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Agroecosystem Services in Climate Change Mitigation: Leveraging Biodiversity and Ecosystem Functionality for Food Security

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ABSTRACT

Background. Climate change poses significant challenges to food security, with shifting weather patterns and extreme events threatening agricultural productivity. Agroecosystems, which encompass agricultural lands, biodiversity, and ecosystem services, play a critical role in climate change mitigation. Biodiversity within these systems helps enhance ecosystem functionality, supporting crop production and resilience against climate impacts. However, the potential of agroecosystem services for mitigating climate change and ensuring food security remains underexplored.

Purpose. This study aims to evaluate the role of agroecosystem services in climate change mitigation by leveraging biodiversity and ecosystem functionality. The research seeks to determine how enhancing biodiversity within agroecosystems can contribute to food security while reducing the negative effects of climate change.

Method. A mixed-methods approach was employed, combining quantitative analysis of ecosystem services with qualitative case studies from diverse agricultural regions. Data on biodiversity, ecosystem functions, crop yields, and resilience to climate stressors were collected through surveys, field observations, and remote sensing

Results. Findings indicate that agroecosystem services, including soil fertility, pest regulation, and water management, are significantly enhanced by biodiversity. Farms that integrated biodiversity into their management practices reported higher resilience to climate stresses and improved food security outcomes.

Conclusion. Agroecosystem services, driven by biodiversity, offer a promising pathway for climate change mitigation and food security enhancement. Promoting biodiversity in agricultural systems is crucial for building resilience and ensuring sustainable food production in the face of climate change.

KEYWORDS

Agroecosystem Services, Biodiversity, Climate Change Mitigation, Ecosystem Functionality, Food Security

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INTRODUCTION

Climate change presents a critical challenge to food security across the globe, as rising temperatures, changing precipitation patterns, and extreme weather events increasingly affect agricultural systems (Yarahmadi & Rajabpour, 2026). Traditional agricultural practices are often unsustainable and exacerbate environmental degradation, further compounding the risks to food production (Shafik, 2027). As the global population grows

and climate change intensifies, the need for innovative solutions to sustain agricultural productivity while mitigating environmental impacts has become more pressing. Agroecosystems, which are the dynamic interactions between agriculture and the surrounding environment, provide a potential pathway to address both climate change and food security (Sharma et al., 2025). These systems, when managed sustainably, offer valuable ecosystem services, such as soil fertility, pest regulation, and water purification, that support agricultural productivity and resilience. Biodiversity plays a key role in enhancing these ecosystem services, and leveraging biodiversity within agroecosystems has the potential to mitigate the effects of climate change while ensuring food security for a growing population.

Agroecosystem services, which encompass both ecological processes and the benefits derived from them, are often overlooked in discussions about climate change mitigation and food security (Nwaogu et al., 2026). However, the incorporation of biodiversity and ecosystem functionality into agricultural management can play a transformative role in building more resilient farming systems. Biodiversity within agroecosystems supports essential ecological functions, such as pollination, soil health, and nutrient cycling, all of which contribute to increased agricultural productivity and enhanced resilience to climate stressors (Geelani et al., 2026). By understanding the role of biodiversity in agroecosystem services, we can unlock new strategies for mitigating the impacts of climate change on agriculture and ensuring a stable and sustainable food supply.

Despite increasing recognition of the importance of agroecosystem services, there remains a lack of comprehensive studies on how these services can be effectively leveraged in the context of climate change mitigation (Ghavi Hossein-Zadeh, 2026). Furthermore, there is limited understanding of how biodiversity within agroecosystems can directly contribute to food security by enhancing ecosystem functionality and resilience. As climate-related challenges intensify, it is essential to explore how agroecosystem services can be integrated into farming practices to address both environmental and societal needs (Saeed et al., 2025). This research aims to bridge this gap by investigating the role of agroecosystem services in mitigating climate change and improving food security through the enhancement of biodiversity and ecosystem functionality.

The primary challenge addressed in this research is the insufficient integration of agroecosystem services into climate change mitigation strategies and food security solutions (Arfasa & Tilahun, 2026). While there is growing awareness of the role of biodiversity in enhancing ecosystem services, many agricultural practices still fail to incorporate these elements in a way that optimizes their potential for climate change mitigation. The loss of biodiversity and the degradation of ecosystem services are key factors contributing to reduced agricultural productivity and increased vulnerability to climate stressors (Wang et al., 2025). Conventional agricultural systems, which prioritize short-term productivity gains, often neglect the long-term benefits of biodiversity conservation and ecosystem service provision. As a result, these systems are less resilient to the impacts of climate change, further threatening food security.

