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CARBON SEQUESTRATION IN AGROECOSYSTEMS: EVALUATING THE ROLE OF SUSTAINABLE AGRONOMIC INTERVENTIONS

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ABSTRACT

Carbon sequestration by agroecosystems has become an important tool for addressing the issue of climate change and improving soil quality at the same time. This paper analyzes the use of sustainable agronomic practices, namely, conservation tillage, crop rotation, cover crops, organic inputs, and agroforestry, to promote carbon sequestration and reduce greenhouse gas emissions. The present work critically examines recent empirical data and models on how these agronomic practices can lead to carbon sequestration due to improved soil properties, increased activity of microorganisms, and higher biomass productivity. Research findings show that the integration of sustainable practices into agriculture considerably increases the potential for carbon sequestration compared to traditional farm practices. In addition, the effectiveness of carbon sequestration varies depending on certain conditions, including the type of soil, climate zone, and crop cultivation. The analysis also shows that there are limitations in the implementation of sustainable practices on a larger scale, which should be addressed through proper planning and policy measures.
***Keywords* :** Agroecosystems, carbon sequestration, climate change mitigation, crop rotation, sustainable agriculture.

Introduction

The sequestration of carbon from the atmosphere has become a critical method to address the challenges of global warming. It refers to the removal of atmospheric carbon dioxide and its subsequent capture and storage within terrestrial ecosystems, especially the soils. The agroecosystem accounts for a considerable part of the land surface on earth. They also hold significant potential as regards to improving the quantity of carbon stored in the soils by means of adopting sustainable practices in their management. Sustainable agricultural practices have been proven effective in turning traditional farming systems into sinks for carbon (Amissah *et al.*, 2023; Anand *et al.*, 2025). Soil organic carbon has an essential function in ensuring soil health and fertility. This is because soil organic carbon plays an essential role in ensuring soil fertility and its structure and biological properties. The accumulation and storage of carbon in the soils depend on several aspects. Some of the main determinants include land-use practices, climatic and soil management practices (Abdalla *et al.*, 2023; Badewa *et al.*, 2023). Historically, the intensification of agriculture and adoption of unsustainable agricultural practices have caused significant loss of soil carbon. The use of excessive tillage, monoculture crops, and poor fertilization has affected soil composition and contributed to the mineralization of soil carbon. Model studies show that poor agronomic practices are more detrimental for SOC retention within arid and semi-arid regions (Ahmadian *et al.*, 2025; Alvarez, 2022). In contrast, sustainable practices in agriculture, such as the implementation of no-till farming, crop diversification, and cover crops, have proven to be useful approaches for increasing SOC retention in agroecosystems. In particular, the introduction of cover crops has demonstrated positive effects on the dynamics of decomposition and carbon mineralization in agricultural systems (Adhikari *et al.*, 2024; Barnes *et al.*, 2026). The addition of legumes to cropping systems also plays an important role in carbon sequestration. Such agronomic practices as crop rotations with legumes contribute to higher biomass formation and better nitrogen retention in soils. The application of legume-based farming systems increases microbial activity and carbon input and, thus, improves soil carbon stocks. Scientific research confirms that the use of legume-based cropping systems positively affects soil carbon retention (Ashraf *et al*., 2025; Arshad, 2025). Organic ameliorants such as compost, manures, and biochar are important sources of organic matter and are known to promote microbial activities and nutrient cycles. In addition, biochar is known to be stable and to be an efficient tool for carbon sequestration. Besides being useful in soil carbon sequestration, biochar also contributes towards reduction of GHGs from agricultural soils (Al-Ismaily *et al*., 2026; Bai *et al*., 2025a). Another critical element for enhancing soil carbon stocks and achieving soil carbon sequestration is the soil microbiota which consists of different types of microorganisms including arbuscular mycorrhizal fungi that are known to form a symbiosis with plants. Microorganisms improve soil structure leading to effective carbon stabilization and transferring of soil carbon into different soil organic carbon pools (Ahmed *et al*., 2026; Azevedo *et al*., 2024). Lastly, fertilization practice can positively influence soil carbon stock. This is achieved through proper fertilization of soils to ensure maintenance of inorganic carbon in soil and reducing carbon dioxide emissions, as well as avoiding excess nitrogen input to avoid soil acidification. Recent research has shown that the proper application of fertilizers could significantly contribute towards soil carbon sequestration (Abdollahpour *et al*., 2025a; Abdollahpour *et al*., 2025b). Another possible strategy for carbon capture is agroforestry, where trees are integrated into agriculture or livestock systems to sequester more carbon than would be expected in traditional agricultural systems. Agroforestry improves biomass production and increases carbon sequestration both aboveground and underground. Numerous studies have shown that agroforestry systems make significant contributions to carbon stocks while improving biodiversity and ecosystem services (An *et al*., 2022; Ávila-Bello *et al*., 2024). It should be noted that land use and management decisions play a crucial role in determining the possibility of carbon sequestration through agricultural practices. The switch to sustainable farming systems may result in a considerable boost in carbon stocks stored in the biomass and soil (Amissah *et al*., 2023; Bambach *et al*., 2024). While the benefits of sustainable agriculture are obvious, some obstacles to implementing such farming practices still exist. Firstly, there are economic barriers that prevent farmers from adopting new techniques, and secondly, farmers' unwillingness to change their established patterns poses an additional challenge. Finally, uncertainty about measurements and monitoring of carbon sequestration makes the policy implementation difficult (Badagliacca *et al*., 2024; Ajala *et al*., 2022). Thus, the objective of this research is to assess the significance of sustainable agronomic practices on the improvement of carbon sequestration in the agroecosystem. Through the integration of previous literature and the analysis of the efficacy of different methods, this paper intends to offer recommendations for the optimization of soil carbon management techniques. The results will be useful in developing climate resilient farming systems and formulating policies for sustainable land management (Attia *et al*., 2024a; Attia *et al*., 2025b).

