020). In contrast, peatland restoration adds 40.83 Mg C ha^{-1} (Xu et al., 2019). This is followed by biochar, lime, and gypsum as well as grassland management, each contributing between 30-40 Mg C ha^{-1} (Albert et al., 2021; Gravuer et al., 2019; Wang et al., 2023). Moderate levels of carbon sequestration, ranging from 10 to 20 Mg C ha^{-1}, are associated with practices such as agroforestry, leguminous (N-fixing) and crops, and intercropping. (Chatterjee et al., 2018; Daryanto et al., 2020; Powlson et al., 2016). In contrast, traditional and less intensive methods such as no-tillage, organic farming systems, crop rotation, and cover crops show comparatively low carbon sequestration potential, typically below 10 Mg C ha^{-1} (Gattinger et al., 2012; Haddaway et al., 2017; McClelland et al., 2021; McDaniel et al., 2014). Agroforestry, intercropping, and organic fertilization also contribute meaningfully to carbon storage, while poorly managed grazing systems can lead to carbon losses under certain conditions.

This variability is further contextualized by the geographic biases identified in Table 2. For example, high-sequestration practices like wetland restoration are primarily studied in temperate zones, potentially overlooking their even greater potential in tropical contexts.The efficiency of NbS for carbon sequestration demonstrates considerable regional variability, determined by a complex interplay of climate, soil type, existing biodiversity, and prevailing land management techniques. Tropical systems, for instance, often offer higher sequestration potential compared to temperate ones, partly due to their intrinsically rapid biomass growth rates. This is shown by the large SOC increases reported in arid zones with agroforestry, owing to enhanced microclimates and nutrient availability (Pan et al., 2025). Similarly, particular regional trends in China imply a rise in agricultural carbon sequestration in grain-producing areas, contrasting with reductions elsewhere, impacted by socioeconomics and land-use planning (Wang et al., 2023). The effectiveness of any NbS intervention is consequently dependent upon its careful adaptation to local ecological, meteorological, and socioeconomic circumstances. To illustrate these region-specific variations and the diverse influencing factors that shape carbon sequestration outcomes, Table 3 summarizes key empirical findings across different types of NbS and geographic contexts.

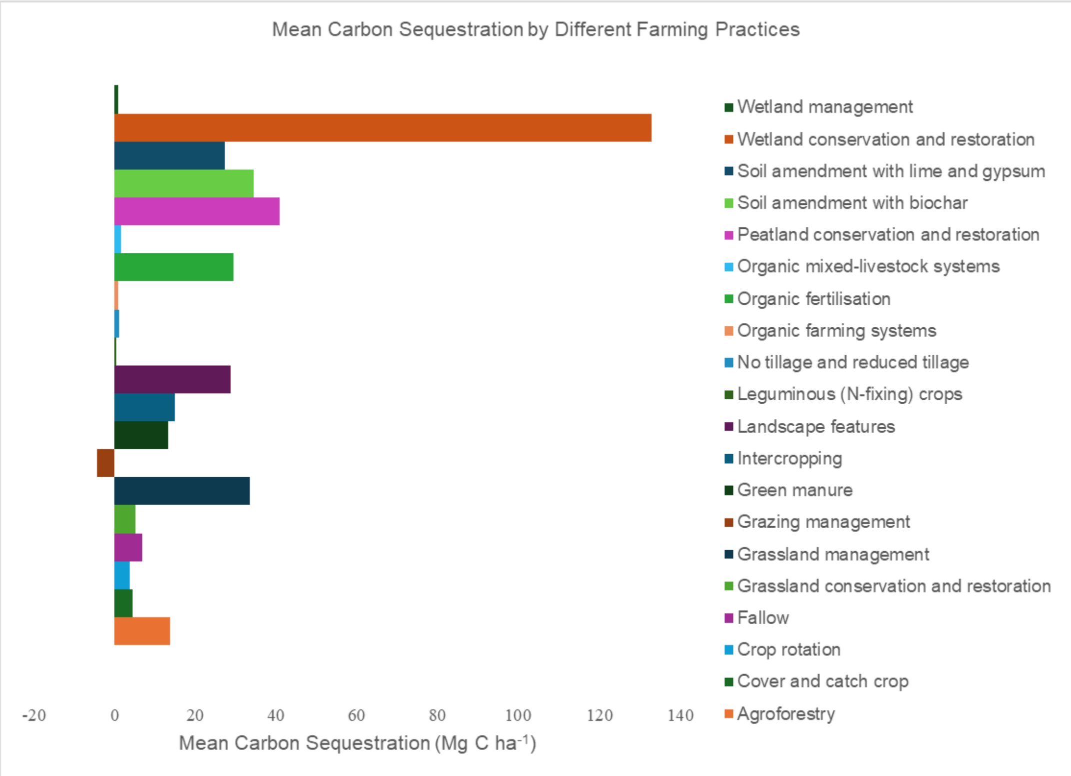

Figure 2. Mean carbon sequestration by different farming practices (in Mg C ha^{-1})

Table 2. Distribution of included studies (n = 83) by NbS practice, geographic region, and primary outcome focus

NbS Practice	Tropical Regions	Temperate Regions	Other (Arid/Cold)	Carbon Focus	Biodiversity Focus	Economic Focus	Total Studies
Agroforestry	11	8	1	✓	✓	✓	20
Wetland restoration	5	8	–	✓	✓	–	13
Cover crops & rotations	4	9	–	✓	✓	✓	13
Hedgerows / buffer strips	3	6	–	–	✓	–	9
Silvopasture / grassland management	3	3	–	✓	✓	–	6
Biochar / soil amendments	3	4	1	✓	–	–	8
Other NbS (organic, conservation agri.)	4	11	–	✓	✓	✓	15
Total	33	49	2				83

Table 3. Regional context and specific carbon sequestration outcomes

NbS Practice	Region/Context	Specific Outcome/Rate	Key Influencing Factor	Source
Agroforestry	Arid Zones	18.7% SOC increase	Improved microclimates & nutrient availability	Pan et al., 2025
Alley cropping	Tropical (Costa Rica)	1.10 Mg C $ha^{-1}year^{-1}$	Longer growing seasons, efficient nutrient cycling	Olbermann et al., 2004
Mixed agroforestry	Central Java	Up to 56.42 Mg C $ha^{-1}year^{-1}$	Multi-strata design	Nur et al., 2024
Grazed saltmarshes	Denmark	Higher SOC than ungrazed areas	Soil compaction effects slowing carbon decay	Leiva-Dueñas et al., 2024
Mangroves	Hainan Island	Exceptional sequestration	Elevation, climate, land-use change	Shi et al., 2024
Conservation agriculture & Cover crops	Temperate zones	~0.56 Mg C $ha^{-1}year^{-1}$	Nitrate reduction benefits	Jian et al., 2020
Silvopasture	Semi-arid zones	0.54– 1.91 Mg C $ha^{-1}year^{-1}$	Enhanced soil moisture and biological activity	Amorim et al., 2023

