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Carbon-Neutral Cropping Systems: A way forward to Sustainable Agriculture

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ABSTRACT

Carbon-neutral farming seeks to balance agricultural emissions with carbon sequestration through sustainable land management, renewable energy use, and efficient resource practices. Major emission sources—fertilizers, land-use change, livestock, and crop production—require targeted mitigation. Practices like conservation tillage, cover cropping, agroforestry, and improved soil management enhance soil carbon storage, while renewable energy reduces dependence on fossil fuels. Agroforestry also boosts biodiversity and provides ecosystem services, with carbon credits offering added income for farmers. Stronger policies, technological innovation, and reliable monitoring systems are crucial for advancing carbon-neutral agriculture.

Keywords: Carbon-neutral farming, Carbon sequestration, Carbon credits, Greenhouse gas mitigation, Sustainable land management, Climate-smart agriculture.

1.INTRODUCTION

Carbon-neutral farming is a transformative approach that balances agricultural carbon emissions with carbon sequestration to combat climate change. It improves soil health, enhances biodiversity, and reduces greenhouse gases from conventional practices. Key strategies include sustainable farming methods, better resource-use efficiency, and the adoption of modern low-emission technologies. Policy support, such as the EU Green Deal, further accelerates the shift toward carbon-neutral practices. However, strong monitoring and verification systems are essential to ensure the credibility and success of these initiatives.

2.Carbon Sources in Agriculture

Agriculture significantly contributes to carbon emissions. These sources is crucial for developing strategies to mitigate greenhouse gas emissions and promote sustainable practices in agriculture. Fertilizers are a major emission source, contributing nearly 60% of agricultural carbon

emissions in regions like Shaanxi Province due to nitrous oxide release. Land-use changes and tillage practices also add significantly to emissions, especially in state farms, while shifting to low-input agriculture can reduce this impact. Livestock production generates substantial emissions through enteric fermentation and manure mismanagement. Crop production, particularly rice cultivation, is another notable source with fluctuating emission levels. Regionally, northern and eastern China show higher agricultural emissions, and the planting sector presents both major carbon sources and strong carbon sinks, reflecting complex carbon dynamics.

3.Key Practices for Carbon Reduction

Carbon reduction is a multifaceted approach that encompasses various strategies across different sectors, aimed at mitigating climate change impacts. Carbon reduction include enhancing energy efficiency, transitioning to renewable energy, and implementing sustainable supply chain practices. Improving energy efficiency can significantly reduce operational emissions and lower costs, while transitioning to renewable energy remains essential for cutting greenhouse gas outputs. Sustainable supply chain measures, such as optimized logistics and green procurement, further help minimize industrial carbon footprints. In agriculture, practices like conservation tillage and cover cropping enhance soil health and boost carbon sequestration. Although these strategies support meaningful carbon reduction, high initial costs and regulatory uncertainties pose challenges. However, technological innovation and strong stakeholder collaboration can accelerate progress in adopting these sustainable solutions.

4.Soil as a Major Carbon Sink

Soil plays a crucial role as a major carbon sink, significantly contributing to the mitigation of climate change by sequestering atmospheric CO₂. This process involves both organic and inorganic carbon sequestration, with soils storing more carbon than the combined total in vegetation and the atmosphere. Soils store carbon in two forms: organic carbon from plant residues and roots, and inorganic carbon formed as pedogenic carbonates. Soil organic carbon (SOC) is a key part of soil organic matter and is essential for soil fertility and health. Practices like no-till farming, crop rotation, compost or biochar application, cover cropping, and agroforestry greatly enhance soil carbon storage by improving soil structure. Climate, soil texture, and land use strongly influence sequestration, with cooler and humid regions storing more SOC, while drylands hold large inorganic carbon stocks. Tropical peatlands and mangroves contain the highest SOC levels globally. Reforestation further strengthens soil carbon sinks by increasing forest topsoil carbon over time. Since soil carbon is vulnerable to degradation and climate impacts, region-specific management is essential to maximize sequestration potential.