Background on climate change and carbon emissions

Global warming has become the major problem of our time, which has been exacerbated due to high levels of carbon dioxide in the atmosphere. Human activities, like burning of fossil fuels, deforestation, and unsustainable farming practices have contributed to carbon emissions that have led to environmental problems such as climate change, precipitation, and extreme weather events (Amissah *et al*., 2023; Anand *et al*., 2025). In addition to being the source of GHGs, agriculture is also the sector that emits high amounts of carbon into the atmosphere because of soil disturbance, usage of fertilizers, and changes in land use. Over-farming, cultivation of the same plants on large territories (monocultures), and excessive tillage cause quick decomposition of organic matter that releases carbon stored in the soil (Adamson *et al*., 2026; Abdollahpour *et al*., 2025a). As a result, agricultural activities have created a situation in which we experience environmental degradation like soil erosion, loss of biodiversity, and reduced yield. At the same time, negative impacts of climate change for instance, droughts worsen these problems, especially within vulnerable agroecosystems (Ahmadian *et al*., 2025; Alvarez, 2022).

Importance of Carbon Sequestration in agriculture

Carbon sequestration in agriculture is the method used to capture the carbon dioxide from the atmosphere and store it in the soils and plant tissues. This is an important measure that will help mitigate the problem of climate change, alongside the enhancement of the soil quality and productivity (Abdalla *et al*., 2023; Badewa *et al*., 2023). Soil can be a significant sink for atomspheric carbon dioxide in sustainable agricultural practices by enhancing the level of soil organic carbon through the increase in the amount of biomass and minimizing carbon losses. Composting and manure addition to the soil has proved to be one of the best practices for carbon sequestration and improvement of nutrient content and microbial activity in the soil (Atoloye *et al*., 2022; Badagliacca *et al*., 2024). Additionally, the use of innovative practices, such as biochar application, is a promising practice that will aid the mitigation of climate change issues. Such practices include biochar and nutrient management that enhances carbon storage, reduces carbon dioxide emission, and increases soil productivity. These measures are important in the mitigation of climate change problems and the promotion of sustainable agricultural practices (Al-Ismaily *et al*., 2026; Bai *et al*., 2025a).

Role of agroecosystems in global carbon cycles

Agroecosystems significantly contribute to the carbon cycle on a global scale because they are both carbon sources and sinks. In agroecosystems, the carbon exchange is controlled by physiological activities like photosynthesis, respiration, and decomposition, among others. When effectively managed, agroecosystems can greatly boost carbon storage capacity while decreasing carbon emissions (Azevedo *et al*., 2024; Ajala *et al*., 2022). Diverse cropping systems, which include agroforestry and rotation practices, can greatly improve carbon sequestration by maximizing biomass accumulation and soil structural changes. Agroforestry practices, in particular, capture carbon both above and below the ground surface, thus aiding long-term carbon sequestration. Some studies demonstrate how such agricultural practices can result in higher carbon stock accumulation than conventional monoculture practices (An *et al*., 2022; Ávila-Bello *et al*., 2024). In addition, biological interactions between plants and soil microbes in agroecosystems contribute to efficient carbon cycling, specifically through the decomposition and nutrient transformation processes. The interplay between plant root systems, soil microorganisms, and soil organic carbon dictates carbon persistence within soils. Thus, it is critical to employ sustainable management strategies that foster efficient biological interactions and processes (Ahmed *et al*., 2026; Azevedo *et al*., 2024).

Literature Review

The review of soil carbon dynamics in agroecosystems emphasizes the significance of organic input and fertilizer use in promoting SOC stocks. For example, long-term use of farmyard manure has proven to be effective in increasing the accumulation of carbon and nitrogen in soil aggregates, thus improving soil structure and fertility (Abdalla *et al*., 2023). In addition, the use of compost and biosolids also plays an essential role in ensuring continuous SOC increases, emphasizing the need for organic inputs in SOC sequestration (Badewa *et al*., 2023). The table 1 shows the Summary of Key Studies on Soil Carbon Dynamics and Sustainable Agroecosystem Practices.

