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Carbon Farming: A Sustainable Path to Lower Greenhouse Gas Emissions

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Carbon farming is an emerging agricultural strategy aimed at tackling climate change by capturing atmospheric carbon dioxide (CO₂) and storing it in soil and vegetation. This article analyses various carbon farming techniques, focusing on their environmental, economic, and social benefits, especially in the Indian context. Key practices include agroforestry, cover cropping, minimal tillage, and biochar application, which collectively improve soil carbon levels and farm ecosystem health. The article explains how biological processes like photosynthesis and soil organic matter stabilization drive carbon sequestration. Environmental advantages include reduced greenhouse gas emissions, enhanced soil fertility, and increased biodiversity. Socio-economic benefits are also emphasized, particularly for rural Indian communities, where carbon farming can support sustainable agriculture, raise incomes via carbon credit markets, and strengthen food security. Despite these advantages, adoption faces challenges such as high initial costs, resource needs, inconsistent results due to soil and climate variability, and policy limitations. The article shows the importance of supportive policies and highlights new innovations in India, such as satellite-based monitoring and AI-driven soil diagnostics. It concludes by emphasizing the vital role of carbon farming in India's climate action plans and its potential to serve as a global model for sustainable agricultural practices in similar regions.

Introduction

Carbon farming encompasses a variety of agricultural techniques intended to boost carbon storage in soil and vegetation, thereby reducing atmospheric carbon dioxide (CO₂), a major greenhouse gas. Methods such as agroforestry, cover cropping, and permaculture are central to this approach. By enhancing natural processes like photosynthesis and increasing soil organic matter, carbon farming shifts agriculture from being a CO₂ emitter to a carbon sink. Research shows that these practices can significantly mitigate rising CO₂ levels. With the continued increase in global greenhouse gas emissions (fig 1)—including CO₂, methane, and nitrous oxide—climate systems are undergoing rapid and severe changes, as highlighted by the Intergovernmental Panel on Climate Change. Recent studies stress the urgent need for effective carbon reduction strategies to combat the climate crisis. In this context, carbon farming is gaining recognition as a promising, sustainable method that not only helps lower atmospheric carbon levels but also supports agricultural productivity. This article aims to offer a detailed overview of carbon farming, examining its practices, environmental and agronomic benefits, challenges, and its potential contribution to global climate mitigation strategies. Emphasis is placed on recent peer-reviewed research and key international reports to critically assess the current understanding and future prospects of carbon farming.

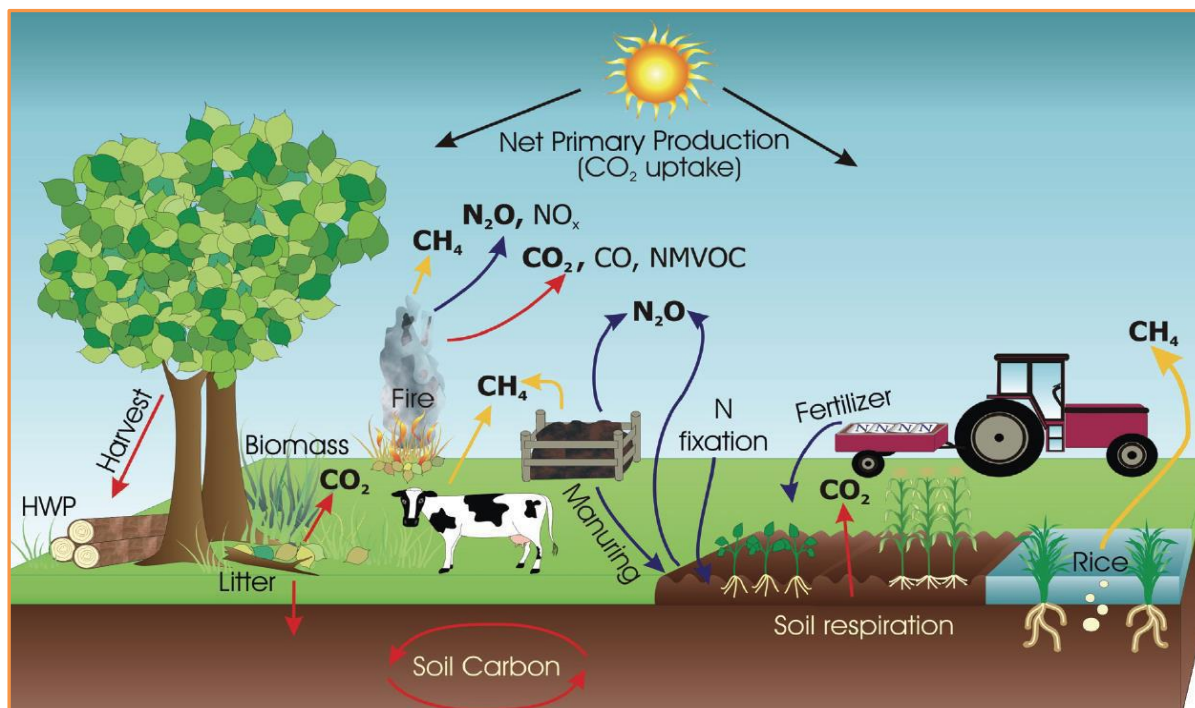


Fig. 1. The emission of main greenhouse gases and processes in managed farmland (Source: Saikanth *et al.*, 2023.)

