

Sequestration of Carbon to Acquire Carbon Credit and Minimization of Potent Greenhouse Gases

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ABSTRACT

The escalating global population, coupled with increased urbanization and industrialization, is placing immense strain on natural resources and exacerbating climate change through greenhouse gas (GHG) emissions. Primary sources of these emissions include the burning of fossil fuels, deforestation, and intensive agricultural practices, all of which release significant quantities of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Soil organic carbon (SOC),

representing the largest terrestrial carbon reservoir, is crucial in climate change mitigation as it sequesters atmospheric carbon. This study aims to assess the capacity of soil carbon sequestration and carbon credit mechanisms to reduce GHG emissions, enhance soil health, and foster sustainable agriculture. Practices like conservation tillage, crop rotation, cover cropping, direct-seeded rice cultivation, alternate wetting and drying, organic amendments, agroforestry, and biochar application are proven to boost SOC levels, improve soil fertility, and increase water retention. Beyond restoring degraded soils, carbon sequestration also benefits biodiversity and farm productivity. Carbon credits offer a complementary market-based incentive for emission reductions, enabling farmers and industries to offset their GHG outputs. Notably, smallholder farmers can supplement their income by adopting practices eligible for carbon credits and engaging in carbon markets. Nevertheless, challenges persist, including the natural limit of soil carbon saturation, the risk of emission reversal due to land-use changes, difficulties in monitoring, and the potential for carbon credits to be misused for “greenwashing.” Despite these obstacles, combining carbon sequestration with carbon credit systems presents a scalable approach to reducing atmospheric CO₂, promoting agricultural sustainability, and fulfilling international climate obligations like the Paris Agreement, thereby positioning agriculture as a vital contributor to global climate solutions.

Keywords Carbon credit, Carbon sequestration, Carbon trading, Conservative agriculture, GHG’s.

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INTRODUCTION

By 2050, the world's population will reach 9.7 billion, which would represent a significant rise from 7.7 billion in 2019 (United Nations 2019). The world's growing population has created a scarcity of resources from nature, putting a strain on environmental protection and agriculture, particularly regarding food security (United Nations 2019). Residing in the 21st century, trending globally with urbanization and industrialization, the modern generation is lavishing with latest equipment's which in turn is surrounding the environment with surplus pollutants posing threat to climate, soil, and the biosphere (Onder and Yildirim 2021). Pollution is brought about by numerous human activities that emit toxic substances into the environment, impacting air, water and land quality. Industrialization is one of the leading causes, whereby factories release smoke, chemicals, and toxic waste into the air and water bodies (Fig. 1).

Global warming is mostly due to human activities that enhance the levels of greenhouse gases in the worldwide atmosphere. The release of carbon dioxide (CO₂), the most important greenhouse gas, is caused by the combustion of fossil fuels like coal, oil and natural gas for energy and transport (Siddik *et al.* 2021, Islam *et al.* 2025b). Deforestation also plays a role because forests that pull CO₂ are destroyed for agriculture, industrialization, or urbanization. Industrial processes and factories release not just CO₂ but also other powerful greenhouse gases such as nitrous oxide (N₂O) and methane (CH₄) (Fig. 2). Agriculture, particularly livestock production, releases methane from the digestive system of animals, and the appli-

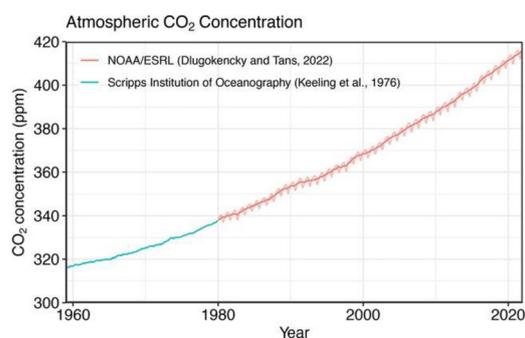


Fig. 1. Atmospheric CO₂ concentration (Jain 2022).

