

Carbon farming:

Practices and challenges

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Agriculture and climate change are interconnected, each profoundly influencing the other as agriculture is both a contributor and victim of climate change. To attain carbon neutrality, we have to shift our focus from carbon dioxide emissions towards carbon dioxide removal (CDR) from the atmosphere. Even CDR is an integral part of IPCC scenarios that aim to limit global warming to 1.5°C relative to pre-industrial levels. Compared to natural forests, carbon is lost much more from our cultivated lands because crops are harvested every year, soil is tilled annually, and faulty agricultural practices are employed. Hence, to attain carbon neutrality, we should adopt a novel approach known as carbon farming.

Keywords: Carbon neutrality, Climate change, Novel approach

ENHANCING soil organic carbon is a pre-requisite to carbon farming, as it is the major pool for soil organic carbon sequestration, accounting for nearly three times as much carbon as aboveground biomass and twice the amount of carbon present in the atmosphere. Carbon farming is a component of climate-smart agriculture in which carbon is removed from the atmosphere, i.e. sequestration of carbon, and that sequestered carbon is conserved and locked in soil.

Geological sequestration

It involves storing anthropogenic carbon dioxide (CO₂) deep underground in geological formations to prevent it from entering the atmosphere. It is generally injected deep underground (generally more than 800 m) in minute pores and spaces in rock structures and the impermeable cap rocks act as a seal to ensure safe storage of CO₂.

Oceanic sequestration

Oceanic sequestration involves storing carbon in the oceans, either by enhancing natural processes or direct injection. The sequestration of carbon in the ocean involves the following processes.

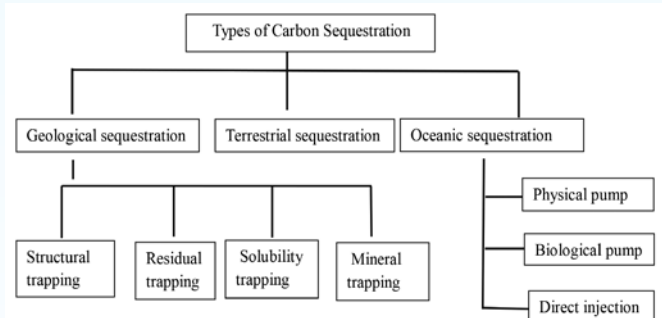
Biological pump: The marine organisms' phytoplankton absorb CO₂ during photosynthesis, and after their death, they sink, taking carbon to deeper ocean layers.

Physical pump: CO₂ dissolves in cold deeper ocean water and is transported by ocean currents.

Direct injection: CO₂ is injected into deep ocean layers, where high pressure and low temperature keep it dissolved.

Terrestrial sequestration

It involves storing carbon in forests, soils, and vegetation. Terrestrial sequestration mainly occurs through the process of photosynthesis, whereby plants absorb CO₂ and convert it into organic carbon compounds. These compounds are stored in the biomass of plants, including leaves, stems, branches, and roots, as well as in the soil, where carbon is incorporated into organic matter through litterfall, root exudates, and microbial activity.



Mass balance for carbon

The mass balance for carbon in the ecosystem can be expressed by the following equation:

Input – Output = Storage

Inputs, Photosynthesis and soil amendments; Outputs, Plant and microbial respiration, and Emissions of volatile organic compounds (VOCs); Storage, Plant and microbial biomass, and soil carbon as SOC and SIC pools.

Strategies for promoting carbon farming through climate action plans

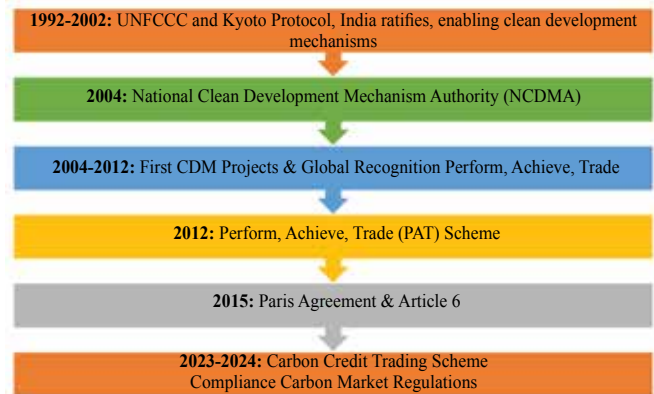
National action plan on climate change: The National Action Plan on Climate Change (NAPCC) was released by the Prime Minister on June 30, 2008, and outlines a national strategy that aims to enable the country to adapt to climate change and enhance ecological sustainability. This comprehensive framework encompasses the National Mission for a Green India and the National Mission on Sustainable Agriculture, which emphasizes climate-resilient practices and resource conservation.