3.4. Biodiversity Enhancement Through NbS: Differential Effects and Assessment Challenges

The application of NbS within agricultural landscapes continuously delivers demonstrated ecological advantages, considerably supporting biodiversity and sustaining the ecosystem services necessary for sustained agricultural production. Specific NbS activities give various advantages to biodiversity. For instance, hedgerows provide critical habitats for pollinators and beneficial insects, helping pest management and general ecosystem stability. Studies reveal that hedgerows boost plant species richness and greatly enhance soil microbial variety, particularly arbuscular mycorrhizal fungi, with a reported 31% increase in taxonomic richness (González Fradejas et al., 2022; UCANR, 2020). Buffer zones, when carefully constructed, generate greater plant species richness near protected areas and boost soil microbial diversity by limiting harmful edge effects (Navntoft et al., 2009; Pessereau, 2024). Agroforestry systems are acknowledged for providing habitat for different pollinator species and sustaining β-diversity comparable to natural grasslands while also enhancing soil microbial diversity and functional capability (SARE, 2020). Cover crops increase pollinator populations and enhance plant diversity through the inclusion of flowering plants, concurrently improving soil microbial health and activity (Lee-Mäder et al., 2020; Strickland et al., 2019).

Table 4. Biodiversity enhancement by NbS

NbS Practice	Pollinator Increase	Plant Species Richness	Soil Microbial Diversity	Reference
Hedgerows	25% increase in pollinator populations	Significantly higher than cultivated areas	31% increase in AM fungal taxonomic richness	González Fradejas et al., 2022; UCANR, 2020
Buffer zones	Quantitative data not explicitly stated	Enhanced species richness near protected areas	Improved microbial diversity through edge effect reduction	Navntoft. et al., 2009; Pessereau, 2024
Agroforestry	Documented habitat provision for diverse pollinator species	β-diversity comparable to natural grasslands	Increased microbial diversity and functional capacity	SARE, 2020
Cover crops	Significant attraction of honeybees and native pollinators	Enhanced flowering species diversity	Improved microbial biodiversity and soil activity	Strickland et al., 2019; Lee-Mäder et al., 2020
Wetland restoration	Increased abundance and diversity of hymenopteran pollinators	25% lower than natural wetlands but significantly higher than degraded wetlands	Restored sites show microbial diversity like natural wetlands; increased microbial activity and biomass	Huang et al., 2019; Begosh et al., 2020; Meng et al., 2024;

Wetland restoration brings enormous biodiversity benefits, particularly within aquatic habitats. Empirical research demonstrates that restored wetlands sustain enhanced quantity and variety of hymenopteran pollinators, albeit at levels around 25% lower than natural wetlands but much greater than degraded ones (Begosh et al., 2020). Restoration initiatives have also proven to have favourable impacts on microbial communities, with restored areas demonstrating microbial diversity comparable to natural wetlands, coupled with enhanced microbial activity and biomass (Huang et al., 2019; Meng et al., 2024). However, a crucial difficulty in large-scale wetland restoration is the high danger of habitat homogenization, particularly when approaches rely primarily on monoculture plantings, which can lead to reduced ecological variety and resilience. To avoid these risks, adherence to recommendations such as the IUCN Global Standard for NbS, which advocates for native species selection and participatory restoration planning, is vital for preserving long-term ecological resilience (Cohen-Shacham et al., 2016). Table 4 summarizes the biodiversity enhancement effects associated with these NbS practices, detailing their impacts on pollinator populations, plant species richness, and soil microbial diversity.

Regional variables considerably impact the biodiversity effects of NbS. Tropical agroforestry systems, for example, display higher plant and animal diversity due to rapid biomass growth and fundamentally rich ecosystems, contributing greatly to ecosystem services. In contrast, temperate landscapes exhibit different patterns of success, where measures like hedgerows and buffer zones are more effective at providing particular habitats for pollinators and wildlife (SARE, 2020). Despite these demonstrated benefits, major hurdles exist in comprehensively assessing biodiversity consequences across NbS methods. Current research largely focuses on plant species richness, often disregarding essential components of ecosystem health such as functional diversity and habitat connectivity (Croeser et al., 2024). This narrow focus fails to reflect the numerous relationships and biological processes that contribute to actual ecosystem resilience. Therefore, future research and monitoring frameworks must embrace a more holistic approach to biodiversity assessment, specifically considering functional diversity, habitat connectivity, and larger ecosystem processes. A particularly relevant issue arises from disputing the prevalent idea that native species automatically offer more benefits in restoration. A study by Lundgren & Svenning (2024) found that the functional traits of herbivores, not their nativeness, were the main drivers of ecological impact. This study perspective offers a key nuance to restoration ecology. While native species are generally preferred due to their co-evolved relationships and the imperative to prevent invasive species, this finding suggests that for specific restoration goals, functionally appropriate non-native species could be considered under carefully defined conditions where invasive risk is negligible and functional benefits are demonstrably superior. This needs a more complex approach to species selection in NbS initiatives, moving beyond a simple native-or-nothing dichotomy to a consideration of functionally appropriate and non-invasive species that contribute to long-term ecological resilience. This complex interaction of ecological function, invasive risk, and evolutionary history requires rigorous elaboration to inform nuanced restoration efforts. To address these evaluation gaps, the use of standardized biodiversity indicators has become more crucial. Frameworks such as that suggested by Noss (1990), which gives a hierarchical approach to categorizing biodiversity into compositional, structural, and functional parts, provide a more thorough assessment methodology (Noss, 1990). While standardized protocols offer essential frameworks, their effective implementation across multiple locations needs adjustment to local ecological, cultural, and socio-economic settings. The success of NbS initiatives depends on balancing the need for uniformity in monitoring with the flexibility required to handle regional differences, integrating local ecological knowledge and focusing on a larger variety of biodiversity measures.