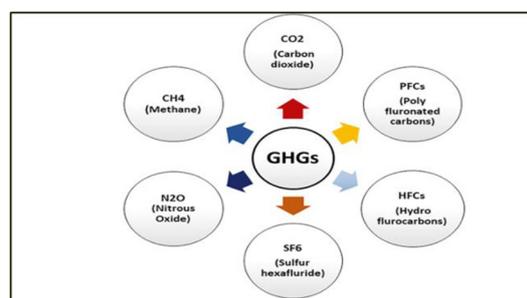


Fig. 2. Major Greenhouse gases (Nathaniel *et al.* 2025).

cation of fertilizers releases nitrous oxide (Sharma *et al.* 2018).

It causes air, water and soil pollution that makes the planet less inhabitable for humans and animals. Pollution is responsible for international problems such as global warming, acid rain, and ozone layer reduction. Pollution also kills animals, plants, and aquatic organisms, resulting in biodiversity loss. Additionally, pollution affects agriculture by contaminating water and soil and reducing crop production (Kolawole and Iyiola 2023).

Soil carbon pool loss is the term used to describe decreased levels of organic carbon contained in the soil, and they can have catastrophic effects on soil health, agricultural output, and climate control. Microbial decomposition of plants, animals, and bacteria accounts for a major part of organic matter, which is soil carbon (Khatoon *et al.* 2017). It has a crucial role in soil structure, fertility, and water retention (Biswas *et al.* 2023). Besides, the diversity of the soil is damaged due to the depletion of soil organic matter since there are fewer species and beneficial cycling nutrients. At a global level, the emission of carbon dioxide (CO₂) from deteriorating soils also promotes global climate change because the greenhouse gas gets trapped in the environment (Filonchuk *et al.* 2024). Generally, the loss of the soil carbon pool is detrimental to environmental equilibrium, farm sustainability, and health.

Raising the pool of carbon in the soil is important to improving soil health, boosting farm output, and fighting climate change. Additional carbon in soil enhances structure, expands water-holding ca-

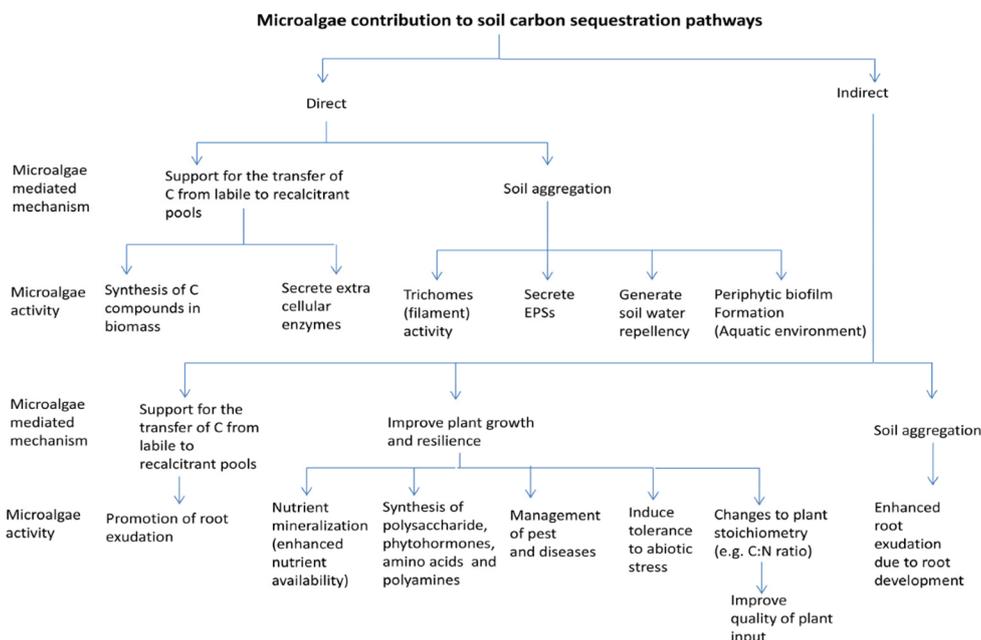


Fig. 3. Microalgae contribute to soil carbon sequestration (De-Silva *et al.* 2024).

capacity, and contributes to healthy microbial activity. Numerous techniques could be modified to enhance sequestration of carbon in soil.