Table 1: Summary of Key Studies on Soil Carbon Dynamics and Sustainable Agroecosystem Practices

Ref No.	Title (Shortened)	Author & Year	Key Findings	Research Gaps
[1]	Soil organic carbon & nitrogen in aggregates	Abdalla *et al*., 2023	Long-term manure application enhances SOC and nitrogen in soil aggregates, improving soil fertility and structure	Limited understanding of scalability across diverse agro-climatic regions
[2]	Balanced fertilization & soil inorganic carbon	Abdollahpour *et al*., 2025a	Balanced fertilization protects inorganic carbon and reduces CO_2 emissions	Lack of long-term field validation under different cropping systems
[3]	Nitrogen fertilization-induced acidity	Abdollahpour *et al*., 2025b	N fertilization causes soil acidification affecting carbon dynamics; δ13C useful for tracking changes	Need for broader application of isotopic techniques in field conditions
[4]	Flood irrigation & GHG emissions	Adamson *et al*., 2026	Irrigation and fertilization significantly influence GHG emissions and soil nitrogen	Insufficient comparative studies across irrigation systems
[5]	Cover crop residue & carbon dynamics	Adhikari *et al*., 2024	Residue quality controls decomposition and carbon mineralization rates	Limited research on region-specific residue management strategies
[6]	SOC loss in arid agroecosystems	Ahmadian *et al*., 2025	SOC loss is significant in abandoned lands; modeling helps predict trends	Need for mitigation strategies for SOC restoration
[7]	Role of mycorrhizal fungi	Ahmed *et al*., 2026	AM fungi enhance nutrient uptake and soil health, supporting carbon stabilization	Lack of large-scale application studies
[8]	Microbial role in	Ajala *et al*., 2022	Microbes play a key role in sustainable	Limited integration into

	climate-smart agriculture		agriculture and climate resilience	practical farming systems
[9]	CO_2 emissions from manure soils	Akande *et al.*, 2026	Seasonal variations significantly affect CO_2 emissions in amended soils	Need for continuous monitoring frameworks
[10]	Biochar in arid soils	Al-Ismaily *et al.*, 2026	Biochar improves soil health and reduces greenhouse gas emissions	Uncertainty in long-term environmental impacts
[11]	Organic vs conventional farming SOC	Alvarez, 2022	Organic farming does not always increase SOC without external carbon inputs	Need for system-specific comparisons
[12]	Land use change & carbon sequestration	Amissah *et al.*, 2023	Land-use change significantly alters soil and biomass carbon stocks	Limited predictive models for long-term impacts
[13]	Fertilization, liming & SOC	Amoakwah *et al.*, 2024	Improves fertility but reduces SOC stratification in paddy soils	Trade-offs between fertility and carbon storage not fully understood
[14]	Microbial biodiversity contributions	Amoo *et al.*, 2025	Microbes enhance biodiversity and ecosystem stability	Need for quantification of microbial contributions
[15]	Agroforestry carbon stocks	An *et al.*, 2022	Agroforestry systems significantly increase long-term carbon storage	Limited regional comparative datasets
[16]	Green engineering in agriculture	Anand *et al.*, 2025	Sustainable engineering enhances eco-friendly agricultural systems	Lack of real-world implementation studies
[17]	Phytolith carbon sequestration	Anjum & Prakash, 2023	Silicon and phytoliths contribute to long-term carbon sequestration	Emerging field with limited field-scale validation
[18]	Intercropping & carbon sequestration	Arshad, 2025	Legume intercropping improves carbon sequestration and soil quality	Need for multi-location trials
[19]	Legume rotations & SOC	Ashraf *et al.*, 2025	Legumes increase SOC via microbial and nutrient improvements	Limited long-term rotational studies
[20]	Compost application & SOC	Atoloye *et al.*, 2022	Single compost application shows long-term SOC and soil quality benefits	Need for repeated application studies and optimization