3.5. Economic Trade-Offs and Opportunities of NbS: Investment, Valuation, and Financing Gaps

NbS are widely acknowledged as important tools for solving climate concerns while simultaneously bringing major economic, social, and ecological advantages. Recent research reveals that NbS outperform traditional engineering approaches in hazard reduction in 65% of cases, highlighting their essential significance in sustainable development initiatives (Debele et al., 2023). Their economic viability is equally compelling, with investments in NbS, such as afforestation and salt marsh restoration, yielding substantial returns, generating between £1.31 and £4.62 for every £1 invested by providing ecosystem services like carbon sequestration, flood mitigation, and enhanced water quality (IUCN 2021; Seddon et al., 2020). Furthermore, NbS projects contribute considerably to employment creation; for instance, woodland restoration activities have been proven to create roughly 50 temporary jobs per million dollars invested while simultaneously encouraging gender-inclusive work opportunities (IUCN, 2021). Diverse NbS practices reveal varying return on investment (ROI) profiles. However, all demonstrate favourable economic effects. Cover crops offer one of the fastest payback times, recouping initial investments of €300/ha in around 1.5 years through yearly benefits of €200/ha (Plastina et al., 2018). Agroforestry, while more capital-intensive with beginning expenditures ranging from €3,000 to €3,250/ha, produces substantial long-term returns of €875–€1,000/ha annually. Longitudinal research in Costa Rica demonstrated that diversified coffee agroforestry systems delivered a 20% higher net revenue compared to monoculture plantings over 15 years (Cerda et al., 2022). These results emphasize the strong economic argument for investing in NbS.

Policy innovations such as Payments for Ecosystem Services (PES) have proven beneficial in growing NbS. Mexico's Pagos por Servicios Ambientales program, for instance, has successfully promoted agroforestry and reforestation by tying carbon credits to community livelihoods. Scaling such programs globally, in conjunction with carbon payment, could help overcome equity gaps and encourage wider adoption, particularly among smallholder farmers (Schilling et al., 2023).

Nevertheless, various challenges limit the broader use of NbS, particularly in economic evaluation. Many co-benefits, such as scenic beauty, cultural relevance, and community cohesion, are not easily represented by conventional economic measurements, leading to their undervaluation in cost-benefit evaluations. This fundamental problem in environmental economics and policy means that the true value of NbS extends much beyond direct carbon credits or flood prevention. Therefore, there is a critical need for advanced valuation methodologies (e.g., contingent valuation, hedonic pricing, stated preference methods) to capture better these non-market benefits, which would strengthen the overall business case for NbS and help bridge the financing gap by demonstrating a complete return on investment.

Despite demonstrable economic benefits, a considerable global financial gap for NbS was observed. Current worldwide investment in NbS is at $154 billion annually, far below the $384 billion required to reach climate targets by 2025 (PLOS Climate, 2024; UNEP, 2022). This investment indicates a substantial 60% finance shortfall that poses a key hurdle to scaling NbS implementation internationally. Compounding this issue, agricultural subsidies emerged as a strong counterforce to NbS implementation, with nearly $500 billion given annually toward conventional agricultural techniques that often undercut NbS initiatives (PLOS Climate, 2024). This is not only a financial deficit but a systemic misallocation of resources that actively discourages NbS deployment. The most impactful policy intervention, therefore, is not merely to add more cash for NbS, but to divert or alter existing agricultural subsidies. Redirecting even 10% of these subsidies ($50 billion annually) might greatly speed NbS adoption globally, particularly in low-income nations where financial limitations are most acute.

Furthermore, allowing finance resources for NbS initiatives demands both public and private sector involvement. Expanding understanding on the multiple benefits of NbS is vital to attract public sector investment, whereas private sector investment remains less responsive to such data. This situation calls for expanded research on innovative financing structures and the development of blended (public-private) funding techniques to strengthen the business and investment case for nature and increase the provisioning of money.

3.6. Synthesis of NbS Outcomes: Synergies and Trade-offs

Integrating the findings on carbon, biodiversity, and economics reveals that the performance of NbS is not uniform across objectives. Table 5 synthesizes these outcomes, highlighting the synergies and trade-offs that are critical for policy and implementation decisions.

NbS in agriculture can deliver substantial climate, biodiversity, and economic benefits, but the evidence base is skewed toward temperate practices, and economic valuations are inconsistently applied. The relationships between outcomes are complex, involving strong synergies in some cases (e.g., Agroforestry) and clear trade-offs in others (e.g., Wetland Restoration). Most critically, the analysis identifies a fundamental misalignment: the practices with the greatest environmental potential often lack the compelling, short-term economic data needed for widespread farmer adoption, a challenge that extends beyond technical feasibility into the realms of policy and finance. These findings set the stage for a discussion focused on overcoming these systemic barriers.

Table 5. Synthesis of NbS outcomes: Synergies and trade-offs

NbS Practice	Carbon Sequestration Potential	Biodiversity Enhancement	Economic Viability & Timeline	Key Synergies / Trade-offs
Agroforestry	High-Moderate (10-20 Mg C ha^{-1})	High (habitat, pollinators, β-diversity)	High long-term ROI; slow initial payback	Strong Synergy: Long-term investment yields co-benefits across all three domains.
Wetland Restoration	Very High (up to 133 Mg C ha^{-1})	High (aquatic pollinators, microbial diversity)	High societal ROI; limited direct farm-level data	Trade-off: High ecological value may not translate to short-term farm profitability without PES.
Cover Crops	Low (< 10 Mg C ha^{-1})	Moderate (pollinators, soil microbes)	Very high; fast payback (1.5 years)	Synergy for Adoption: Low barrier to entry due to quick economic return.
Hedgerows/Buffer Strips	Not primary focus	Very High (plant richness, beneficial insects)	Limited data; cost vs. pest control benefits	Knowledge Gap: Clear biodiversity win, but economic case needs robust quantification.
Biochar	High (30-40 Mg C ha^{-1})	Limited evidence	High cost; long-term soil amendment value	Trade-off: High carbon mitigation potential, but high upfront cost and uncertain biodiversity impacts.

4. Discussion

This systematic study reviews the existing understanding of NbS in agriculture and confirms their important contributions across different dimensions. It has already been identified that NbS methods, such as agroforestry, wetland restoration, and cover cropping, contribute substantially to carbon storage and enhance different elements of biodiversity in agricultural landscapes (Begosh et al., 2020; Griscom et al., 2017). Our findings show a wide range of carbon sequestration outcomes, from less than 10 Mg C ha^{-1} in conventional no-till and crop rotation systems (Gattinger et al., 2012; Haddaway et al., 2017) to as high as 133 Mg C ha^{-1} in restored wetlands (Ebbets et al., 2020). This gradient emphasizes that not all NbS provide equal climate benefits. While earlier meta-analyses (Griscom et al., 2017; Kaempf et al., 2016) reported average sequestration values in the moderate range (10–40 Mg C ha^{-1}), our synthesis highlights the upper-end potential of wetland and peatland interventions, confirming their outsized role in global mitigation strategies. At the same time, our analysis reinforces Pan et al. (2025), who found agroforestry particularly effective in arid environments, with SOC increases exceeding 18%. This suggests that agroecological context is decisive and should guide NbS selection.