Soil carbon

The quantity of carbon within soil plays a crucial

role in the functioning of the global carbon cycle. Additionally, it is stated by (Rahman *et al.* 2020) that soil carbon is both an engine and a catalyst for the ecosystem functions. Knowing soils, the largest terrestrial carbon pool, it is crucial to know about the changing global carbon cycle (Chapin *et al.* 2009). SOC stores hold approximately 1550 Pg, or simply

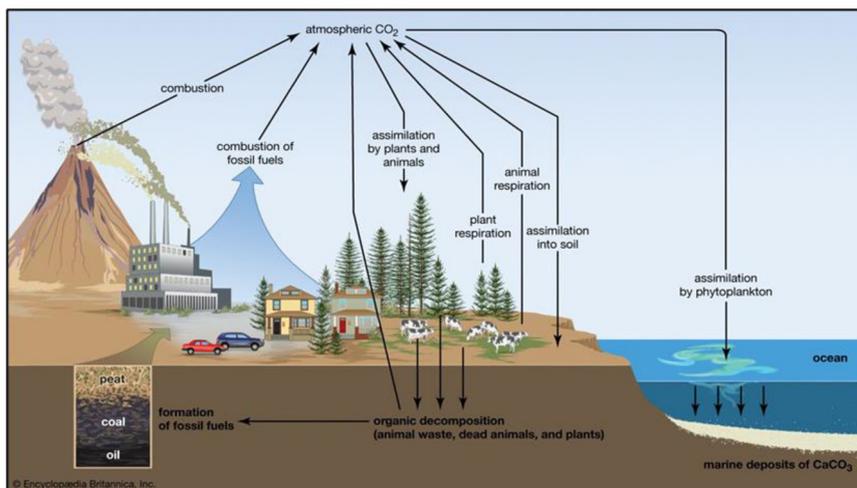


Fig. 4. Carbon Sequestration (De-Silva *et al.* 2024).

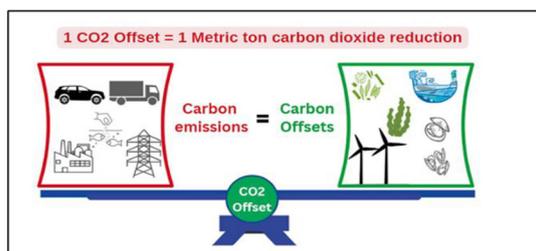


Fig. 5. Carbon offset credit (Nathaniel *et al.* 2025).

about 62% of the total carbon pool soil (Ferdush and Paul 2021).

Soil carbon is an important aspect of the Earth's carbon cycle, held in soil in organic and inorganic carbon forms. Soil carbon content is crucial in fertility of soil, plant growth, and the regulation of climate. Soil organic carbon (SOC), the biologically active and more dynamic pool, comes from the residues of plants and animals and residues after they are decomposed and forms an essential component of soil organic matter. However, inorganic soil carbon, like calcium carbonate, is produced by mineral processes and is more stable, particularly in arid conditions.

Soil is a substantial carbon sink, holding more carbon than the atmosphere and all living plant biomass (Fig. 3). Therefore, it is an effective weapon in the fight against climate change. By sequestering carbon in soil through sustainable land management—such as reduced tillage, cover cropping, composting, and reforestation—we are able to take excess carbon dioxide out of the atmosphere and sequester it safely in the earth.

Carbon sequestration

Carbon sequestration is the process of reducing the net increase in atmospheric CO₂ levels by converting it into other long-lived global pools, such as oceanic, pedologic, biotic and geological pools (Lal 2008). Ecosystem management incorporates two approaches: Conserving and sustaining ecosystems and enhancing carbon sequestration through increased soil and plant biomass (Adhisankaran *et al.* 2024). Soil is the largest carbon reservoir on land, which can help alleviate climate change. Sequestering atmospheric

CO₂ is characterized by plants, plant waste, and other organic elements preserved as SOM in a land unit's soil (Six *et al.* 2006). As a multifunctional strategy to combat climate change, save the environment, boost biodiversity, restore degraded soils, and improve agricultural output, carbon sequestration is gaining popularity (Wang *et al.* 2010) (Fig. 4). Through bioconcentration during photosynthesis, the CO₂ sequestration technique—also referred to as capture and storage—occurs (Singh and Dhar 2019). Microbial carbon fixing is a crucial step for anyone hoping to attain carbon neutrality and halt the increase in CO₂ emissions. Consequently, the potential for carbon storage in terrestrial and marine carbon sinks has garnered a lot of interest lately. The current study highlights the importance of microbial carbon sequestration as a crucial mechanism (Jiao *et al.* 2022).