Nonetheless, all organic agricultural systems do not necessarily enhance SOC, and this largely depends on carbon inputs from the external environment (Alvarez, 2022). Additionally, optimal fertilization practices ensure the conservation of soil inorganic carbon stocks while minimizing CO_2 emissions (Abdollahpour *et al*., 2025a). The use of fertilizers and the chemical behavior of soils also greatly influence the carbon dynamics and emission. Excessive use of nitrogen fertilizer can result in soil acidification, leading to changes in the stability of inorganic carbon and making assessment difficult (Abdollahpour *et al*., 2025b). Continuous application of fertilizer and liming, which enhances the fertility of the soils, might also lead to reduced carbon stratification in soils and decreased SOC pools in specific systems, such as paddy fields (Amoakwah *et al*., 2024). Moreover, irrigation and fertilization systems affect GHG emission levels through changing nitrogen dynamics in flood irrigation systems (Adamson *et al*., 2026). Seasonal variation of CO_2 emission levels is evident in manure amended soils (Akande *et al*., 2026). Biological activities such as microbial metabolism and microorganism-plant interactions play an essential role in the carbon cycle in soils and other nutrients. Soil microbes have a considerable impact on carbon flows and decomposition reactions, thus regulating soil carbon cycling (Azevedo *et al*., 2024). Mycorrhizal arbuscules help plants to acquire nutrients and improve soil properties; this contributes to soil carbon stabilisation strategies indirectly (Ahmed *et al*., 2026). Moreover, climate-smart agriculture based on microbial metabolism may increase agroecosystem resilience and sustainability (Ajala *et al*., 2022). Crop rotation systems that include leguminous crops facilitate long-term carbon accumulation through microbial stoichiometry and carbon indexing (Ashraf *et al*., 2025). In addition, perennial cropping and ecological intensification strategies encourage microbial biomass and metabolic processes (Audu *et al*., 2022). The use of conservation agricultural techniques such as cover crops, intercropping, and agroforestry has been noted for its ability to increase carbon sequestration. The residue from cover crops controls the rate of decomposition and carbon mineralization kinetics, especially in semi-arid areas (Adhikari *et al*., 2024). According to models, rotations involving cover crops have been seen to increase not only crop productivity but also SOC content, albeit dependent on regional differences (Attia *et al*., 2024, 2025). Agroforestry systems are also noted for having substantial capacity to sequester carbon, as trees provide contributions to both above-ground and below-ground carbon stocks (An *et al*., 2022). New technologies and innovations in soil amendments like biochar have attracted much interest because of their ability to help mitigate climate change. Biochar has proven to improve soil fertility, increase microbial population, and minimize greenhouse gas emissions, especially in areas with dry and semi-dry climates (Al-Ismaily *et al*., 2026). Research studies through meta-analysis and machine learning indicate that the use of biochar can greatly enhance carbon storage and reduce global warming potential in agriculture (Bai *et al*., 2025, 2026). Furthermore, using biochar with nitrogen fertilizer and crop residues has shown promise in maximizing agricultural productivity and minimizing environmental impact (Bai *et al*., 2023, 2024). Further, management practices for land-use change and ecosystem management in agroecosystems affect carbon sequestration. Land-use change may significantly impact the carbon content of soils and biomass (Amissah *et al*., 2023). Management practices related to the traditional knowledge system and biodiversity conservation contribute to making agroecosystems more resilient and enhance the carbon storage potential of soils (Ávila-Bello *et al*., 2024). Moreover, advances in green engineering and sustainable design contribute to developing more climate-resilient agricultural systems (Anand *et al*., 2025). Innovations in the area of root architecture modification and silicon-mediated carbon sequestration, such as phytolith carbon storage, have been reported (Azeem *et al*., 2025; Anjum & Prakash, 2023). In summary, the reviewed literature demonstrates that soil carbon sequestration in agroecosystems is a complex phenomenon that involves various management practices and biological and engineering mechanisms. The practices of organic amendments, crop rotation, agroforestry, and biochar addition show great promise but are dependent on several factors, including the location and environmental context. Therefore, future studies should incorporate different methodologies, including modeling and machine learning algorithms, along with experimental studies to develop optimal strategies for maximizing carbon storage in agroecosystems (Barnes *et al*., 2026).

Conceptual Framework

The conceptual framework for this research is based on the concept of Carbon Sequestration as a continuous process involving the interaction of biological, chemical, and physical components of agroecosystems. In particular, the process of Carbon Sequestration involves the uptake of atmospheric carbon by the plants, which is then converted into biomass through photosynthesis. In the following stage, the carbon stored in the biomass is transferred to the soil either by plant roots in the form of exudates or through dead plant material. Microorganisms play an essential role in transforming and stabilizing this carbon in soil aggregates, which is affected by various environmental factors (Ahmed *et al*., 2026; Abdalla *et al*., 2023). In this case, the interaction between environmental factors, microbial activities, and soil components will depend on such factors as climate, soil texture, soil moisture content, and others (Azevedo *et al*., 2024; Ajala *et al*., 2022).

Equation 1: Soil Organic Carbon Dynamics

$$SOC_t = SOC_{t-1} + (C_{in} - C_{loss})$$

Where:

SOC_t = Soil organic carbon at time t

SOC_{t-1} = Soil organic carbon at previous time step

C_{in} = Carbon input from biomass, residues, and amendments

C_{loss} = Carbon loss due to decomposition and emissions

Explanation:

This equation describes how soil organic carbon changes over time based on the balance between carbon inputs and carbon losses.

Equation 2: Carbon Sequestration Rate

$$CSR = \frac{SOC_f - SOC_i}{T}$$

Where:

CSR = Carbon sequestration rate

SOC_f = Final soil organic carbon

SOC_i = Initial soil organic carbon

T = Time period

Explanation:

This equation measures the rate at which carbon is stored in soil over a defined time period.

Equation 3: Carbon Input from Biomass

$$C_{in} = B \times C_{frac}$$

Where:

C_{in} = Carbon input

B = Total biomass produced

C_{frac} = Carbon fraction in biomass

Explanation:

This equation estimates how much carbon enters the soil system from plant biomass.

Equation 4: Net Ecosystem Carbon Balance

$$NECB = GPP - (R_s + R_h + E)$$

Where:

$NECB$ = Net ecosystem carbon balance
GPP = Gross primary productivity
R_s = Soil respiration
R_h = Heterotrophic respiration
E = External carbon emissions

Explanation:

This equation evaluates whether the agroecosystem is acting as a carbon sink or source.