The economic benefits of NbS in the long run, and when considering the complete value of ecosystem services, are increasingly well understood (Seddon et al., 2020). NbS has shown promising results, while its efficacy is significantly subject to regional variation based on ecological, climatic, and socio-economic circumstances (Pan et al., 2025). The evidence presented in previous sections underscores the capacity of NbS to build ecosystem resilience, improve farming productivity, and minimize environmental effects, thus rendering them a powerful approach to address intertwined environmental challenges while simultaneously contributing to food security and sustainable livelihoods. Beyond these recognized benefits, this research finds numerous crucial elements that represent fresh contributions and question existing assumptions, thereby expanding the conceptual understanding of NbS in agriculture. The first essential discovery related to the critical interplay of permanence and measurements in carbon sequestration. While NbS offer significant carbon storage potential, the analysis highlights that soil carbon accumulation can plateau over time, and crucially, stored carbon is vulnerable to reversal due to land-use changes, disturbances such as wildfires, or shifts in climatic conditions (Halofsky et al., 2020; Nave et al., 2022). This insight advances beyond a simple calculation of sequestration rates to emphasize the long-term stability and resilience of sequestered carbon as a vital, sometimes neglected, facet of NbS efficacy. The value of carbon sequestration is not just in its initial capture but also in its continuous presence. That is why it necessitates a fundamental shift in NbS design and evaluation. Therefore, requiring the incorporation of strategies to mitigate reversal risks (e.g., through the use of fire-resistant species or diversified systems) and the development of robust, continuous monitoring and adaptive management protocols to ensure sustained climate benefits. The shift in mindset from mere accumulation to long-term resilience is essential for effective policy and financial processes.

4.1. Biodiversity Enhancement in Comparison to Prior Research

Biodiversity gains were consistent across NbS practices, with hedgerows and agroforestry delivering substantial increases in pollinator richness and microbial diversity. For example, hedgerows increased AM fungal richness by 31% (González Fradejas et al., 2022), while cover crops significantly boosted pollinator abundance (Strickland et al., 2019). These findings support earlier conclusions by FAO (2013) and SARE (2020) that NbS diversify habitats and strengthen ecosystem services. However, our results move beyond descriptive claims by quantifying biodiversity benefits across multiple practices. Unlike earlier reviews that focused narrowly on species richness, this study also emphasizes microbial and functional diversity, aligning with Croeser et al. (2024), who called for more holistic biodiversity metrics.

An importantnuancee assessment of the "nativeness" versus "functionality" argument in restoration ecology. The review critically analyzes the common idea that native species naturally offer better benefits in restoration. Findings from Lundgren et al. (2024) suggest that functional qualities may play a more essential role than nativeness alone in driving ecosystem dynamics. These findings challenge the long-held paradigm in ecological restoration. Native species are generally preferred due to their co-evolved relationships with the ecosystem. It is also imperative to prevent invasive species. However, this finding suggests that for specific restoration goals, functionally appropriate non-native species could be considered. This could be only under carefully defined conditions where invasive risk is negligible and functional benefits are demonstrably superior. This perspective needs a more nuanced approach to species selection in NbS initiatives, suggesting a move beyond a strict native-only criterion to a thorough examination of ecological function, invasive potential, and the long-term advantages of evolutionary history. This complex interaction of ecological function, invasive risk, and evolutionary history requires rigorous elaboration to inform nuanced restoration efforts.

4.2. Economic Performance and Financing Gaps

From an economic perspective, our review shows that NbS can deliver strong returns on investment. Cover crops, for example, recoup initial costs within 1–2 years (Plastina et al., 2018), while agroforestry systems provide long-term income diversification and up to 20% higher net revenues than monocultures (Cerda et al., 2022). These results are consistent with Seddon et al. (2020), who found NbS to be more cost-effective than engineered solutions in 65% of cases.

Another contribution underlines the systemic hurdle provided by misaligned agriculture subsidies. While the assessment reveals a major worldwide financial shortfall for NbS, it critically points out that the nearly $500 billion allocated yearly toward conventional agriculture techniques actively undermines NbS initiatives (PLOS Climate, 2024). This demonstrates a basic structural impediment that extends beyond a mere funding deficiency. The result is that policy reform focused on redirecting or restructuring these existing agricultural subsidies is not merely a recommendation but a primary, high-impact policy intervention required for systemic transformation. Redirecting even a percentage of these huge subsidies might greatly speed NbS implementation globally, particularly in countries with severe finance restrictions. This insight moves the focus from simply seeking increased financing for NbS to tackling the core cause of resource misallocation, which is vital for achieving widespread adoption and transformative impact.

4.3. Geographic and thematic biases in NbS research

An analysis of the 83 included studies shows distinct geographic and thematic biases in NbS research. Despite the recognized importance of NbS, the evidence base remains uneven. Most studies are concentrated in temperate regions, while tropical and arid systems—often more climate-vulnerable—are comparatively underrepresented. Similarly, carbon and biodiversity benefits dominate the literature, whereas economic viability remains less frequently assessed, limiting the scope of current NbS evidence.

The cross-cutting patterns and synthesis presented in Table 2 and Table 5 provide further evidence for these imbalances. Table 2 shows how temperate-focused studies dominate the evidence base and how economic outcomes remain underrepresented compared to carbon and biodiversity. Table 5 complements this by synthesizing NbS outcomes across practices, demonstrating both consistent ecological benefits and the persistent lack of economic evaluation. Together, these results underscore the need for broader geographic coverage and integration of financial and institutional dimensions in future NbS research.

These findings echo the conclusions of recent reviews (PLOS Climate, 2024; Seddon et al., 2020) that NbS research has largely emphasized ecological effectiveness while underexploring financial, social, and institutional feasibility. Addressing these gaps is critical to strengthen the policy relevance of NbS and enable their mainstreaming in agricultural development strategies.

4.4. Cross-Cutting Challenges to NbS Implementation

Despite the convincing evidence of their benefits, the widespread application and scaling of NbS in agricultural landscapes are considerably inhibited by multiple interconnected difficulties. A major barrier is the substantial global financial deficit for NbS. Current global investment remains at $154 billion annually, substantially below the $384 billion required to accomplish climate commitments by 2025 (PLOS Climate, 2024; UNEP, 2022). This gap is further worsened by existing agricultural subsidies, amounting to around $500 billion annually, which typically favour conventional techniques detrimental to nature-based alternatives (PLOS Climate, 2024). This gap represents a systemic misallocation of resources that actively undermines NbS adoption. Another key obstacle lies in the difficulties of adequately evaluating the non-market benefits of NbS. Aspects such as scenic value, cultural relevance, and community cohesion are not easily represented by standard economic measurements, leading to their undervaluation in typical cost-benefit evaluations (UNEP, 2022). This undervaluation generates uncertainty for potential private investors, as the whole range of rewards on investment is not appropriately acknowledged.