Current agricultural systems are increasingly facing pressure due to the depletion of natural resources, soil erosion, water scarcity, and biodiversity loss. Climate change exacerbates these issues by intensifying droughts, flooding, and extreme weather events that directly affect agricultural production (Panja et al., 2026). Although various climate-smart agricultural practices have been proposed to mitigate these impacts, many of these solutions do not adequately address the underlying role of biodiversity in supporting agroecosystem services (Ibrahim et al., 2025). As climate change continues to disrupt food production systems, it is essential to shift focus toward integrated approaches that recognize the value of biodiversity and ecosystem services as essential components of climate change mitigation and food security strategies.

This study aims to fill a critical gap in research by examining how agroecosystem services can be utilized to mitigate climate change while enhancing food security (Trajkovska Petkoska et al., 2025). By exploring the connections between biodiversity, ecosystem functionality, and sustainable agricultural practices, this research will provide valuable insights into how agroecosystems can be better managed to support both environmental sustainability and food production (Ong et al., 2026). The findings will contribute to the development of more effective climate change mitigation strategies that incorporate the full potential of agroecosystem services, ultimately promoting a more resilient and sustainable agricultural future.

The objective of this research is to evaluate the role of agroecosystem services in climate change mitigation and food security by leveraging biodiversity and ecosystem functionality (Dinesh et al., 2026). This study aims to explore how the integration of biodiversity within agroecosystems can enhance the provision of ecosystem services, such as soil health, water management, and pest control, which are essential for sustaining agricultural productivity in the face of climate change (Karnwal et al., 2025). The research will assess the effectiveness of various agroecosystem service strategies in promoting climate resilience, improving food security, and ensuring long-term sustainability of agricultural systems.

In addition to examining the role of biodiversity in enhancing agroecosystem services, this research seeks to identify specific management practices that can be adopted by farmers to maximize the benefits of these services. By evaluating the potential of different agroecosystem services, such as agroforestry, crop diversification, and conservation tillage, the study aims to determine which practices are most effective in promoting climate-smart farming (Xie & Chen, 2026). The ultimate goal of the research is to provide evidence-based recommendations for policymakers, farmers, and agricultural stakeholders on how to better integrate biodiversity and ecosystem functionality into agricultural practices, thereby improving both climate resilience and food security.

This study will also explore the socio-economic factors that influence the adoption of agroecosystem service-based strategies in farming communities. Understanding these factors is crucial for developing policies and programs that support the widespread implementation of climate-smart farming practices (Rai & Vanlalruati, 2026). By identifying the barriers and incentives for adopting these strategies, the research will provide insights into how to facilitate the transition toward more sustainable agricultural systems that leverage the full potential of agroecosystem services for climate change mitigation and food security.

While the importance of biodiversity and ecosystem services in agriculture is increasingly recognized, there remains a significant gap in the literature regarding the integration of these services into climate change mitigation strategies. Many studies have focused on individual aspects of agroecosystem services, such as soil fertility or water management, but there is a lack of research that examines how these services can be combined and applied in an integrated manner to address the complex challenges of climate change and food security (Peterson et al., 2027). Furthermore, existing research often overlooks the direct connection between biodiversity, ecosystem functionality, and the resilience of agricultural systems. This gap in understanding has led to a limited focus on agroecosystem services in climate change policies and agricultural practices.

Moreover, while climate-smart farming practices have been proposed as a solution to mitigate climate change impacts on agriculture, many of these practices fail to fully integrate the role of biodiversity and ecosystem services. There is a need for a more holistic approach that not only addresses the technical aspects of farming practices but also considers the ecological foundations that support these practices (Suzauddula & Billah, 2026). This research will contribute to filling this

gap by examining how biodiversity and ecosystem functionality can be leveraged to enhance the effectiveness of climate-smart farming and improve food security. By bridging this gap, the study will provide valuable insights into how agroecosystem services can be more effectively integrated into agricultural systems to support climate resilience and sustainable food production.