Carbon credit

A carbon credit represents the removal of one ton of greenhouse gases (GHGs), including CO₂ or its equivalent, from the atmosphere (Peralta *et al.* 2022). Carbon credits are vital to carbon trading since they contribute to reducing the damage that greenhouse gas emissions inflict on the environment (Lokuge and Anders 2022). In cap-and-trade, organizations that have lower emissions than their allocated level are awarded carbon credits (Fig. 5). The credits provide financial incentives for firms and individuals to reduce their carbon footprint by selling or trading to other organizations that have higher emissions than they have (Adhisankaran *et al.* 2024).

Countries and businesses can strive toward achieving the emission reduction goals of international accords such as the Paris Agreement and the Kyoto Protocol with the help of carbon credits. A low-carbon economy and transition to alternative energy sources are the results of the expanding market for carbon credits (Fig. 6). The rate of carbon emissions, which is 50 Gt CO₂-e/year, is used to determine the limit of carbon credits (Mathews 2008). Carbon credit sales entails purchasing of discharge licenses from individuals or firms that have the ability to cut or retain carbon emissions. Carbon credit value is determined by market forces using trading activity among buyers

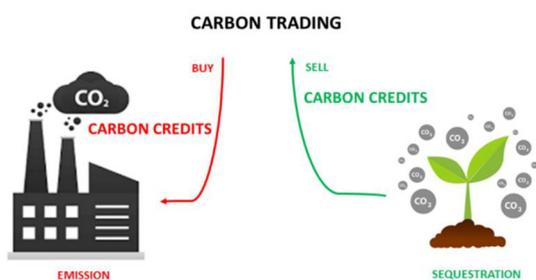


Fig. 6. Carbon trading or emission trading mechanism (Adhiskaran *et al.* 2024).

and sellers (Peralta *et al.* 2022).

Steps of carbon credit certification

The process of earning carbon credit has several crucial steps (Fig. 7). One, a company or organization measures its greenhouse gas emissions so that it is aware of its environmental impact. In an effort to neutralize these emissions, a reduction or removal carbon project is conducted—such as planting trees, constructing renewable power, or harvesting methane. The project is then validated by an independent third party to ensure that the emissions reductions are actual, quantifiable, and long term. Once verified, the project receives carbon credits, one credit per metric ton of carbon dioxide (CO₂) or its comparable. The credits are issued by a widely accepted carbon registry and may be sold or traded on carbon markets. Companies that have exceeded their emission limits can purchase these credits to balance their excess emissions. By this process, carbon credits facilitate

the connection of emission reduction with economic reward, promoting better practices globally.

Carbon sequestration and mitigation of climate change

The United Nations Framework Convention on Climate Change's Kyoto treaty allows nations to get carbon credits for carbon-sequestration efforts in the fields of forestry, land use, and land-use change as part of their obligations under the treaty (Anukwonke and Abazu 2022). Common methods for sequestering carbon include revegetation, enhanced forestry or agricultural techniques, afforestation, and reforestation. The Intergovernmental Panel on Climate Change (IPCC) asserts that enhanced farming methods and mitigation initiatives related to forests can significantly reduce atmospheric carbon dioxide emissions at a comparatively low cost. This includes some sustainable practices that aid in the sequestration of carbon in those important terrestrial sinks, such as better management of crop and grazing land, increased fertilizer use efficiency, conservation tillage techniques, restoration of degraded land, and preservation of existing forests (Lehmann 2009, Mallik *et al.* 2024).