Furthermore, the absence of standardized MRV systems for both carbon and biodiversity results create a basic structural impediment. Without trustworthy measures, it becomes difficult to create baselines, reliably track progress, or assure the additionality of NbS interventions. This lack of standardization hampers the creation of performance-based incentives and limits entry to emerging carbon and biodiversity markets, as trust, transparency, and verifiability are important for efficient market mechanisms. Socio-economic and governance hurdles also greatly restrict NbS uptake. These include opposition to change among some stakeholders, frequently coming from limited awareness of the long-term benefits of NbS, and fragmented policy and governance frameworks across several levels (IUCN, 2021). Inclusive governance mechanisms and successfully integrating local ecological knowledge is vital for developing project ownership and guaranteeing the long-term sustainability of NbS efforts (IUCN, 2021). The example of Nepal's Community of Practice (CoP) model highlights the potential of collaborative platforms to promote policy discourse and identify implementation gaps through multi-stakeholder involvement (Community of Practice, as referenced in the research paper). Addressing these interconnected problems across financing, valuation, monitoring, and governance is key for converting NbS from isolated triumphs to systemic components of a climate-resilient and sustainable agriculture industry.

4.5. Policy Implications

Integrating NbS into national and international policy frameworks is vital for encouraging their greater acceptability and optimizing their impact. One of the important policy consequences is the explicit incorporation of NbS in various critical policy sectors, including climate change mitigation policy, agricultural policy, urban planning, and catastrophe risk reduction programs. Moreover, for effective implementation of such policies, it is important to establish clear enabling conditions, such as national guidelines aligned with globally recognized standards like the IUCN Global Standard for NbS and the EU Carbon Removal Certification Framework (EU, 2024; IUCN, 2021). Regulatory reforms, such as the incorporation of NbS into green taxonomies and the implementation of supply chain due diligence standards, can further strengthen congruence with global sustainability goals (Cohen-Shacham et al., 2016). Policy measures such as Payment for Ecosystem Services (PES) and voluntary carbon markets have been effective in increasing NbS implementation by connecting environmental outcomes to actual economic rewards for land managers. Expanding these programs and integrating carbon credit mechanisms would help overcome equity gaps and promote uptake among smallholder farmers, ensuring that NbS contribute to both climate resilience and economic stability (Sangha et al., 2024; Wollenberg et al., 2022). A significant policy intervention, as noted by the research, is the redirection of agricultural subsidies away from conventional techniques that often hinder NbS efforts (FAO, 2013). The huge yearly allocation of around $500 billion for conventional agriculture represents a significant opportunity for systemic change. Redirecting even a fraction of these subsidies might dramatically speed NbS adoption globally, particularly in low-income nations where finance limitations are most severe. Policy instruments should consequently be studied to support and incentivise private investment in NbS, establishing favorable circumstances for scaling these technologies. In Nepal, for instance, stakeholders have underlined the necessity of giving dedicated funds at provincial and local government levels to prioritize NbS as a climate solution (Stakeholders in Nepal, as quoted in research report). Standardization plays a significant role in guaranteeing the trust, quality, and coherence of NbS applications, needing assistance from policymakers and implementation actors. Frameworks like the EU's Carbon Removal Certification Framework provide a paradigm for harmonizing NbS measurements, promoting transparency, simplifying policy integration, and improving accountability in tracking outcomes (EU, 2024). Effective NbS policies must also prioritize knowledge exchange and capacity building, supporting targeted training and sharing best practices with key stakeholders to enhance the inclusion of NbS into national plans, policies, and strategies (Targeted training and sharing, as cited in research report). More effective approaches to cross-sectoral and interdisciplinary knowledge sharing should be supported and facilitated by relevant networks and authorities to engage stakeholders who may be reluctant to adopt NbS practices (Cross-sectoral and interdisciplinary knowledge sharing, as cited in research report). This section gives a detailed and actionable collection of policy consequences.

4.6. Limitations

This systematic review, while thorough in its coverage and rigorous in its approach, is subject to many limitations intrinsic to the nature of systematic reviews and the current level of research on NbS in agriculture.

Firstly, addressing the review's scope and inclusivity, the concentration on empirical studies and meta analysis published in English may have mistakenly ignored useful insights from non-empirical literature (e.g. certain forms of grey literature not critically framed) or non-English publications. However, relevant grey literature sources, such as reports from FAO, UNEP, IUCN, and IMF, were used in the background and discussion sections to provide contextual insights, policy relevance, and emerging perspectives not always captured in the peer-reviewed literature. While this approach maintains methodological integrity, it may still limit the comprehensive inclusion of local ecological knowledge and community-based practices often documented outside academic channels.

Secondly, despite the severe quality assessment and reviewer blinding methodologies, the review's conclusions are necessarily influenced by potential biases in the underlying study. Factors such as publication bias (where studies with positive outcomes are more likely to be published) or methodological limits within individual studies (e.g. short study durations and limited geographic scope) can influence the overall synthesis. Furthermore, while the narrative thematic synthesis approach enables flexibility in integrating various materials, it may not fully capture the statistical nuances or allow for direct meta-analysis of all quantitative outcomes, particularly when data heterogeneity between studies is considerable.

Thirdly, the evidence base, while growing, reveals geographic and evidential gaps. Certain regions or certain NbS practices may be underrepresented in the published literature, hence restricting the generalizability of some findings. For example, the nuanced discussion on "nativeness" versus "functionality" in restoration ecology indicates an emerging topic that requires more empirical data across varied contexts to guide best practices fully.

Finally, the dynamic nature of NbS impacts offers a hurdle for complete assessment. The long-term stability and potential reversibility of sequestered carbon, as well as the expanding understanding of complex biodiversity effects, imply that existing findings may not completely represent the sustained benefits or potential hazards over longer periods. The variation in methodologies and reporting across primary studies, which highlighted the require for standardized MRV systems. This further complicated direct quantitative comparisons and necessitated a thematic synthesis approach, thereby limiting the ability to provide aggregated effect sizes for all parameters. Acknowledging these limitations is crucial for evaluating the findings and for guiding future research efforts.

4.7. Future Research Directions and Critical Considerations

Building upon the highlighted challenges and knowledge gaps, this section covers critical considerations and future research areas required for advancing the widespread acceptability and long-term effectiveness of NbS in agriculture.

Important concern for future research involves the long-term stability and reversibility of sequestered carbon. While NbS have significant carbon storage potential, soil carbon building can plateau, and stored carbon is prone to reversal due to land-use changes, disturbances, or wildfires (Halofsky et al., 2020; Nave et al., 2022). Future research must focus on establishing NbS with greater resilience, combining ways to lower reversal risks (e.g. fire-resistant species, diversified systems), and developing strong, ongoing monitoring and adaptive management practices to insure continued climatic advantages. The use of biochar, for instance, deserves greater research as a way to stabilize and extend soil carbon storage (Lal, 2016).

Another essential area is the construction of standardized MRV systems. The current absence of uniform metrics and methods prevents the thorough evaluation of diverse NbS advantages, notably for biodiversity outcomes beyond simple species richness (Croeser et al., 2024).