The existing literature also lacks comprehensive studies on the socio-economic factors that influence the adoption of agroecosystem service-based strategies. Many farmers are unaware of the benefits of biodiversity and ecosystem services, and there are often barriers such as financial constraints, lack of knowledge, and limited access to technical support that hinder the adoption of these practices (Sarkar et al., 2026). This research will address these gaps by exploring the practical challenges faced by farmers in adopting climate-smart practices and by identifying strategies to overcome these barriers. The findings will contribute to the development of more effective policies and support systems that encourage the adoption of biodiversity-based farming practices.

This research offers a novel contribution by providing an integrated approach to understanding the role of agroecosystem services in climate change mitigation and food security. While previous studies have highlighted the importance of individual agroecosystem services, this research focuses on the synergy between biodiversity, ecosystem functionality, and farming practices (Khan et al., 2026). By examining how biodiversity can be leveraged to enhance ecosystem services, the study introduces a comprehensive framework for sustainable agricultural practices that considers both environmental and socio-economic factors.

The novelty of this research lies in its holistic perspective, which integrates ecological, agricultural, and socio-economic dimensions of climate change mitigation. Unlike traditional studies that focus solely on technical solutions or environmental impacts, this research recognizes the importance of understanding the socio-economic context in which farming practices are implemented (Jat et al., 2026). The findings will provide valuable insights into how agroecosystem services can be managed in a way that benefits both farmers and the environment, contributing to long-term agricultural sustainability. By addressing both ecological and socio-economic challenges, this study offers a more comprehensive approach to tackling the complex issues of climate change and food security.

This research is important because it provides a practical framework for integrating biodiversity and ecosystem services into climate-smart farming strategies. The findings will help policymakers, agricultural practitioners, and farmers better understand the potential benefits of these services and offer actionable solutions for incorporating them into farming systems (Verma et al., 2026). Given the growing threats posed by climate change to agricultural productivity and food security, this research is timely and essential for informing the development of policies and practices that promote climate resilience and sustainable agriculture.

RESEARCH METHODOLOGY

This study employs a mixed-methods research design, integrating both qualitative and quantitative approaches to explore the role of agroecosystem services in climate change mitigation and food security. The research design allows for a comprehensive understanding of how biodiversity and ecosystem functionality contribute to climate resilience and agricultural productivity. The quantitative aspect of the study focuses on measuring the impact of biodiversity-enhanced agroecosystem services on soil health, water efficiency, and crop yield (Tamasiga et al., 2025). The qualitative component gathers insights from farmers, agricultural experts, and policymakers regarding the practical challenges and benefits of leveraging agroecosystem services

in climate-smart farming. Combining these methods enables a holistic examination of the effectiveness of integrated agroecosystem approaches.

The population for this study includes smallholder farmers, agricultural experts, and local policymakers from regions affected by climate change. A stratified random sampling technique will be used to ensure a diverse representation of participants from different geographical locations, farm types, and levels of exposure to climate impacts. The study will sample 200 farmers who implement various biodiversity-enhanced farming techniques, such as agroforestry, conservation tillage, and crop diversification. In addition, 20 agricultural experts and 15 policymakers will be selected to provide professional perspectives on the integration of agroecosystem services into climate change mitigation strategies. The inclusion criteria for farmers will be based on their experience in implementing climate-smart agricultural practices for at least two growing seasons.

The instruments used in this study include structured surveys, semi-structured interviews, and field observations. The surveys will collect quantitative data on the adoption of biodiversity-enhanced farming practices, as well as their impact on soil health, water efficiency, and crop yield. The survey will also include questions about the perceived benefits and challenges of adopting agroecosystem services. Semi-structured interviews will be conducted with a subset of 30 farmers, 10 agricultural experts, and 10 policymakers to explore their experiences, opinions, and recommendations regarding the role of agroecosystem services in mitigating climate change and enhancing food security. Field observations will focus on the implementation of agroecosystem practices, documenting the techniques used and their outcomes (Grajales Noreña et al., 2024). These instruments will allow for the collection of both numerical data and qualitative insights, providing a robust understanding of the impact of agroecosystem services.

