Carbon Farming: A Nature-Based Strategy for Climate Change Mitigation and Soil Health Enhancement – A Review

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***Abstract*—Carbon farming comprises a set of land management practices designed to enhance the sequestration of atmospheric carbon dioxide into soil organic matter and vegetation while simultaneously reducing greenhouse gas emissions from agricultural systems. This review critically examines the role of carbon farming in improving soil health, enhancing ecosystem services, and contributing to climate change mitigation. Major carbon farming practices, including conservation agriculture, agroforestry, crop diversification, integrated farming systems, green manuring, and organic amendments, are evaluated for their effectiveness in increasing soil organic carbon (SOC) stocks. Evidence indicates that improvements in SOC significantly enhance soil fertility, water retention capacity, and microbial activity while reducing reliance on synthetic inputs. Despite these benefits, adoption remains limited due to socio-economic, technical, and institutional constraints. Policy mechanisms such as carbon credit trading under the Energy Conservation (Amendment) Act, 2022 provide opportunities for incentivizing farmers. Strengthening extension systems, monitoring frameworks, and market linkages is essential for scaling carbon farming in developing countries.**

***Index Terms*—Carbon sequestration, Soil organic carbon, Climate-smart agriculture, Agroforestry, Conservation agriculture, Carbon credits**

I. INTRODUCTION

Agriculture plays a dual role in the global carbon cycle, acting both as a source and a sink of greenhouse gas emissions. The agriculture, forestry, and other land use (AFOLU) sector contributes nearly one-fourth of global anthropogenic emissions, making it a critical focus area for climate mitigation strategies.

Soil degradation and declining soil organic carbon levels have emerged as major constraints to agricultural productivity, particularly in regions dominated by smallholder farming systems such as India. Low organic matter content reduces soil fertility, water retention capacity, and nutrient cycling efficiency.

Carbon farming has emerged as a climate-smart agricultural approach that integrates soil management practices aimed at increasing carbon sequestration while maintaining or improving agricultural productivity. This approach aligns environmental sustainability with economic viability by generating potential carbon credit-based income for farmers.

II. CONCEPT AND PRINCIPLE OF CARBON FARMING

Carbon farming refers to agricultural and land management practices that enhance the capture of atmospheric carbon dioxide and its storage in soil organic carbon pools and biomass. The primary objective is to increase long-term carbon storage while minimizing greenhouse gas emissions.

Soil organic carbon is a fundamental indicator of soil quality and plays a critical role in maintaining soil structure, fertility, and biological activity. Enhancing SOC contributes directly to improved crop productivity and ecosystem resilience.

III. SOIL ORGANIC CARBON AND ITS AGRONOMIC IMPORTANCE

Soil organic carbon influences several essential soil functions, including:

- Improvement in soil aggregation and structure
- Enhanced water infiltration and retention
- Increased nutrient availability and cycling
- Stimulation of microbial diversity and enzymatic activity
- Reduction in soil erosion and degradation

Empirical studies suggest that even a 1% increase in SOC can significantly reduce fertilizer requirements while improving soil productivity and resilience to climatic stress.

IV. CARBON FARMING PRACTICES

4.1 Conservation Agriculture

Conservation agriculture is based on minimum soil disturbance, permanent soil cover, and diversified crop rotations. Long-term adoption of no-tillage systems enhances soil carbon accumulation and reduces carbon loss through oxidation. Residue retention on soil surfaces further contributes to carbon sequestration and improves soil moisture conservation.

4.2 Agroforestry Systems

Agroforestry integrates trees with crops and/or livestock systems, resulting in enhanced above- and below-ground carbon storage. It improves biodiversity, microclimate regulation, and livelihood diversification.

4.3 Crop Diversification and Rotation

Diversified cropping systems involving cereals, legumes, and oilseeds improve soil microbial activity and enhance carbon inputs through continuous biomass production. Crop rotations also reduce pest pressure and improve nutrient cycling efficiency.

4.4 Green Manuring

Green manure crops such as Sesbania aculeata (dhaincha), Crotalaria juncea (sunhemp), and leguminous cover crops enhance soil organic matter and nitrogen availability. Incorporation of these crops into soil improves microbial biomass and SOC levels. Long-term field studies in India indicate SOC improvements ranging from 0.2% to 0.4% under green manuring practices.

4.5 Integrated Farming Systems (IFS)

Integrated farming systems combine crop production with livestock, fisheries, and horticulture components. This approach promotes resource recycling, improves nutrient efficiency, and enhances soil carbon inputs through organic waste recycling.

4.6 Organic Amendments and Biochar Application

Organic manures, compost, and biochar contribute to long-term carbon stabilization in soils. Biochar, due to its recalcitrant structure, provides persistent carbon storage and improves soil physicochemical properties.

4.7 Residue Management and Low-Input Systems

Efficient utilization of crop residues through composting or direct incorporation reduces biomass burning and enhances SOC accumulation. These practices also contribute to reduced greenhouse gas emissions.

V. CARBON SEQUESTRATION POTENTIAL

Field studies indicate that conservation agriculture and diversified cropping systems can increase SOC by 16–122% over varying time scales. Agroforestry systems significantly enhance both above-ground and below-ground carbon storage. Residue retention and long-term soil cover have been shown to increase SOC by up to 70% under suitable agro-ecological conditions.

VI. SOCIO-ECONOMIC AND ENVIRONMENTAL BENEFITS

Carbon farming provides multiple co-benefits, including:

- Reduced cost of production through lower fertilizer use
- Increased farm income through carbon credit mechanisms
- Enhanced resilience to drought and climate variability
- Improved soil fertility and long-term productivity
- Contribution to national climate mitigation targets

These benefits are particularly relevant for small and marginal farmers in developing countries.

VII. CONSTRAINTS TO ADOPTION

Despite its potential, widespread adoption of carbon farming is constrained by:

- Limited awareness among farmers
- Lack of technical guidance and extension services
- High transition costs from conventional systems
- Absence of standardized carbon measurement frameworks
- Weak access to carbon markets

VIII. POLICY FRAMEWORK AND FUTURE SCOPE

Policy support is essential for scaling carbon farming practices. The Energy Conservation (Amendment) Act, 2022 provides a foundation for carbon credit trading in India. Future strategies should focus on:

- Development of robust soil carbon monitoring systems
- Farmer-centric training and capacity building
- Integration of carbon farming into national agricultural programs
- Development of verified carbon credit markets
- Promotion of climate-smart agriculture technologies

IX. CONCLUSION

Carbon farming represents a sustainable and scalable approach to addressing climate change while improving soil health and agricultural productivity. Practices such as conservation agriculture, agroforestry, crop diversification, and integrated farming systems significantly enhance soil organic carbon levels and reduce greenhouse gas emissions.

However, successful implementation requires strong institutional support, policy incentives, and effective knowledge dissemination systems. With appropriate interventions, carbon farming can play a transformative role in achieving climate-resilient and sustainable agricultural systems.