Source of atmospheric carbon

The main sources of atmospheric carbon are human activity and natural processes. Plant and animal respiration, organic matter decomposition, volcanic eruptions, wildfires and carbon exchange with seas

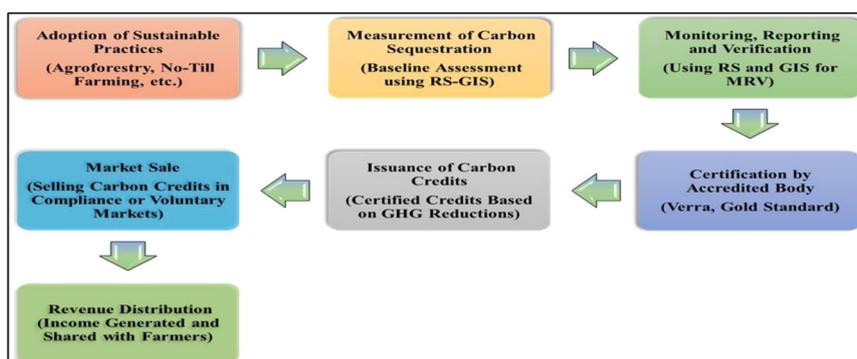


Fig. 7. Steps included in developing a carbon credit mechanism (Ghosh & Sharma 2024).

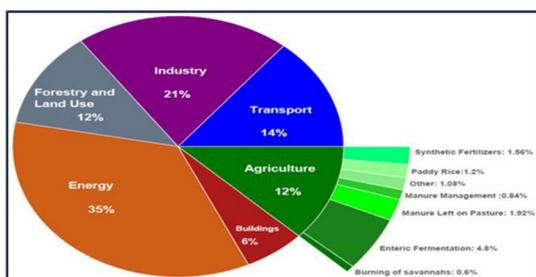


Fig. 8. Agrifood system emissions by component in India, Source: (Wijerathna & Pathirana 2022)

are examples of natural sources. For millions of years, these processes have been a part of the carbon cycle on Earth (Peccerillo 2021). However, anthropogenic (human) activities have raised atmospheric carbon levels considerably, particularly in the form of methane (CH₄) and carbon dioxide (CO₂). Fossil fuel combustion (coal, oil and natural gas), deforestation, agriculture (especially raising cattle and rice), industrial emissions and waste management are the main human sources (Munsif *et al.* 2021). Large volumes of stored carbon are released into the atmosphere as a result of these activities, upsetting the natural equilibrium and accelerating climate change.

Emissions from agriculture

Greenhouse gas emissions from intensive farming methods in developing nations have a major effect on climate change. India accounts for 19% of the 10–12% of global greenhouse gas emissions that come from agriculture (Cariappa *et al.* 2024). Burning crop leftovers, using synthetic fertilizers, and growing rice are the main activities that cause greenhouse gas emissions. In particular, methane emissions from rice farming in India make up around 138.68 kilotons, but N₂O emissions from synthetic fertilizers and crop residue burning produce about 405.77 and 3.59 kilotons, respectively (FAOSTAT 2024). Additionally, only 1% of agricultural land is made up of drained agricultural peatlands, however they account for roughly 33% of greenhouse gas emissions from agriculture worldwide. Since emissions comes from all phases of production, non-resilient farming methods are a major contributor to climate change (Anthony and Silver 2024).

Chemical amendments

Due to the rising need for food, chemical fertilizers are being used more often, which might harm ecosystems and raise greenhouse gas emissions. Nitrogen fertilizers are the main source of anthropogenic N₂O emissions, and their manufacture alone is responsible for almost 1% of global GHG emissions (Rao and Balachandar 2017). According to FAO forecasts, the usage of synthetic N fertilizers is predicted to rise by 50% worldwide between 2012 and 2050, thereby jeopardizing the climate aim of the Paris Agreement. Despite being necessary for plant growth, phosphorus is frequently lost to streams, leading to eutrophication (Li *et al.* 2020). Potassium chloride, which is the main source of potassium, an essential mineral for plant growth, increases greenhouse gas emissions during manufacture (Murrell *et al.* 2021).