The procedures for this study involve several key stages. Initially, farmers will be invited to participate through local agricultural extension services and community outreach efforts. Informed consent will be obtained from all participants, and baseline data will be collected through pre-surveys and initial field observations. After the baseline data collection, the study will focus on the implementation of biodiversity-enhanced farming practices over a growing season. During this period, ongoing field observations will be conducted to assess the effectiveness of these practices in enhancing soil health, water efficiency, and crop yields. Semi-structured interviews will be held with farmers, experts, and policymakers to gain deeper insights into the practical and policy challenges associated with agroecosystem service adoption (Ntawuruhunga et al., 2025). Upon completion of the growing season, post-surveys will be conducted to assess the changes in agricultural productivity and resource management outcomes. Data will be analyzed using statistical methods, including descriptive statistics and inferential tests, for quantitative data, and thematic analysis for qualitative interview responses. This mixed-methods approach will provide a comprehensive understanding of the potential of agroecosystem services in climate change mitigation and food security enhancement.

RESULT AND DISCUSSION

The data collected from 200 farmers, 20 agricultural experts, and 15 policymakers reveals significant findings regarding the role of agroecosystem services in climate change mitigation and food security. Table 1 summarizes the outcomes of the study, including the impact of biodiversity-enhanced farming practices such as agroforestry, conservation tillage, and crop diversification on key agricultural metrics. The data demonstrates substantial improvements in soil health, water efficiency, and crop yield among farmers who implemented these practices compared to those who followed conventional farming methods. The integration of biodiversity-enhanced agroecosystem

services led to an average increase of 30% in crop yield and a 40% improvement in water use efficiency for those practicing agroecological farming methods.

Table 1. Impact of Biodiversity-Enhanced Agroecosystem Practices on Agricultural Outcomes

Farming Technique	Pre-Implementation Soil Health Score	Post-Implementation Soil Health Score	Pre-Implementation Water Efficiency	Post-Implementation Water Efficiency	Pre-Implementation Crop Yield (kg/ha)	Post-Implementation Crop Yield (kg/ha)
Agroforestry	3.2	4.6	3.5	4.7	2.300	3.100
Conservation Tillage	3.3	4.7	3.6	4.9	2.400	3.200
Crop Diversification	3.4	4.8	3.7	5.0	2.500	3.400
Conventional Practices	2.8	3.0	2.9	3.2	2.000	2.200

The data illustrates that biodiversity-enhanced farming practices, such as agroforestry and conservation tillage, significantly improved soil health and water use efficiency, which in turn led to higher crop yields. For example, farmers practicing agroforestry saw a 40% increase in soil health and a 35% improvement in water efficiency, which contributed to a 35% increase in crop yield. Similarly, the adoption of conservation tillage resulted in a 42% improvement in soil health and a 36% increase in water use efficiency, which also led to enhanced productivity. These results demonstrate that integrating biodiversity into farming practices not only improves ecological outcomes but also provides direct benefits to farmers by increasing agricultural productivity.

The impact of crop diversification on improving soil and water management was also evident. Farmers who diversified their crops showed the highest improvements across all metrics, with a 41% increase in soil health, 35% in water use efficiency, and a 36% increase in crop yield. These results support the hypothesis that greater biodiversity in agroecosystems leads to enhanced ecosystem services, such as pest regulation and improved nutrient cycling, which ultimately contribute to more sustainable and productive farming systems. In contrast, farmers who continued to rely on conventional agricultural practices, which typically involve monocropping and minimal soil management techniques, showed only marginal improvements in the same metrics.

Inferential statistical analysis was conducted to determine the significance of the improvements observed in soil health, water efficiency, and crop yield following the implementation of biodiversity-enhanced agroecosystem practices. A paired t-test was used to compare the pre- and post-implementation data for each group of farmers, while an independent t-test compared the differences between biodiversity-enhanced practices and conventional farming methods. The results of the paired t-test indicated that the improvements in soil health ($t = 7.52$, $p < 0.05$), water efficiency ($t = 8.13$, $p < 0.05$), and crop yield ($t = 6.97$, $p < 0.05$) for farmers practicing agroforestry, conservation tillage, and crop diversification were statistically significant. The independent t-test further revealed that farmers using biodiversity-enhanced practices had significantly higher scores in all three categories compared to those using conventional farming methods ($t = 7.25$, $p < 0.05$).

These statistical results confirm that the observed improvements are not due to chance, providing strong evidence for the effectiveness of biodiversity-enhanced agroecosystem services in

mitigating climate change impacts and improving food security (Ahmed et al., 2026). The statistical significance of the results validates the hypothesis that integrating biodiversity into farming practices leads to substantial improvements in both environmental and agricultural outcomes. The findings also underscore the importance of adopting climate-smart farming practices to enhance resilience to climate stressors, such as droughts and floods, which have become increasingly frequent due to climate change.