5.Role of Renewable Energy on Farms

Renewable energy plays a crucial role in transforming agricultural practices by enhancing sustainability, reducing greenhouse gas emissions, and improving economic viability. The integration of renewable energy sources such as solar, wind, biomass, and biogas on farms not only addresses environmental concerns but also offers economic benefits and energy independence. Renewable energy helps reduce the carbon footprint of farms while improving their overall efficiency. Solar, wind, biomass, and biogas systems provide clean and reliable power for irrigation, greenhouses, and

processing operations, while also supporting sustainable waste management by converting farm residues into energy. Adoption of these technologies depends on factors such as farmer education, farm size, financial support, and openness to innovation, with entrepreneurial farmers more likely to adopt advanced solutions. Government subsidies, feed-in tariffs, and technical assistance further encourage the transition, and strong policy frameworks are essential for expanding renewable energy use in agriculture.

Table 1. Carbon-Neutral Farming Practices in India

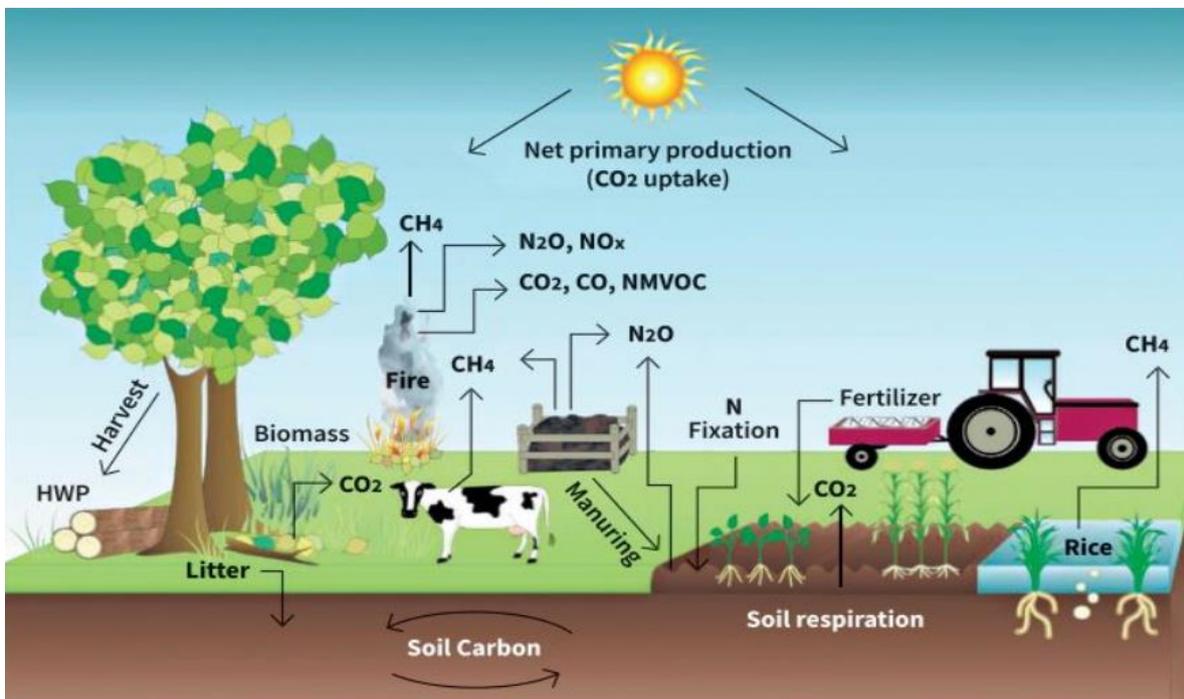
Practice	Description	Key Benefits	Examples
Conservation Tillage / Zero Tillage	Minimizing soil disturbance to reduce carbon loss and improve soil structure.	Higher soil carbon storage, reduced fuel use, better soil moisture.	Widely promoted in Punjab & Haryana under the Happy Seeder initiative.
Agroforestry	Integrating trees with crops or livestock systems.	Carbon sequestration, biodiversity support, additional income.	Practiced in states like Uttar Pradesh, Karnataka, Tamil Nadu, and under Sub-Mission on Agroforestry (SMAF).
Organic Farming	Avoiding synthetic fertilizers and pesticides; relying on natural inputs.	Higher soil organic carbon, reduced emissions, improved soil health.	Implemented through PKVY and MOVCDNER in Sikkim, Uttarakhand, and Northeast India.
Renewable Energy Adoption	Use of solar pumps, biogas plants, wind and biomass energy on farms.	Lower fossil fuel use, reduced emissions, energy independence.	PM-KUSUM supports solar irrigation pumps nationwide.
Biochar Application	Converting crop residues into biochar to enhance soil carbon stability.	Long-term carbon sequestration and soil fertility improvement.	Research-based adoption in states like Andhra Pradesh and Maharashtra.
Cover Cropping & Green Manuring	Growing cover crops to enrich soil carbon and reduce erosion	Improved SOC, nutrient cycling, and reduced fertilizer demand.	Common in rice-wheat systems of Punjab, Haryana, and UP.
Integrated Nutrient Management (INM)	Balanced use of organic and inorganic nutrients.	Lower nitrous oxide emissions, improved soil quality.	Promoted under National Mission for Sustainable Agriculture (NMSA).