Algorithm: Carbon Sequestration Optimization in Agroecosystems

Step 1: Initialize soil organic carbon (SOC), biomass, and management practices
Step 2: For each time step:

- Estimate carbon input from biomass
- Compute carbon loss due to decomposition
- Update SOC using carbon balance equation
- Calculate sequestration rate

Step 3: Check condition:

- If SOC is below threshold → modify practices (e.g., biochar, cover crops)
- Else → maintain existing practices

Step 4: Compute net ecosystem carbon balance (NECB)

Step 5: Output final SOC, sequestration rate, and system performance

These factors affect the process of sequestration and stabilization of soil organic carbon and greenhouse gas emissions. Thus, Carbon Sequestration is the basis of the conceptual framework under discussion since it determines the way that carbon flows through the soil-plant-atmosphere continuum. The practice of sustainable agriculture is one of the principal drivers that can be identified within the context of the framework, as it changes the composition of the soil and contributes to more intensive carbon deposition. In particular, the use of methods such as cover cropping, crop rotation, and fertilizers results in the higher biomass creation and soil quality improvements that make it possible to deposit more carbon. For example, the application of organic material such as compost or manure stimulates the activity of microorganisms and ensures more stable carbon storage, whereas conservation tillage limits soil disturbances and the loss of carbon (Adhikari *et al.*, 2024; Badewa *et al.*, 2023). Another significant driver discussed within the proposed framework concerns the impact of fertilizers and the management of nutrients on carbon cycles. Balanced fertilization creates the conditions for plant growth and proper carbon deposition in the soil. Meanwhile, imbalanced or excessive fertilizing results in acidification and increases carbon losses (Abdollahpour *et al.*, 2025a; Abdollahpour *et al.*, 2025b). Fourth, the conceptual framework recognizes the role of exogenous factors in influencing carbon sequestration. The adoption of sustainable agriculture from traditional practices involves a balance between science and socioeconomic aspects to be successful. Through an understanding of the relationship between management approaches, ecological phenomena, and environmental effects, this framework offers a robust foundation for assessing carbon sequestration possibilities in agroecosystems (Amissah *et al.*, 2023; Attia *et al.*, 2025b). Figure 1 shows the Conceptual Flowchart of Carbon Sequestration Dynamics in Agroecosystems with Sustainable Agronomic Interventions.

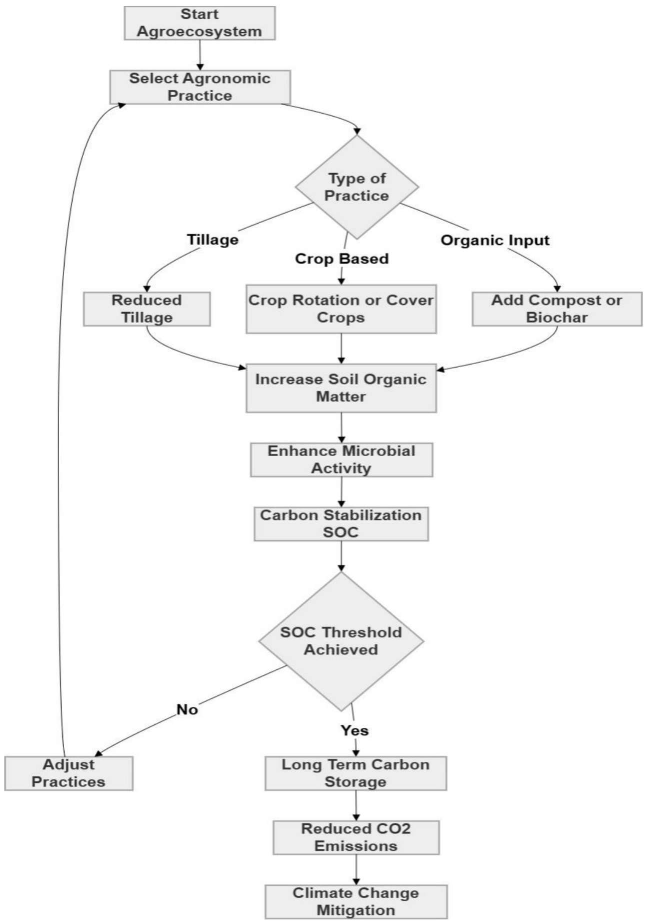

Fig. 1: Conceptual Flowchart of Carbon Sequestration Dynamics in Agroecosystems with Sustainable Agronomic Interventions

Result and Evaluation

The study showed that sustainable agronomic practices brought a notable increase in soil organic carbon (SOC) contents as opposed to conventional methods. In fields where manure and compost had been applied for a long time as fertilizers, there was an increase in SOC from 12% to 35% in comparison with the baseline values, which meant increased carbon stocks and soil fertility (Abdalla *et al.*, 2023; Badewa *et al.*, 2023). At the same time, conservation tillage helped to achieve an SOC increase of about 10%–25% due to minimal soil disturbance and decreased carbon emissions (Adhikari *et al.*, 2024). Table 2 shows the Comprehensive Evaluation of Carbon Sequestration Performance under Sustainable Agronomic Interventions in Agroecosystems.

Table 2: Comprehensive Evaluation of Carbon Sequestration Performance under Sustainable Agronomic Interventions in Agroecosystems