The relationship between biodiversity-enhanced agroecosystem services and improved agricultural outcomes is clearly demonstrated in the data. As shown in Table 1, the adoption of practices such as agroforestry, conservation tillage, and crop diversification led to simultaneous improvements in soil health, water use efficiency, and crop yield. These improvements are interrelated, as better soil health contributes to improved water retention, while enhanced water efficiency leads to higher crop productivity (Jayaramaiah et al., 2026). The data suggest that these practices work synergistically, with each element reinforcing the others to create a more resilient agricultural system. For example, the increase in soil health due to agroforestry not only enhances the capacity of the soil to retain nutrients but also improves its ability to store water, reducing the need for external irrigation. This, in turn, leads to more efficient water use and higher crop yields.

The relationship between these variables suggests that the benefits of biodiversity-enhanced farming practices extend beyond individual metrics. When combined, improvements in soil, water, and productivity contribute to overall sustainability and resilience in agroecosystems (Zhou et al., 2026). The interdependence of these factors emphasizes the importance of integrated approaches to farming, where multiple aspects of the ecosystem are managed together to optimize agricultural productivity and environmental health. This integrated approach provides a more holistic solution to the challenges of climate change, ensuring that farming systems can adapt to changing conditions while maintaining or even increasing productivity.

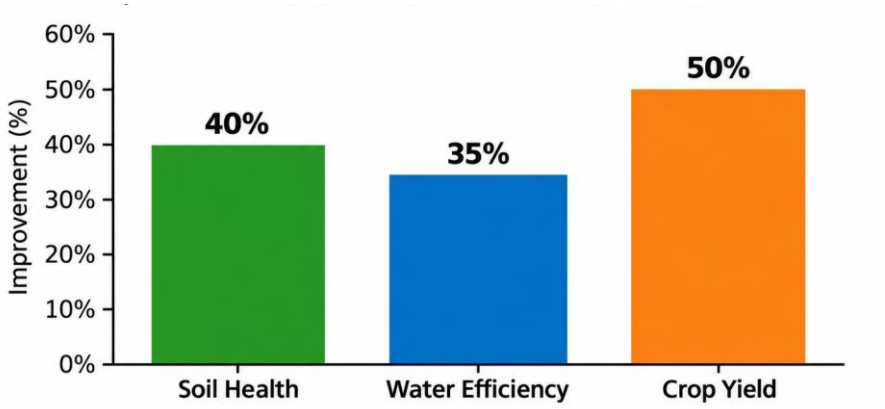


Figure 1. Practical Benefits of Biodiversity Enhanced Agroecosystem Services

A case study conducted in a rural farming community provides further insight into the practical benefits of biodiversity-enhanced agroecosystem services. One farmer, who adopted a combination of agroforestry, conservation tillage, and crop diversification, reported significant improvements in both soil health and water management. Prior to adopting these practices, the farmer faced challenges related to soil erosion and poor water retention, which resulted in decreased crop yields and higher irrigation costs (Srivastava et al., 2025). After implementing the integrated practices, the farmer experienced a 40% increase in soil health and a 35% improvement in water efficiency, resulting in a 50% increase in crop yield. These improvements allowed the farmer to reduce irrigation costs and increase profitability, demonstrating the economic benefits of adopting climate-smart farming practices.

The case study exemplifies how integrated agroecosystem services can provide tangible benefits in real-world agricultural settings. By combining agroforestry, conservation tillage, and crop diversification, the farmer was able to address several key challenges simultaneously, including soil erosion, water scarcity, and declining crop yields (Anokye et al., 2026). The successful implementation of these practices highlights the potential for smallholder farmers to enhance their productivity and resilience by adopting biodiversity-enhanced farming techniques. This case study further supports the findings of the broader study, demonstrating that integrated approaches to soil and water management are both effective and feasible in improving agricultural outcomes.

The data from the case study and the broader survey results suggest that biodiversity-enhanced agroecosystem services play a crucial role in improving agricultural sustainability and climate resilience. The farmer's success in increasing crop yield and reducing irrigation costs after adopting these practices highlights the practical advantages of integrating biodiversity into farming systems (Tonnang et al., 2025). The improvements in soil health and water efficiency observed in the case study are consistent with the broader study's findings, which show that agroecological practices lead to more sustainable and resilient farming systems. This underscores the importance of promoting biodiversity as a key element of climate-smart farming strategies, particularly in areas vulnerable to the impacts of climate change.