Furthermore, there is a pressing need for more integrated studies that incorporate ecological, economic, and social data to give a holistic assessment of the trade-offs and synergies related with NbS interventions (Cohen-Shacham et al., 2016). This comprises extensive socio-economic evaluations that expand beyond direct cash returns to cover issues like livelihood implications, community well-being, and equal access to benefits.

Future research should also address the intricacies of land-use trade-offs, ensuring that large-scale NbS deployment does not accidentally lower mitigation potential through increased land competition. This demands robust policy safeguards. Finally, future considerations must emphasize the necessity of inclusive governance systems and properly incorporating local ecological knowledge to create project ownership and ensure long-term sustainability.

5. Conclusions

This systematic review highlights the significant potential of NbS in agriculture as an effective strategy to address interconnected environmental challenges, such as climate change and biodiversity loss, at the same time contributing to food security and sustainable livelihoods. The findings consistently support the capacity of NbS ability to enhance carbon sequestration, improve biodiversity, and provide economic benefits, particularly in the long run and when evaluating the full value of ecosystem services.

Despite this overwhelming proof, the general operationalization and scalability of NbS are hindered by severe challenges. These include continuous financial shortfalls, difficulty in complete economic and ecological assessment, the absence of standardized monitoring, reporting, and verification (MRV) and intricate socio-economic and governance dynamics. The study emphasizes that current agricultural subsidies supporting conventional methods act as a systemic barrier, indicating that redirecting this financial resource towards NbS represents a high-impact strategy for their implementation, especially in low-income regions.

Beyond these barriers, this review also identified key research and knowledge gaps. Most studies focus on temperate regions and ecological outcomes, leaving tropical and arid systems—often more climate-vulnerable—underrepresented. Similarly, while carbon and biodiversity benefits are well documented, fewer studies assess economic viability, institutional feasibility, or social equity outcomes. Addressing these gaps will require broader geographic coverage, integrated evaluation of ecological and socio-economic impacts, and development of robust MRV frameworks to track progress and build trust among stakeholders.

Practical implications emerge from these findings. Policymakers and practitioners must design context-specific interventions that integrate ecological functions with livelihood benefits. Establishing enabling conditions, such as Payments for Ecosystem Services (PES) and access to voluntary carbon and biodiversity markets, can incentivize adoption. At the same time, capacity building, inclusive governance, and knowledge-sharing platforms are vital to ensure that NbS initiatives are not only technically effective but also socially equitable and sustainable in the long term.

Future research should prioritize several areas. Long-term, integrated studies are needed to evaluate the permanence of carbon storage and to understand trade-offs between ecological, economic, and social outcomes. Improved valuation methods are essential to capture non-market benefits such as cultural services and community well-being. Expanding research in tropical and arid regions, alongside innovative financing models and policy reforms, will be critical to scaling NbS globally.

In conclusion, NbS hold immense promise for transforming agriculture into a climate-resilient, biodiversityfriendly, and economically viable system. Realizing this potential will require bridging current evidence gaps, aligning policies and financial incentives, and fostering collaborative action between researchers, policymakers, and farming communities. By doing so, NbS can move from isolated pilot projects to integrated, large-scale solutions that secure both environmental health and human well-being for future generations.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

Albert, H. A., Li, X., Jeyakumar, P., Wei, L., Huang, L., Huang, Q., & Wang, H. (2021). Influence of biochar and soil properties on soil and plant tissue concentrations of Cd and Pb: A meta-analysis. *Sci Total Environ.*, *755*, 142582. https://doi.org/10.1016/j.scitotenv.2020.142582.

Amorim, H. C., Ashworth, A. J., O'Brien, P. L., Thomas, A. L., Runkle, B. R., & Philipp, D. (2023). Temperate silvopastures provide greater ecosystem services than conventional pasture systems. *Sci Rep.*, *13*(1), 18658. https://doi.org/10.1038/s41598-023-45960-0.

Araya, S. N., Mitchell, J. P., Hopmans, J. W., & Ghezzehei, T. A. (2022). Long-term impact of cover crop and reduced disturbance tillage on soil pore size distribution and soil water storage. *Soil*, *8*(1), 177–-198. https://doi.org/10.5194/soil-8-177-2022.

Begosh, A., Smith, L. M., Park, C. N., McMurry, S. T., & LaGrange, T. G. (2020). Effects of wetland presence and upland land use on wild hymenopteran and dipteran pollinators in the Rainwater Basin of Nebraska, USA. *Wetlands*, *40*, 1017–1031. https://doi.org/10.1007/s13157-019-01244-w.

Cerda, R., Avelino, J., Harvey, C. A., & Villanueva, C. (2022). Agroforestry systems improve coffee productivity and income: Evidence from Costa Rica's diversified coffee farms. *Agric Syst.*, *196*, 103–117. https://doi.org/10.1016/j.agsy.2022.

Chatterjee, N., Nair, P. R., Chakraborty, S., & Nair, V. D. (2018). Changes in soil carbon stocks across the forest-agroforest-agriculture/pasture continuum in various agroecological regions: A meta-analysis. *Agric Ecosyst Environ.*, *266*, 55-67. https://doi.org/10.1016/j.agee.2018.07.014.

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). *Nature-based Solutions to Adddress Global Societal Challenges*. IUCN. http://doi.org/10.2305/IUCN.CH.2016.13.en

Croeser, T., Garrard, G., Sharma, R., Ossola, A., & Bekessy, S. A. (2024). Nature-based solutions for urban biodiversity: Spatial targeting of retrofits can multiply ecological connectivity benefits. *Landsc Urban Plan.*, *251*, 105169. https://doi.org/10.1016/j.landurbplan.2024.105169.

Czyżewski, B. & Kryszak, Ł. (2025). Assessing potential reductions of agricultural GHG in countries with different land productivities: Long-term integrated efficiency in DEA hybrid meta-frontier model. *PLOS ONE*, *20*(2), e0315571. https://doi.org/10.1371/journal.pone.0315571.

Daryanto, S., Fu, B., Zhao, W., Wang, S., Jacinthe, P. A., & Wang, L. (2020). Ecosystem service provision of grain legume and cereal intercropping in Africa. *Agric Syst.*, *178*, 102761. https://doi.org/10.1016/j.agsy.2019.102761.

Debele, S. E., Leo, L. S., Kumar, P., Sahani, J., Ommer, J., Bucchignani, E., & Di Sabatino, S. (2023). Nature-based solutions can help reduce the impact of natural hazards: A global analysis of NBS case studies. *Sci Total Environ.*, *902*, 165824. https://doi.org/10.1016/j.scitotenv.2023.165824.