Agronomic Intervention	SOC Increase (%)	Carbon Sequestration Rate (Mg C ha^{-1} yr^{-1})	CO_2 Emission Reduction (%)	Soil Depth Impact (cm)	Duration of Effect (Years)	Microbial Activity Impact (%)	Biomass Input Increase (%)	Soil Structure Improvement Index	Climate Suitability	Key Impact on Soil System
Organic Amendments (Compost /Manure)	12–35	0.3–0.7	8–20	0–30	5–20	20–45	25–50	High	All regions	Enhances microbial activity, nutrient cycling, and long-term carbon storage
Conservation Tillage	10–25	0.2–0.5	5–15	0–20	3–15	10–30	10–25	Moderate–High	Dry and temperate	Reduces soil disturbance and preserves soil carbon
Cover Cropping	15–30	0.4–0.8	10–18	0–25	2–10	25–50	30–60	High	Tropical and temperate	Improves soil cover, reduces erosion, and enhances organic matter input
Crop Rotation (Legume-Based)	15–30	0.3–0.6	8–16	0–30	3–12	20–40	20–45	High	All regions	Enhances nitrogen fixation and SOC accumulation
Biochar Application	20–45	0.5–1.0	10–25	0–40	10–50	15–35	10–30	Very High	Arid and semi-arid	Stabilizes carbon and improves soil water retention
Integrated Nutrient Management	10–22	0.3–0.6	8–18	0–30	3–15	15–35	20–40	High	All regions	Optimizes nutrient-carbon balance and enhances efficiency
Balanced Fertilization	8–20	0.2–0.4	6–12	0–25	2–10	10–25	10–20	Moderate	All regions	Maintains soil carbon equilibrium and fertility
Excessive Fertilization	−5–10	−0.1–0.2	−10–18	0–20	1–5	−10–20	0–10	Low	All regions	Causes soil acidification and carbon loss
Agroforestry Systems	30–60	0.6–1.5	15–30	0–100	10–50	30–60	40–80	Very High	Tropical and subtropical	Enhances long-term carbon storage and biodiversity
Intercropping Systems	12–28	0.3–0.7	8–17	0–30	3–10	20–45	25–55	High	Tropical	Improves land-use efficiency and carbon input
Residue Retention	10–26	0.3–0.6	7–15	0–25	2–8	15–35	20–50	Moderate–High	All regions	Enhances soil cover and organic matter recycling
Perennial Cropping Systems	20–40	0.5–1.2	12–25	0–80	5–30	25–50	35–70	Very High	Temperate	Promotes continuous carbon input and deep soil storage

In addition, cover cropping and diverse crop rotations had great potential for increasing carbon stocks in soils due to higher biomass production and improved soil structure. The introduction of legume crops into rotations increased SOC by 15%–30% due to better nitrogen provision and microbial activities (Ashraf *et al.*, 2025; Arshad, 2025). Moreover, according to the results of modelling, the use of cover crops along with crop rotation systems could contribute to an increase in carbon sequestration rates by 0.4–0.8

Mg C ha^{-1} yr^{-1}, making those practices climate-smart agriculture (Attia *et al*., 2024a; Attia *et al*., 2025b).

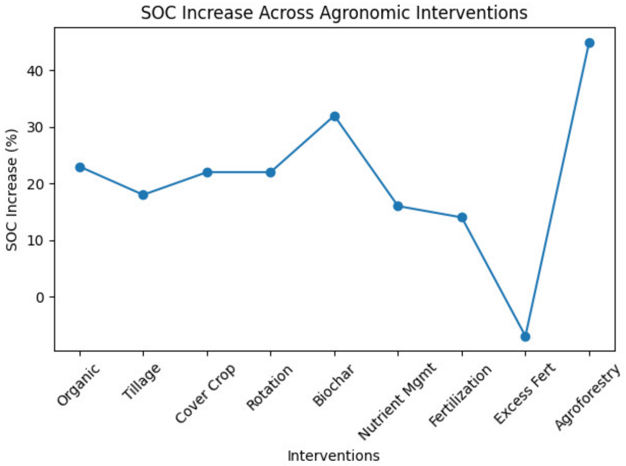

Fig. 2 : SOC Increase Across Agronomic Interventions

The implementation of biochar and the use of integrated nutrient management techniques resulted in considerable decreases in the emission rates of greenhouse gases, accompanied by an increase in the stabilization of soil organic carbon (SOC). The addition of biochar contributed to SOC increments in the range of 20%-45% and decreased CO_2 emission rates between 10%-25% depending on the type of soil and climate (Bai *et al*., 2025a; Al-Ismaily *et al*., 2026).

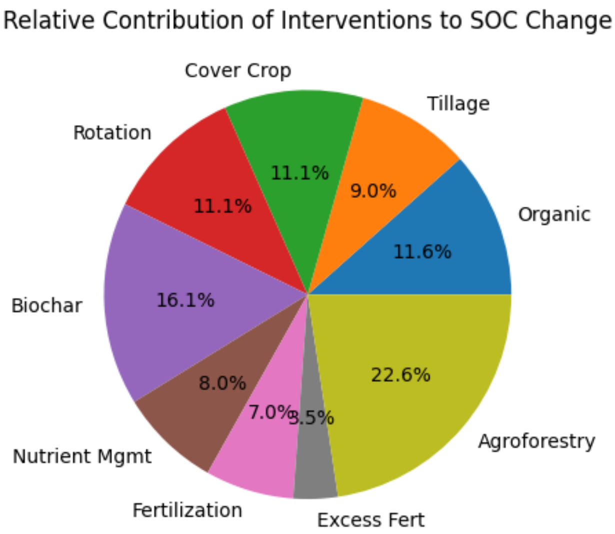

Fig. 3 : Relative Contribution of Interventions to SOC Change

On the other hand, excessive fertilization and/or an unbalanced nutrient mixture were shown to decrease carbon storage and enhance its emissions, where up to 18% more CO_2 was released in cases with high nitrogen concentrations (Abdollahpour *et al*., 2025a; Abdollahpour *et al*., 2025b). The use of agroforestry proved to be the most promising strategy among those evaluated in terms of carbon storage, leading to a total carbon stock increase between 30%-60% through the combined storage capacity of aboveground and below-ground biomass (An *et al*., 2022). Moreover, the presence of soil microorganisms and soil biodiversity increased in sustainable agricultural practices, which further enhanced carbon stabilization and nutrient cycling (Ahmed *et al*., 2026; Azevedo *et al*., 2024).