Organic amendment

Almost 2.9 million farmers oversee about 70 million hectares of organic land, reflecting the expansion of organic farming in many nations. However, there are disadvantages to applying modifications, including as problems like nutrient eutrophication and greenhouse gas emissions (Singh *et al.* 2024). Despite its widespread usage in agriculture, animal manure increases CO₂, CH₄ and N₂O emissions (Fig. 8). Composting aids in turning organic waste into materials that resemble humus, but proper handling of the process is necessary to lower greenhouse gas emissions (Shakoor *et al.* 2021).

A substantial amount of the world's N fertilizer usage comes from cereals, which are also a vital part of the human diet. About 30% of global agricultural CH₄ emissions come from rice, making it a significant source of greenhouse gas emissions (Gupta *et al.* 2021). Rice generates the greatest N₂O emissions in India's agricultural and food industry, according to FAOSTAT. It contributes for 47.97% of total emissions, with wheat coming in second at 27.98% (Fig. 9). It is critical to reduce N₂O emissions from rice and wheat in order to reduce India's agrifood system's environmental effect. Nitrogen fertilizers are commonly utilized to boost maize yield, result-

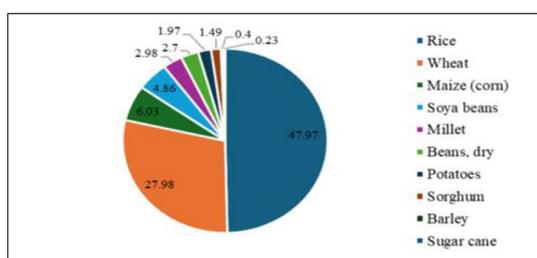


Fig. 9. Crop-wise emission of N_2O from India (Ramzan *et al.* 2020).

ing in higher emissions (Meng *et al.* 2016). Palm oil production generates approximately 2.8–19.7 kg CO_2 eq per kilogram (Reijnders and Huijbregts 2008).

Fossil fuel combustion

The burning of fossil fuels is the largest anthropogenic source of CO_2 emissions into the atmosphere. The process is one of burning carbon-rich fuel sources like coal, oil and natural gas to generate energy to drive electricity, transportation, heating and industrial processes (Bhui 2021). When these fuel sources are combusted, the carbon in them burns with oxygen in the air to produce CO_2 as a product. This carbon was sequestered below the ground for millions of years, and its sudden release into the atmosphere interferes with natural carbon equilibrium.

The burning of fossil fuels accounts for more than 70% of the world's CO_2 emissions. Power plants, vehicles, aircraft and factories are among the largest emitters. For instance, coal power plants produce more CO_2 per energy unit than oil or natural gas power plants. In transportation, automobiles, trucks, ships and aircraft consume gasoline and diesel, both of which emit large quantities of CO_2 . Industrial processes like cement and steel manufacturing also add to it by consuming fossil fuels and through chemical reactions (Akinyemi and Ramonu 2019).

Conventional approach to carbon sequestration

Enhanced land management and farming practices designed to expand the quantity of organic matter and improve soil carbon sequestration form the bulk of traditional methods of soil carbon sequestration. The techniques are elaborated below....

Regenerative agriculture

Conservation agriculture (CA) is a farm method that involves crop rotation, permanent soil cover, and reduced tillage. As a good method for environmental conservation, climate change adaptation and mitigation, and sustainable land management, FAO encourages CA (Tadiello *et al.* 2023). CA is one of the main drivers of adaptation and mitigation of climate change in agriculture, according to various international projects (Sanchez *et al.* 2019). Conservation agriculture is a cost-effective measure to maintain soil health and enhance SOC storage. Conservation agriculture is also associated with other advantages that contribute to agricultural sustainability. Through improved soil carbon stock at the farm level and reduced vehicle use, conservation agriculture has the potential to mitigate direct CO_2 emissions (Piccoli *et al.* 2016, Islam *et al.* 2025a). Field application of three interconnected concepts and other exemplary agronomic practices—among them, those that are the centerpiece of soil carbon sequestration—is what makes up conservation agriculture.