Ebbets, A. L., Lane, D. R., Dixon, P., Hollweg, T. A., Huisenga, M. T., & Gurevitch, J. (2020). Using meta-analysis to develop evidence-based recovery trajectories of vegetation and soils in restored wetlands in the northern Gulf of Mexico. *Estuaries Coasts*, *43*, 1692–1710. https://doi.org/10.1007/s12237-019-00536-y.

EU. (2024). *Carbon Removals and Carbon Farming Certification (CRCF) Regulation (EU 2024/3012)*. EU Climate Action. https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming_en

FAO & IUCN. (2024). Agroforestry for biodiversity and ecosystem services: Global practices and evidence. Food and Agriculture Organization of the United Nations. https://www.fao.org/agroforestry

FAO. (2013). *Climate-smart Agriculture Sourcebook.* https://www.fao.org/climate-smart-agriculture-sourcebook/en/

Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., & Niggli, U. (2012). Enhanced top soil carbon stocks under organic farming. *Proc Nat Acad Sci.*, *109*(44), 18226-18231. https://doi.org/10.1073/pnas.1209429109.

González Fradejas, G., García de León, D., Vasar, M., Koorem, K., Zobel, M., Öpik, M., & Rey Benayas, J. M. (2022). Hedgerows increase the diversity and modify the composition of arbuscular mycorrhizal fungi in Mediterranean agricultural landscapes. *Mycorrhiza*, *32*(5), 397–407. https://doi.org/10.1007/s00572-022-01090-5.

Gravuer, K., Gennet, S., & Thorne, J. H. (2019). Carbon sequestration through ecological restoration: A regional meta-analysis. *Glob Change Biol.*, *25*(2), 563–579. https://doi.org/10.1111/gcb.14535.

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., et al. (2017). Natural climate solutions. *Proc Nat Acad Sci.*, *114*, 11645–11650. https://doi.org/10.1073/pnas.1710465114.

Haddaway, N. R., Hedlund, K., Jackson, L. E., Kätterer, T., Lugato, E., Thomsen, I. K., Jørgensen, H. B., & Isberg, P.-E. (2017). How does tillage intensity affect soil organic carbon? A systematic review. *Environ Evid.*, *6*, 30. https://doi.org/10.1186/s13750-017-0108-9.

Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2020). Changing wildfire, changing forests: The effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecol.*, *16*, 4. https://doi.org/10.1186/s42408-019-0062-8.

Hannah, L., Roehrdanz, P. R., KC, K. B., Fraser, E. D., Donatti, C. I., Saenz, L., & van Soesbergen, A. (2020). The environmental consequences of climate-driven agricultural frontiers. *PLOS ONE*, *15*(2), e0228305. https://doi.org/10.1371/journal.pone.0228305.

Huang, L., Kou, W., Wu, L., Feinstein, L., Kong, Z. Y., & Ge, G. (2019). Microbial composition and activity of natural, restored, and reclaimed wetland soils: A case study of Poyang Lake Basin, China. *Wetlands*, *39*, 113–123. https://doi.org/10.1007/s13157-018-1020-y.

IPBES. (2016). The assessment report on pollinators, pollination and food production. *Intergov Sci-Policy Platf Biodivers Ecosyst Serv.*, https://ipbes.net/assessment-reports/pollinators

Iseman, T. & Miralles-Wilhelm, F. (2021). Nature-based solutions in agriculture: The case and pathway for adoption. *FAO Nat Conserv.*, https://doi.org/10.4060/cb3141en.

IUCN. (2021). Nature-based recovery: A path to a global green deal [Issue brief]. *Int Union Conserv Nat.*, https://www.iucn.org/resources/issues-brief/nature-based-recovery.

Jian, J., Du, X., Reiter, M. S., & Stewart, R. D. (2020). A meta-analysis of global cropland soil carbon changes due to cover cropping. *Soil Biol Biochem.*, *143*, 107735. http://doi.org/10.1016/j.soilbio.2020.107735.

Kaempf, I., Hoelzel, N., Stoerrle, M., Broll, G., & Kiehl, K. (2016). Potential of temperate agricultural soils for carbon sequestration: A meta-analysis of land-use effects. *Sci Total Environ.*, *566*, 428–435. https://doi.org/10.1016/j.scitotenv.2016.05.067.

Lal, R. (2016). Biochar and soil carbon sequestration. *Agriculture, Environment and Applied Biochar 63*, 175–197. http://doi.org/10.2136/sssaspecpub63.2014.0042.5.

Lee-Mäder, E., Vaughan, M., & Goldenetz-Dollar, J. (2020). Agroforestry and cover cropping for pollinators. *Toward Sustain Crop Pollin Serv.*, 105–126. https://openknowledge.fao.org/server/api/core/bitstreams/57d0e650-10b3-4221-8013-69d33239a999/content

Leiva-Dueñas, C., Graversen, A. E. L., Banta, G. T., Hansen, J. N., Schrøter, M. L. K., Masqué, P., Holmer, M., & Krause-Jensen, D. (2024). Region-specific drivers cause low organic carbon stocks and sequestration rates in the saltmarsh soils of southern Scandinavia. *Limnol Oceanogr.*, *69*(2), 290–308. https://doi.org/10.1002/lno.12480.

Lundgren, E. J. & Svenning, J.-C. (2024). Impacts of herbivores on ecosystems are driven by traits, not nativeness. *Science*, *384*(6690), 897–902, https://doi.org/10.1126/science.adh2616.

McClelland, S. C., Paustian, K., & Schipanski, M. E. (2021). Management of cover crops in temperate climates influences soil organic carbon stocks: A meta-analysis. *Ecol Appl.*, *31*(3), e02278. https://doi.org/10.1002/eap.2278.

McDaniel, M. D., Tiemann, L. K., & Grandy, A. S. (2014). Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecol Appl.*, *24*(3), 560-570. https://doi.org/10.1890/13-0616.1.

Meng, X., Liu, M., Meng, Z., Wu, C., Bao, C., Xu, B., & Cui, X. (2024). Effects of different restoration stages on soil microbial community composition and diversity in Naolihe Wetland, China. *Front Microbiol.*, *15*, 1403849. https://doi.org/10.3389/fmicb.2024.1403849.

Miralles-Wilhelm, F. (2023). Nature-based solutions in agricultural landscapes for reducing trade-offs between food production, climate change, and conservation objectives. *Front Water*, *5*, 1247322. https://doi.org/10.3389/frwa.2023.1247322.

Nave, L. E., DeLyser, K., Domke, G. M., Holub, S. M., Janowiak, M. K., Kittler, B., & Swanston, C. W. (2022). Disturbance and management effects on forest soil organic carbon stocks in the Pacific Northwest. *Ecol Appl.*, *32*(6), e2611. https://doi.org/10.1002/eap.2611.