National mission on sustainable agriculture: The National Mission for Sustainable Agriculture (2014-15) is a key component of the National Action Plan on Climate Change (NAPCC), which emphasizes sustainable farming by enhancing soil health, promoting efficient water use, and encouraging the adoption of organic agriculture. It provides subsidies and financial aid to encourage the adoption of climate-resilient technologies, improved soil management, and water conservation practices, all of which contribute towards carbon farming.

Carbon capture utilization and storage technology (CCUS): According to the IPCC, CCUS involves capturing a concentrated stream of CO₂ from industrial or energy-related sources, conditioning and compressing it, and transporting it to secure sites for long-term storage, thereby preventing release into the atmosphere. Formerly termed Carbon Capture and Storage (CCS), the concept now includes utilization pathways, where captured CO₂ is repurposed. A major application is enhanced oil recovery (EOR), in which CO₂ is injected into depleted reservoirs to increase crude oil extraction while sequestering the gas underground. CCUS is thus a dual-purpose technology mitigating emissions while supporting industrial productivity.

Carbon credit trading scheme: Launched by the Ministry of Agriculture and Farmers Welfare, this scheme enables farmers and organizations to register GHG mitigation projects and earn tradable carbon credit certificates through the voluntary carbon market (VCM). One carbon credit equals one metric tonne of CO₂ equivalent reduced, avoided, or removed. Verified standards like the VCS and Gold Standard provide protocols for measuring and validating reductions in agriculture. By adopting eco-friendly practices and securing verification, farmers can generate credits to sell to companies seeking emission offsets. This not only supports climate change mitigation but also provides farmers with additional income.

National agroforestry policy and sub-mission on agroforestry (SMAF): India was the first country



Historical foundation behind carbon credits

in the world to adopt a dedicated agroforestry policy in 2014. Its main objective was to integrate trees with crops and livestock systems, increasing productivity, income, and environmental benefits. It serves as an important component of carbon farming as agroforestry enhances carbon sequestration, improves soil health, and diversifies farmer income.

Sub-mission on agroforestry (SMAF): This was launched in 2016 onwards under the National Mission for Sustainable Agriculture (NMSA). Its main objective is to incentivize farmers for adopting agroforestry practices by providing financial assistance for nursery development, sapling distribution, and plantation.

Green credit programme (GCP): The Green Credit Initiative was launched by the Honorable Prime Minister during 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 28) as part of the government's Lifestyle for Environment (LiFE) movement. To support this, the Green Credit Rules, 2023 were notified on 12th October 2023 under the Environment Protection Act, 1986. Under this programme Green Credits (GCs) are awarded to individuals or organizations undertaking activities like tree plantation and other eco-friendly practices. The initiative encourages voluntary positive environmental actions, with the initial phase focusing on plantations on degraded lands, wastelands, and watershed areas managed by Forest Departments. The Green Credit Rules, 2023, operate separately from the Carbon Credit Trading Scheme, 2023, meaning GC generation is independent of carbon credits. The GCP covers a wide range of activities, including, tree plantation, water management, sustainable agriculture, waste management, air pollution reduction, mangrove conservation and restoration, eco mark label development, and sustainable buildings and infrastructure.

Agro-techniques for carbon farming

Crop management:

- **Cover crops:** Cover crops play a vital role in carbon farming by acting as a link between atmospheric carbon dioxide and long-term soil carbon storage. When these crops are grown between main crop cycles, they capture carbon dioxide through



Wheat + lentil

photosynthesis and channel it into their roots, stems, and leaves. When incorporated into soil, cover crop biomass enriches organic matter, enhances fertility, and increases soil carbon. Their roots release organic compounds through rhizodeposition, stimulating microbial activity and promoting humus formation. Deep-rooted species are particularly effective as they deposit carbon in deeper soil layers, making it less vulnerable to decomposition. Additionally, cover crops protect existing soil carbon by forming a surface cover that reduces erosion and preserves carbon-rich topsoil. Thus, cover crops play a dual role—capturing new carbon while safeguarding stored carbon—contributing significantly to soil health and long-term carbon sequestration.

- **Biochar application:** Biochar is produced through pyrolysis. During this process, a large portion of the carbon in biomass is converted into stable aromatic carbon rings. Unlike the crop residues or manure that decompose quickly and release CO₂, biochar is highly resistant to microbial breakdown. It can remain in soils for hundreds to thousands of years, effectively locking carbon in soil.
- **Terra-Preta:** *Terra Preta* (meaning “black earth” in Portuguese) is an ancient biochar-based soil management technique that has a direct link to carbon farming. It is created by indigenous communities found in the Amazon Basin and made by adding charcoal (biochar), food waste, manure,



Biochar application



Direct seeded rice sown by happy seeder under zero tillage

bones, and organic residues into nutrient-poor tropical soils. The charcoal (biochar) in *Terra Preta* is highly stable. It resists decomposition as it locks carbon in the soil for centuries, making it one of the ancient models of permanent carbon sequestration.