Livestock Methane Reduction	Improved feed management, digesters, composting.	Lower methane emissions and better waste management.	Adoption of gobar-dhan biogas units in rural India.
Precision Farming	Using sensors, GPS, and efficient irrigation to optimize inputs.	Reduces fertilizer use, emissions, and resource wastage.	Practiced in Tamil Nadu, Telangana, and under Digital Agriculture Mission.

6. Agroforestry and Biodiversity Benefits

Agroforestry, which integrates trees with crops or livestock, presents a complex relationship with biodiversity. While it has the potential to enhance biodiversity compared to conventional agricultural systems. Agroforestry increases habitat diversity, supporting a wide range of species such as birds and arthropods. Silvoarable systems show notably higher biodiversity than conventional croplands, although silvopastoral systems do not consistently exceed pastures or forests. These systems provide food, breeding sites, and habitat connectivity that strengthen wildlife populations. Enhanced biodiversity improves pollination, pest control, and soil health, offering economic benefits to farmers. However, biodiversity outcomes vary across regions and land-use types. Landscape context and land-use history strongly influence how effectively agroforestry enhances biodiversity.

Fig 1. Carbon farming Practices



Source: Carbon farming Making agriculture fit for 2030, a study for European parliament’s Committee on Environment, Public health and Food safety

7. Carbon Credits and Farmer Income

The integration of carbon credits into agricultural practices, particularly agroforestry, presents a significant opportunity to enhance farmer income. It indicates that carbon revenue can augment farmers' earnings by 40-50%, providing additional financial stability beyond traditional crop sales. Carbon credits offer farmers an additional income source, potentially providing up to Rs. 25,000 per hectare per year while reducing vulnerability to market fluctuations. Agroforestry-based carbon sequestration supports both income generation and improved soil health, along with lower greenhouse gas emissions. However, effective implementation requires reliable verification methods and stronger policy support. Voluntary carbon markets also pose limitations, as they often do not fully account for the specific conditions of Indian agroforestry systems, restricting farmers' access to global carbon finance.

8. Challenges

Carbon-neutral farming faces several challenges, including high initial costs for renewable energy systems, soil carbon monitoring tools, and low-emission machinery. Reliable measurement and verification of carbon sequestration remain difficult due to variations in soil type, climate, and management practices. Farmers often lack awareness, training, and technical support needed for adopting carbon-neutral technologies. Policy gaps, inconsistent incentives, and limited access to carbon markets further slow progress. Additionally, smallholders may struggle with land, capital, and technology constraints, making large-scale adoption challenging.

9. CONCLUSION

Carbon-neutral farming helps reduce greenhouse gas emissions while improving soil health, biodiversity, and farmer livelihoods. By integrating conservation agriculture, agroforestry, renewable energy, and improved soil carbon management, farms can operate as productive systems and effective carbon sinks. Carbon credits offer additional income and encourage wider adoption of sustainable practices. However, progress is limited by high costs, policy gaps, limited technical awareness, and complex carbon measurement requirements. Stronger policies, digital monitoring systems, and farmer capacity-building are essential to overcome these barriers. With coordinated efforts and sustained support, carbon-neutral farming can significantly advance climate goals while strengthening agricultural resilience and economic viability.

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