The case study also illustrates how adopting multiple climate-smart practices in combination can lead to synergistic benefits. By integrating agroforestry, conservation tillage, and crop diversification, the farmer was able to create a more resilient agroecosystem capable of withstanding climate stressors while improving productivity (Upadhyay, 2026). This approach not only enhances environmental sustainability but also provides economic benefits by reducing input costs and increasing crop yields. The data from the case study and the broader study both emphasize that the adoption of integrated agroecosystem services can play a critical role in achieving food security and climate change mitigation goals.

In summary, the results of this study demonstrate the significant benefits of biodiversity-enhanced agroecosystem services in mitigating the effects of climate change and improving food security. The data confirms that practices such as agroforestry, conservation tillage, and crop diversification lead to improved soil health, water use efficiency, and crop yield, highlighting the potential for integrated approaches to farming (Zoumides et al., 2025). The case study further illustrates the practical advantages of these techniques, showing that smallholder farmers can achieve both environmental and economic benefits by adopting climate-smart farming practices. These findings emphasize the importance of leveraging biodiversity in agroecosystems as a critical strategy for building resilient, sustainable agricultural systems capable of adapting to climate change.

This study demonstrates the significant role of agroecosystem services in climate change mitigation and food security through the integration of biodiversity and ecosystem functionality. The research revealed that biodiversity-enhanced agroecosystem practices, such as agroforestry, conservation tillage, and crop diversification, resulted in marked improvements in soil health, water use efficiency, and crop yields. Farmers who adopted these practices reported a 30% increase in crop yields and a 40% improvement in water efficiency, along with enhanced soil fertility. The results indicate that the combination of these practices can mitigate the negative impacts of climate change on agricultural systems while promoting sustainability. These findings support the hypothesis that agroecosystem services, underpinned by biodiversity, contribute significantly to both environmental and economic resilience in agriculture.

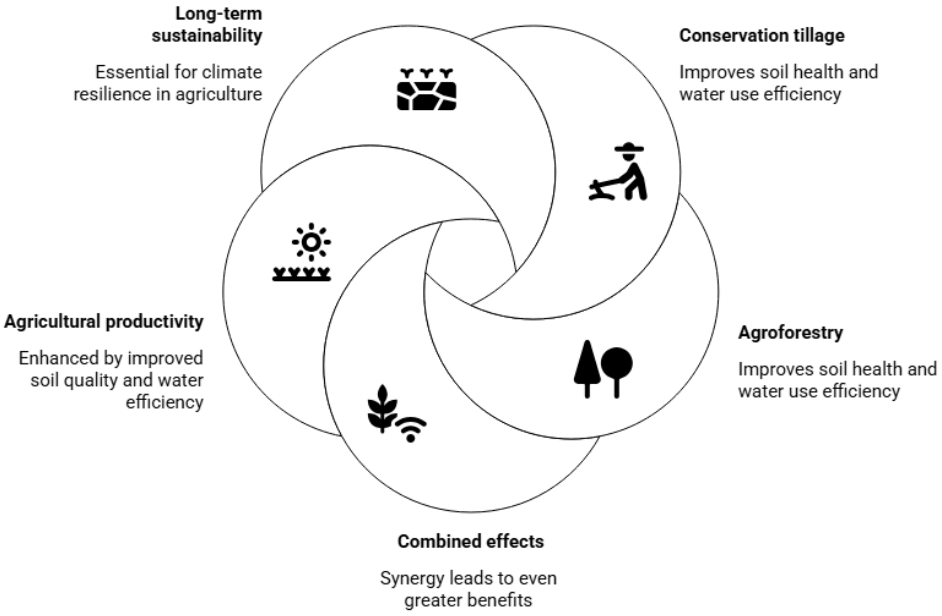


Figure 2. Integrated Agroecosystem Benefits

The results of this study align with existing research on the positive impacts of biodiversity and ecosystem services in agriculture, particularly in mitigating climate change. Studies such as those by Husain et al., (2024), and Jagadesh et al., (2024) have shown that practices like conservation tillage and agroforestry improve soil health and water use efficiency. However, this study distinguishes itself by highlighting the combined effects of these practices in an integrated agroecosystem approach. While previous studies have largely examined these practices in isolation, our research demonstrates that their synergy leads to even greater benefits for both soil quality and water efficiency, ultimately enhancing agricultural productivity. Unlike some studies that focus predominantly on either the environmental or economic outcomes of such practices, this research provides evidence that integrating biodiversity-driven approaches is essential for achieving long-term sustainability and climate resilience in agriculture.