Navntoft, S., Universitet, K., Universitet, A., & Biologisk Institut. (2009). Buffer zones for biodiversity of plants and arthropods: Is there a compromise on width? *Dan Environ Prot Agency.*
Nor, B. A. & Yusof, Y. (2025). Environmental degradation and food security in Somalia. *Discov Sustain.*, *6*(1), 75. https://doi.org/10.1007/s43621-024-00771-9.
Noss, R. F. (1990). Indicators for monitoring biodiversity: A hierarchical approach. *Conserv Biol.*, *4*(4), 355–364. https://doi.org/10.1111/j.1523-1739.1990.tb00309.4.
Nur, A. A. I., Seyawan, A. D., & Kusumaningrum, L. (2024). Estimation of carbon sequestration in pine forest and agroforestry in Bategede Village, Jepara, Central Java, Indonesia. *Asian J Forest.*, *8*(1). https://doi.org/10.13057/asianjfor/r080106.
Ojo, M. P., Ayanwale, A. B., Adelegan, O. J., Ojogho, O., Awoyelu, D. E. F., & Famodimu, J. (2024). Climate change vulnerability and adaptive capacity of smallholder farmers: A financing gap perspective. *Environ Sustain Ind.*, *24*, 100476. https://doi.org/10.1016/j.indic.2024.100476.
Olbermann, S., Buerkert, A., Tischer, S., & Bareth, G. (2004). Carbon sequestration potentials of an alley cropping system in the tropical humid zone of Costa Rica. *Agric. Ecosyst. Environ.*, *104* (3), 359–377. https://doi.org/10.1016/j.agee.2004.04.001.
Pan, J., Chen, S., He, D., Zhou, H., Ning, K., Ma, N., & Dong, Z. (2025). Agroforestry increases soil carbon sequestration, especially in arid areas: A global meta-analysis. *Catena*, *249*, 108667. https://doi.org/10.1016/j.catena.2024.108667.
Pessereau, E. (2024). *Flowering cover crops to support wild pollinators in annual cropping systems in Wisconsin* [Doctoralthesis, The University of Wisconsin-Milwaukee, U.S.]. http://digital.library.wisc.edu/1793/85284
Piñeiro, V., Arias, J., Elverdin, P., Ibáñez, A. M., Morales Opazo, C., Prager, S., & Torero, M. (2021). Achieving sustainable agricultural practices: From incentives to adoption and outcomes. *Int Food Policy Res* https://doi.org/10.2499/p15738coll2.134287.
Plastina, A., Liu, F., Sawadgo, W., Miguez, F. E., Carlson, S., & Marcillo, G. (2018). Annual net returns to cover crops in Iowa. *J Appl Farm Econ.*, *2*(2), Article 2. https://doi.org/10.7771/2331-9151.1030.
PLOS Climate. (2024), *Supporting the economy with nature-based solutions.* https://www.naturebasedsolutionsinitiative.org/news/economic-recovery-nature-based-solutions/
Powlson, D. S., Stirling, C. M., Thierfelder, C., White, R. P., & Jat, M. L. (2016). Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agric Ecosyst Environ.*, *220*, 164–174/ https://doi.org/10.1016/j.agee.2016.01.005.
Ruane, A. C. & Rosenzweig, C. (2018). Climate change impacts on agriculture. In *Agric Food Syst 2050* (pp. 161–191). World Scientific Publishing Co. https://doi.org/10.1142/9789813278356_0005.
Sangha, K. K., Ahammad, R., Russell-Smith, J., & Costanza, R. (2024). Payments for ecosystem services opportunities for emerging nature-based solutions: Integrating indigenous perspectives from Australia. *Ecosyst Serv.*, *66*, 101600. https://doi.org/10.1016/j.ecoser.2024.101600.
SARE. (2020). *Cover cropping for pollinators and beneficial insects.* https://www.sare.org/wp-content/uploads/Cover-Cropping-for-Pollinators-and-Beneficial-Insects.pdf
Schilling, F., Baumüller, H., Ecuru, J., & von Braun, J. (2023). Carbon farming in Africa: Opportunities and challenges for engaging smallholder farmers. *Center Dev Res.* https://hdl.handle.net/10419/278420
Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philos Trans R Soc B.*, *375*(1794), 20190120. https://doi.org/10.1098/rstb.2019.0120.
Shi, X., Wu, L., Zheng, Y., Zhang, X., Wang, Y., Chen, Q., Sun, Z., & Nie, T. (2024). Dynamic estimation of mangrove carbon storage in Hainan island based on the In VEST-PLUS model. *Forests*, *15*(5), 750. https://doi.org/10.3390/f15050750.
Strickland, M. S., Thomason, W. E., Avera, B., Franklin, J., Minick, K., Yamada, S., & Badgley, B. D. (2019), Short-term effects of cover crops on soil microbial characteristics and biogeochemical processes across actively managed farms. *Agrosyst Geosci Environ.*, *2*(1), e180064, https://doi.org/10.2134/age2018.12.0064.
Thomas, J. & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Med Res Methodol.*, *8*, 45. https://doi.org/10.1186/1471-2288-8-45.
Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity—Ecosystem service management. *Ecol Lett.*, *8*(8), 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x.
UCANR. (2020). *Hedgerows and pollinators—Topics in subtropics.* https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=41435.
UNEP. (2022). *State of Finance for Nature: Investing in Nature-Based Solutions to Meet Climate Targets by 2025*. https://www.unep.org/resources/report/state-finance-nature-2022

Vogel, E., Donat, M. G., Alexander, L. V., Meinshausen, M., Ray, D. K., Karoly, D., Meinshausen, N., & Frieler, K. (2019). The effects of climate extremes on global agricultural yields. *Environ Res Lett.*, *14*(5), 054010. https://doi.org/10.1016/j.indic.2024.100476.

Wang, Z., Yan, W., Peng, Y., Wan, M., Farooq, T. H., Fan, W., Lei, J., Yuan, C., Wang, W., Qi, Y., & Chen, X. (2023). Biomass production and carbon stocks in poplar-crop agroforestry chronosequence in subtropical Central China. *Plants*, *12*(13), 2451. https://doi.org/10.3390/plants12132451.

Wollenberg, E., Richards, M., Smith, P., & Havemann, T. (2022). Carbon credits and payments for ecosystem services: Bridging equity gaps in NbS adoption among smallholder farmers. *Nat Clim Change*, *12*(4), 345–352. https://doi.org/10.1038/s41558-022.

WWAP. (2018). *The United Nations World Water Development Report 2018: Nature-based Solutions for Water.* UNESCO. https://www.unesco.org/en/wwap/wwdr/2018

Xu, S., Liu, X., Li, X., & Tian, C. (2019). Soil organic carbon changes following wetland cultivation: A global meta-analysis. *Geoderma*, *347*, 49–58. https://doi.org/10.1016/j.geoderma.2019.03.033.