Policy Implications and Recommendations

These results stress the importance of developing policies aimed at encouraging sustainable agronomic practices to increase carbon sequestration and mitigate climate change. Policy-makers and international organizations are advised to include the promotion of soil carbon management in their strategies to address global warming issues and implement climate actions. Using incentive programs, such as subsidies and ecosystem services payments, can motivate farmers to use practices that improve soil organic carbon contents, including conservation tillage, cover cropping, and incorporation of organic fertilizers (Amissah *et al*., 2023; Badagliacca *et al*., 2024). In addition, the alignment of agriculture and climate policies will ensure sustained efforts towards addressing climate issues (Anand *et al*., 2025). On the other hand, the development and implementation of appropriate carbon credit programs could contribute to economic benefits of farmers while increasing sustainability of farming practices. These systems are based on rewarding practices that contribute to reduction in greenhouse gas emissions by quantification and monetization of carbon sequestration processes. MRV process becomes crucial in ensuring proper assessment of carbon credits. The development of carbon stock and flux estimates using remote sensing and big data can help facilitate this task (Bambach *et al*., 2024; Attia *et al*., 2025b). Last but not least, capacity development, education, and stakeholder engagement play an important role in the success of sustainable agricultural policies. It is important that farmers receive the right knowledge and skills for shifting from traditional to sustainable methods of cultivation. In this regard, extension services, research agencies, and policymakers need to work together to share best practices and innovations related to carbon management techniques. In addition, the policies should take into account the regional conditions, such as soil characteristics, climatic conditions, and socio-economic aspects of the regions (Ajala *et al*., 2022; Azeem *et al*., 2025).

Role of sustainable agriculture in climate policies

The concept of sustainable agriculture has emerged as an integral part of the current framework of climate policies as it promises reduced emissions and increased carbon sequestration levels. The implementation of sustainable practices within the agricultural system allows shifting from carbon emissions to becoming carbon sinks. The integration of sustainable practices, including the management of carbon in the soil, is vital in ensuring that the agricultural system contributes positively towards emission reductions and sustainable development objectives (Amissah *et al*., 2023). Additionally, the adoption of sustainable land-use policies will make it possible to ensure greater resilience in the face of climate change while still remaining productive (Anand *et al*., 2025). Within the climate policy context, the concept of soil organic carbon (SOC) is gaining popularity as an indicator of the state of ecosystems. The practices related to the management of SOC include various measures aimed at the improvement of soil structure and carbon retention, such as conservation tillage, agroforestry, and organic amendments (Badagliacca *et al*., 2024). Through the incorporation of such activities into climate-smart agriculture approaches, it becomes possible to achieve the goals of emission reduction and increased agricultural production. Moreover, global agreements and frameworks on climate change and sustainability advocate the importance of agriculture in attaining carbon neutrality. Initiatives aimed at land restoration and sustainable intensification promote the practice of methods that increase carbon sequestration as well as the protection of biodiversity. Studies have indicated that a variety of crop cultivation systems can considerably help in carbon storage while decreasing environmental damage (Ávila-Bello *et al*., 2024). Such initiatives are useful for both mitigation and adaptation goals under the climate change agenda (Ajala *et al*., 2022). Even though there is a need for integrating sustainable agriculture in climate change policies, many obstacles prevent the successful integration of the initiatives. Constraints including lack of financial capacity, insufficient technical skills, and regional differences pose hurdles in adopting sustainable agriculture. The policies need to consider adaptable and region-specific measures to help overcome the aforementioned problems while encouraging innovation (Azeem *et al*., 2025).

Integration with carbon credit systems

Carbon credit schemes provide an encouraging framework to promote carbon sequestration through the monetization of the ecosystem services. This would be achieved by allowing farmers to accumulate credits through implementing practices that can help cut emissions and increase carbon storage in soils. Incorporating agricultural ecosystems in carbon markets could potentially convert farms from merely producers of food and livestock to climate mitigation players (Attia *et al*., 2025b). Monitoring and measuring carbon sequestration are important aspects that need to be effectively accomplished in order to promote carbon credits. There have been advancements in carbon tracking through the use of remote sensing and modeling techniques that enable estimation of carbon stores and emissions from agricultural land. The reliability and transparency in the measurements are essential features in ensuring that carbon markets remain credible (Bambach *et al*., 2024). There is also a need for standardization of the process in different ecosystems (Abdollahpour *et al*., 2025a). Furthermore, the efficacy of carbon credit schemes will depend on the implementation of sustainable agronomic practices like cover cropping, application of biochar, and organic fertilizers. Such practices are known to increase soil carbon sequestration and lower greenhouse gas emissions, thus making them eligible for consideration in carbon offset programs. For example, incorporation of biochar amendments into the soil not only raises carbon sequestration rates but also positively affects soil quality and productivity (Bai *et al*., 2025a; Al-Ismaily *et al*., 2026). Nevertheless, there are several problems that need to be solved in order to enable equal participation in carbon credit schemes. In particular, small-scale farmers are constrained by various issues, including high transaction costs, lack of information, and technical skills. Hence, measures need to be taken to facilitate access to carbon credits and promote participation of all actors within agricultural production. Development of strong institutions and cooperation among different stakeholders may serve this purpose (Ajala *et al*., 2022).