Conservation tillage

GHG production and carbon sequestration are significantly influenced by tillage methods (Mehra *et al.* 2018). Tillage is generally applied to enhance crop seed bed preparation and crop residue management. In annual crop fields, it is the major source of soil disturbance. It breaks the soil, making it oxidized and exposing the soil organic material more. When CO_2 is emitted into the atmosphere, organic matter content in the soil reduces. In recent decades, producers have used sophisticated tillage technology and agronomic approaches to reduce tillage intensity and frequency. They also sometimes practice no-till farming (Paus-tian *et al.* 2019). No-tillage (NT) practices can encourage the formation of soil aggregates, improve their stability, and uniformly disperse carbon throughout soil aggregates of varied sizes. Aggregate stability is dependent on soil organic carbon (Yang *et al.* 2022). Conservation tillage techniques also increased the quantity of total nitrogen and soil organic carbon, especially in the 0–20 cm soil layer. The N_2O emissions of the dryland ecosystem were less impacted by these practices, which also increased CH_4 uptake

and reduced net CO₂ flux (Alhassan *et al.* 2021). In comparison with conventional tillage, no-tillage created higher SOC stock in the topsoil (0–20 cm). In 23 years' duration, SOC in the topsoil was 21% higher under no-tillage, which reflects a useful method for the restoration of lost SOC (Briedis *et al.* 2023).

Crop residue

Residues from crops are crucial in the development of organic matter in the soil, which affects the supply of nutrients and carbon storage. This enhances the quality of the soil, encourages the formation of humus, and contributes minerals and carbon to the soil (Zhao *et al.* 2022). Crop residue is established to increase soil quality in numerous research studies done in developing nations. These advantages include higher organic matter, carbon sequestration, water storage, nutrient cycling, and less erosion of soils (Li *et al.* 2016).

With approximately 45% carbon, crop residues contain the greatest concentration of SOC and their management greatly affects carbon dynamics (Blanco-Canqui and Lal 2009). In 2021, crop residues will account for 25% of carbon emissions from the manufacturing of cement and fossil fuels, with an annual worldwide emission of 2.4 Pg C.

Crop rotation

Crop rotation is the process of successively planting various crops on the same field. The technique has gained attention in recent times because of its minimal environmental effect and sustainable food production (Zhang *et al.* 2023). Crop rotation benefits agriculture by minimizing pests, weeds, and diseases and improving soil fertility, structure, and nutrient efficiency use (Giacometti *et al.* 2021). Ecosystem services can be improved by a diverse agricultural rotation involving perennials and cover crops. Crop residue can also raise SOC and total carbon input because it increases the amount of living soil cover.

Legume crops enhance the yield of subsequent crops through enhanced soil microbial activity, soil organic carbon, soil moisture, and general porosity (Zheng *et al.* 2023). Grain legumes contribute SOC

via residual roots and shoots due to their robust and deep root system. Measuring nearly 1.5 meters in length, the root of pigeon pea is famous for sequestering carbon in the lower soil.

Cover crops

To enhance soil organic carbon, soil structure, minimize erosion and loss of nutrients, and to promote sequestration of carbon and nitrogen retention, cover crops to be planted between major crops (Quintarelli *et al.* 2022). Cover crops also reduce farming activities and the consumption of fossil fuels, which assists in reducing climate change. Also, cover crops are grown as green manure, which enhances the carbon sink of the soil and generates a significant amount of biomass (Lal 2015). Carbon in soils can be sequestered by cover crops without affecting primary crop yield (Sharma *et al.* 2018). Compared to their absence, the existence of cover crops enhanced SOC globally by 16% and generated carbon sequestration rate of 167 kg C ha⁻¹ yr⁻¹.

Nutrient management

Plant growth, litter quality, and microbial respiration are all affected by N, P and K fertilizer, which can alter the stocks of soil carbon. These three nutrients benefit SOC stocks through the stimulation of growth, biomass, and soil fertility (Poeplau *et al.* 2018). Organic amendments can combat climate change, enhance soil fertility, and contribute to carbon sequestration (Gopinath *et al.* 2022). But the local environmental conditions control how well they work (Bai *et al.* 2023). Green manure has the ability to raise the carbon pool index (CPI) and lower the carbon management index (CMI). The priming effect is how organic inputs can make the rate of SOC decomposition change (Li *et al.* 2021).