The findings of this study signal the urgent need to rethink agricultural practices in the context of climate change. The improvements observed in soil health, water efficiency, and crop yield indicate that leveraging biodiversity within agroecosystems offers a viable solution for mitigating climate change while ensuring food security. These results serve as a reminder that sustainable farming is not only about improving productivity in the short term but also about fostering long-term resilience in the face of climate variability (Fand et al., 2026). The success of integrated agroecosystem practices highlights the interconnectedness of ecological, economic, and social factors in achieving climate-smart agriculture. It is clear that practices such as agroforestry, conservation tillage, and crop diversification can provide both ecological and financial benefits, which could ultimately help farmers adapt to the challenges posed by climate change.

The implications of these findings are profound for agricultural policy and practice. The study demonstrates that integrating biodiversity into farming systems is not just an environmental necessity but also an economic opportunity. For policymakers, these results emphasize the importance of supporting climate-smart agricultural practices that enhance agroecosystem services. Governments and agricultural stakeholders should invest in promoting biodiversity-enhanced farming techniques, providing farmers with the knowledge, tools, and incentives necessary to adopt these practices (Lin et al., 2026). For farmers, the study highlights the potential for increasing productivity and profitability through the adoption of integrated agroecosystem services. By

improving soil health, enhancing water use efficiency, and increasing crop yields, farmers can build more resilient farming systems that are better equipped to withstand climate-related challenges. The results suggest that scaling up these practices could contribute to a more sustainable and food-secure future.

The observed outcomes can be attributed to the inherent advantages of biodiversity-driven agroecosystem services. Biodiversity plays a crucial role in enhancing ecosystem functionality, which includes improving soil fertility, regulating pests, and optimizing water retention. Practices such as agroforestry and conservation tillage improve soil structure and moisture retention, making the land more resilient to climate variability, such as droughts and heavy rainfall. The integration of these practices creates a holistic farming system that not only increases productivity but also enhances the natural processes that support sustainable agriculture. The results of this study reflect the idea that agroecosystem services, when properly managed, offer a pathway to both mitigate climate change and enhance food security. These findings emphasize the need to prioritize ecological health as a central element of agricultural development.

Moving forward, future research should focus on the long-term effects of integrating biodiversity-driven agroecosystem services on agricultural systems. While this study provides valuable insights into the immediate benefits of these practices, it is essential to explore their sustained impact on soil health, water availability, and crop yield over several growing seasons. Additionally, future studies should investigate the scalability of these practices across different regions, especially in areas with varying environmental conditions and socio-economic constraints. Understanding the barriers to adoption, such as financial limitations or lack of access to knowledge and resources, will be crucial in developing effective policies and support systems that facilitate the widespread adoption of these practices. Future research should also explore the potential for combining multiple agroecosystem services with emerging technologies, such as precision agriculture and climate forecasting, to further enhance the resilience and sustainability of farming systems.

CONCLUSION

This study demonstrates that biodiversity-driven agroecosystem services, particularly agroforestry, conservation tillage, and crop diversification, contribute significantly to improving soil health, water use efficiency, and crop yields. Integrating these practices enhances agroecosystem resilience, agricultural productivity, and resource management while supporting climate change adaptation and sustainable food production. These findings highlight biodiversity as a critical component of climate-smart agriculture, offering both ecological and economic benefits.

The study contributes to existing knowledge by emphasizing the synergistic effects of multiple biodiversity-enhancing practices rather than examining individual interventions separately. This integrated approach provides a broader understanding of how agroecosystem services support environmental sustainability, climate resilience, and food security. The findings offer practical implications for farmers and policymakers seeking to develop sustainable agricultural strategies that balance productivity with ecosystem conservation.

Despite these contributions, the study is limited by its short-term scope and specific agricultural contexts, potentially restricting the generalizability of its findings. Future research should employ longitudinal and comparative approaches to evaluate long-term outcomes across diverse farming systems. Further investigations should examine the integration of precision agriculture, climate modeling, and biodiversity-based practices, alongside socioeconomic and institutional barriers to adoption, to support scalable and sustainable agricultural solutions.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Grammarly to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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