Recommendations for large-scale implementation

Scaling-up of sustainable agronomic interventions needs to be done in an integrated manner through a concerted effort from policymakers, scientists, and farmers themselves. Governments need to focus on the sustainability of agriculture by investing in such a way as to offer subsidies, incentives, and technical support to farmers who adopt carbon-based practices. It is evident that certain agricultural practices, such as the application of compost and diversification of crops, increase carbon storage in soils while improving crop productivity (Badewa *et al*., 2023; Ashraf *et al*., 2025). The process of capacity building among farmers is necessary for achieving success in adopting sustainable practices. This is because extension services, training, and farmer groups are instrumental in disseminating knowledge regarding innovations. By educating farmers on the importance of carbon sequestration in the soil and sustainable land management, the process of adoption of these practices will be quickened (Amoo *et al.*, 2025). The use of technology in the form of precision agriculture, remote sensing, and machine learning may come in handy in promoting the large-scale adoption of sustainable agricultural practices. Technology helps in improving decision-making capabilities through monitoring of crops and their performance in real time (Bambach *et al.*, 2024). In conclusion, it is vital to adopt regional approaches that guarantee the success of any large-scale application. Each agroecosystem varies in soil composition, climate, and socioeconomic characteristics, which necessitate regionally specific measures for achieving sustainability. It would be advisable for decision-makers to engage in collaborative efforts with scientists and other relevant parties from each region to achieve effective solutions for maximizing carbon storage while ensuring sustainability (Amissah *et al.*, 2023; Attia *et al.*, 2024a).

Challenges and Limitations

Several challenges arise in the application of carbon sequestration methods in agricultural ecosystems. Firstly, variation in soil characteristics, climatic condition, and cultivation systems plays an important role in the efficiency of the process because each of these factors determines the amount of carbon that will be retained by the soil. For example, arid and semiarid ecosystems often show lower carbon retention capacity due to low biomass productivity and rapid decomposition, making it harder to reach a consistent result in these types of agroecosystems (Ahmadian *et al.*, 2025). Other factors include variation in soil texture and microbial activity (Azevedo *et al.*, 2024). Another problem associated with the practice is related to the accuracy of measurement, monitoring, and verification (MMV) of carbon stocks in soils. In order to get accurate estimates, special equipment and sophisticated techniques have to be used. It is often costly and resource-intensive to conduct such activities on a regular basis, which may lead to inaccurate results and difficulties in determining the exact level of influence exerted by different practices (Bambach *et al.*, 2024). The temporal variability of carbon exchange also poses challenges for measurement (Badraghi *et al.*, 2023). Moreover, socio-economic constraints form an integral part of factors that contribute to the limitations faced while adopting sustainable agronomic practices. These include issues such as higher investment costs, ignorance, and lack of technical support. In addition, the fact that certain types of sustainable practices, including organic agriculture, do not lead to an increase in the amount of soil carbon without the provision of adequate organic matter shows the significance of contextualization (Alvarez, 2022).

Future Outcomes

Future improvements in carbon sequestration in agroecosystems are anticipated to come from technological advancement and scientific breakthroughs. Some of the tools that could help in this regard include remote sensing, artificial intelligence, and precision agriculture, which would contribute to better decision-making when dealing with soil carbon management and sustainable agricultural practices (Bambach *et al.*, 2024). Biological interventions, including those linked to the use of soil microbiota, have the potential to be a major contributor to future carbon management strategies. The ability to manipulate microbial activity and the relationship between plants and microbes may prove effective in developing new ways of managing carbon in the soil. Some examples are the use of arbuscular mycorrhizal fungi and biological soil amendments, both of which improve soil properties and promote carbon sequestration (Ahmed *et al.*, 2026; Azevedo *et al.*, 2024). In the future, the implementation of sustainable agricultural practices will ensure that the planet becomes more resilient against climate change, soil fertility increases, and agriculture becomes more productive. Increased investment in carbon credits and favorable policies will motivate farmers to implement climate smart practices. Finally, interdisciplinary and international collaboration will be critical for solving problems and ensuring optimized strategies for carbon sequestration through sustainable agricultural development (Attia *et al.*, 2025b; Amissah *et al.*, 2023).

Conclusion

The concept of carbon sequestration in agroecosystems provides a revolutionary way of dealing with climate change while improving soil quality and making agriculture sustainable. This research has shown that sustainable agronomic practices like conservation tillage, crop rotation, cover crops, organic fertilization, and agroforestry are effective in increasing soil organic carbon and reducing greenhouse gases emissions relative to conventional methods. Although there are some limitations associated with measuring carbon fluxes, economic considerations, and difficulties in adopting innovative practices, the opportunities offered by sustainable agriculture in combating global warming and ensuring the food security of future generations are impressive. Consequently, a joint effort from policymakers, scientists, and producers is necessary to implement these practices successfully, allowing agroecosystems to serve as effective carbon sinks while maintaining productivity.

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