Fundamentals of carbon farming

Agroforestry, which involves incorporating trees and shrubs into farming systems, is highly effective for carbon sequestration (Table 1). Cover cropping, where crops are grown to protect and enrich the soil rather than for harvest, also enhances soil carbon levels. Conservation tillage, or reduced tillage, helps maintain soil structure and retains soil organic carbon by minimizing disturbance. Applying biochar—charcoal made from organic biomass—is another proven method for long-term carbon storage in soil. Additionally, cultivating crops with deep root systems increases root biomass, further boosting soil carbon accumulation. Biological carbon sequestration primarily relies on photosynthesis, where plants absorb atmospheric CO_2 and convert it into organic matter stored in their tissues. This natural process plays a key role in carbon farming by removing CO_2 directly from the atmosphere. Soils function as vital carbon sinks through the incorporation and stabilization of organic matter. Soil carbon storage capacity depends on factors such as soil type, climate, and farming methods.

Table 1. Different types of mechanisms of carbon sequestration:

Mechanism	Description	Examples/Types
Biological Sequestration	CO_2 captured by plants via photosynthesis, stored in biomass and soils.	Forests, wetlands, oceanic phytoplankton
Geological Sequestration	CO_2 injected into underground rock formations from point sources.	Saline aquifers, depleted oil/gas fields, coal seams
Ocean Sequestration	CO_2 dissolved into oceans; may alter ocean chemistry.	Deep sea injection, iron fertilization
Chemical Sequestration	CO_2 captured using chemical reactions or solvents.	Mineral carbonation, industrial scrubbers
Biochar Sequestration	CO_2 stored as biochar, a stable carbon form from pyrolyzed biomass.	Biochar from crop residues, manure
Urban Carbon Sequestration	CO_2 absorbed through urban greenery and infrastructure.	Urban trees, green roofs, vertical gardens
Carbonate Mineralization	CO_2 converted into stable carbonate minerals, naturally or industrially.	Silicate weathering, industrial carbonation

Benefits of carbon farming

Carbon farming plays a crucial role in reducing greenhouse gas emissions by capturing atmospheric carbon dioxide and storing it in soil and vegetation. Research shows that techniques like agroforestry, cover cropping, and biochar application are effective in lowering CO₂ levels. In addition to carbon sequestration, these practices improve soil health by boosting organic matter, enhancing water retention, and minimizing erosion. They also support biodiversity by offering habitats and food for various species above and below ground. Economically, carbon farming provides opportunities for farmers to earn through carbon credits in carbon markets, rewarding them for the amount of CO₂ they sequester. This creates an incentive for adopting environmentally friendly practices. Furthermore, carbon farming benefits rural communities by supporting sustainable agriculture, improving food security, and offering new income sources. It strengthens farm productivity and resilience, ultimately enhancing the livelihoods and well-being of rural populations through environmentally responsible farming techniques.

Challenges and limitations

Adopting carbon farming practices often involves considerable costs and resource demands, which can be challenging for many farmers. Initial expenses for materials, labour, and land-use adjustments are often high. Moreover, these practices require technical expertise and training, further increasing implementation costs. The success of carbon farming varies based on local climate and soil conditions—some techniques are effective only in specific environments, and soil characteristics greatly influence how much carbon can be sequestered. Policy challenges also hinder broader adoption. The current regulatory landscape is often fragmented and unclear, making it difficult for farmers to access or comply with existing guidelines. Many policies also lack incentives or fail to address key elements of carbon farming. There is a growing call for structured, supportive regulatory frameworks with clear policies, financial incentives, and technical assistance. Developing such frameworks is vital for encouraging large-scale adoption. In India, government programs like the National Mission for Sustainable Agriculture (NMSA) have played a crucial role in supporting carbon farming. Regional policy adaptations are also necessary, considering local environmental conditions and farming systems. Future strategies could benefit from integrating carbon farming with sustainable methods such as organic agriculture, offering a more holistic approach to climate-resilient farming.

Future directions and potential

India is actively advancing carbon farming through technological innovations aimed at improving its efficiency. Tools like satellite monitoring and AI-driven soil analysis are being utilized to better manage and enhance carbon sequestration. Research is also focusing on genetically modified crops with increased root biomass, which can store more carbon in the soil. A growing movement is underway to combine carbon farming with sustainable practices such as organic farming and precision agriculture, creating a more comprehensive approach that improves both carbon capture and farm productivity. Additionally, integrating traditional farming wisdom with modern science is helping to develop more sustainable and culturally relevant agricultural systems. Carbon farming is expected to become a key component of India's climate change mitigation strategy. Predictive models show that with proper implementation, it can significantly aid in meeting national carbon reduction goals. It also holds promise for strengthening agriculture's resilience to climate impacts. The Indian experience offers a valuable template for other regions with similar climates and farming systems, particularly in South Asia and Africa. To maximize this potential, international cooperation and knowledge exchange are essential for adapting and scaling these practices globally.

Conclusion

Carbon farming is a vital and comprehensive approach to addressing climate change, especially in India. It offers more than just carbon sequestration, delivering environmental, economic, and social advantages. Methods such as agroforestry, cover cropping, and biochar use help lower greenhouse gas emissions, enrich soil quality, and support biodiversity. These practices also create economic opportunities for rural communities through sustainable farming and carbon credit systems. Despite challenges like high initial costs, environmental variability, and limited policy support, carbon farming holds strong future potential. Advances in technology and better policy integration could further improve its impact. This article highlights carbon farming's key role in India's climate goals and calls for greater attention and collaboration to harness its full potential in sustainable agriculture and climate mitigation.

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