- **Zero-Tillage:** ZT eliminates repeated ploughing operations, lowering diesel consumption and reducing CO₂ emissions from machinery. Without ploughing, soil aggregates remain stable and trap organic carbon within, physically protecting the carbon from microbial attack.
- **Organic mulch:** Organic mulching plays an important role in carbon farming because it directly adds organic matter to the soil while simultaneously protecting existing soil carbon. When crop residues, straw, leaves, or compost are applied to the soil surface, they slowly decompose and enrich the soil with carbon-rich organic matter, thereby increasing soil organic carbon stocks. At the same time, the mulch layer shields the soil from direct sunlight, wind, and erosion, reducing the chances of carbon loss through oxidation and surface runoff.

Livestock management :

- **Rotational grazing:** Well-managed rotational or adaptive multi-paddock grazing allows pastures to recover, increasing root biomass and soil organic carbon. This practice also prevents overgrazing, which can degrade soil and reduce carbon storage



Pigeon pea residue in ZTW

potential. When pastures are allowed to rest, plants recover and grow deeper root systems. These roots deposit organic matter into the soil, which increases soil organic carbon over time, and this root system also improves soil structure and water retention, subsequently promoting carbon storage.

- **Manure management:** Composting livestock manure before application to fields can stabilize carbon and reduce methane and nitrous oxide emissions. Direct application of manure to croplands, especially in combination with cover crops, contributes to soil organic matter, improving soil health and carbon storage. When manure is applied to fields, it adds organic matter to the soil. This organic matter, when incorporated into soil aggregates, stores soil organic carbon for longer periods.
- **Integrating silvo-pastoral systems:** Trees along with livestock grazing could provide additional carbon sequestration through woody biomass, while also offering shade and fodder for animals. Agroforestry with livestock can significantly increase carbon stocks both above and below ground.

Forestry management :

- **Reforestation:** It is one of the most effective strategies in carbon farming because it directly removes CO₂ from the atmosphere and stores it in biomass and soils. When trees are planted on previously deforested or degraded land, they act as carbon sinks, absorbing CO₂ through photosynthesis and converting it into biomass. Over time, this biomass stores large amounts of carbon that would otherwise contribute to climate change. Reforestation also improves soil carbon sequestration. As the trees grow, they drop leaf litter and organic residues that decompose, increasing the soil organic carbon content.
- **Bamboo farming:** It could serve as a powerful tool for carbon farming because bamboo is a fast-growing, perennial plant with a high capacity for carbon sequestration. Unlike many trees, bamboo can grow very quickly, allowing it to capture CO₂ from the atmosphere at a much faster rate than conventional forests. Also, its extensive root system contributes to long-term carbon storage in the soil by adding organic matter and improving soil structure. This soil carbon can remain stable for decades, enhancing overall soil fertility and resilience.
- **Alley cropping:** Also known as hedgerow intercropping, it is the integration of trees or shrubs with annual crops in the same field, creating a system that captures and stores carbon both above and below ground. In this practice, rows of trees or shrubs are planted at regular intervals, and crops grow in the “alleys” between them. The trees and shrubs in alley cropping act as carbon sinks, absorbing atmospheric CO₂ through photosynthesis and storing it as above-ground biomass in trunks, branches, and leaves.
- **Mangrove restoration:** Mangroves are a part of



Large cardamom with Ficus tree

“blue carbon” ecosystems as they sequester carbon in both plants and sediments more effectively than most terrestrial ecosystems. Mangroves store a large amount of carbon below ground in waterlogged soils. Their dense root systems trap sediments and organic matter, which decomposes very slowly due to anaerobic conditions, allowing carbon to remain stored for centuries.

Challenges in carbon farming

- Accurate quantification of how much carbon dioxide is emitted and converting it to carbon credits is a difficult task.
- Carbon sequestration is not permanent, since stored carbon in the soil can still be lost unless further protected.
- Farmers may be hesitant to adopt carbon farming practices due to uncertainty about financial returns, lack of awareness, or the need for upfront investment.
- Carbon credit markets are still fragmented, lack transparency, and the prices of carbon credits are volatile.
- Changes in rainfall, rising temperatures, and extreme weather events may compromise the reliability of carbon sequestration efforts.

SUMMARY

India is in the preliminary stage of carbon farming, and for strengthening it, a powerful framework is needed that can connect farmers, industries, and the government together to build a robust carbon credit system, enabling this carbon farming to contribute to India’s GDP. Governments must create stable, long-term policies that support carbon farming within broader climate action strategies and provide low-interest credit grants for farmers transitioning to carbon-friendly practices. The Indian government should establish strong ties with the developed countries so that it can earn by selling carbon credits to them for reducing their emissions. Hence, there is ample scope in carbon farming, and to save the planet, it is necessary to shift from soil-depleting farming to carbon-enriching farming.

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