Direct Seeded Rice (DSR): Because DSR usually consumes less water, methane (CH₄) emissions - A powerful greenhouse gas produced in flooded rice fields immediately decreases. Some DSR system's global warming potential (GWP), such as dry direct-seed rice, is still lower than PTR, somewhat as a result of more aerobic conditions despite the possibility of emissions of nitrous oxide (N₂O) emissions.

As compared to Puddled Transplanted Rice (PTR), DSR is said to conserve 16–38% of irrigation water; DSR and CH₄ emit 30–98% less emissions, depending on the water management type, which is lower a decline in dry-DSR; And lowers global warming potential (GWP) by 20–44%. The low-flood CH₄ emissions are related to low floods and higher aerobic conditions that inhibit methanogenesis and thus methane emissions (Trifunovic *et al.* 2020). Dry-DSR emits a bit more N₂O than PTR, one of the more aerobic of the trading bands. However, the net GWP is lower in DSR than in PTR. Moreover, with improved nitrogen and water management, DSR has room for improvement to minimize CH₄ and N₂O emissions further. In total, thus, the DSR offers adaptation to climate change (water scarcity and poor and irregular monsoon) and mitigation (reduction of GHG emissions).

Alternate wetting and drying (AWD)

According to Jain *et al.* (2023), practice reduces methane emissions by 70% and irrigation amounts required by rice to 20%. Under irrigated rice fields, AWD is a water savings management exercise that maintains yields by reducing water use and greenhouse gas emissions. The recurrent drying and re-flooding of the rice area is another feature that separates this AWD practice.

Experiments have indicated that AWD can lower the global warming potential (GWP) of rice production because of a substantial reduction in methane emissions. Nevertheless, enhanced N₂O emissions can partially counteract these benefits. The net effect would be dependent upon site-specific conditions and implementation of AWD.

Organic farming

Organic agriculture is a nature-friendly approach for climate change. Controlling nutrients, it assists with climate change optimization and mitigation without the application of synthetic fertilizers, which is one of the prime causes of agriculture GHG emission (Wani *et al.* 2013).

Organic agriculture possesses greater potential

to store carbon in soil compared to conventional agriculture (Muller and Aubert 2014). This is done by utilizing soil carbon sequence through the mitigation of CO₂ emissions from the input of agricultural systems, mitigation of N₂O emissions from nitrogen input and soil carbon sequence as a viable mitigation strategy (Gopinath *et al.* 2018).

Organic amendments

Organic matter is one of the major constituents of soil and plays a significant role in influencing the physical, chemical and biological characteristics of the soil. Through retaining more water and nutrients, SOM enhances soil fertility and plant productivity. Further, SOM stabilizes soil, reduces erosion, and enhances surface and groundwater quality (Murphy 2015). By adding more nutrients for high plant yields and residual carbon inputs with physical, chemical and biological soil health, organic matter like fertilizer and fertilizer can add more carbon to the soil. Long-term storage of carbon and building fractions of stable organic matter are made easy by decomposed carbon sources that give soil microorganisms organic matter.

Agroforestry

Agroforestry is a viable and sustainable way to store carbon to slow down climate change. Agroforestry is a sustainable land use management technique that involves growing annual crops, livestock, and/or trees. It offers a number of social, economic, and environmental advantages (Verma *et al.* 2021). Agroforestry's perennial trees act as carbon sinks. Through photosynthesis, they take in CO₂, which they then store in the soil and in their biomass. Agroforestry systems aid in carbon sequestration by releasing mulch and litter, storing carbon underground through deep root systems, adding tree biomass to the soil, and maybe interacting with animals.

Biochar

Turning agricultural waste into biochar, a type of charcoal that increases soil fertility and sequesters carbon when added. The use of biochar significantly lowers the carbon footprint of maize (39.49 mg CO₂ ha⁻¹) and rice (20.37 to 41.29 mg CO₂ ha⁻¹) (Nair and

Mukherjee 2022). Biochar is a porous, fine-grained substance that is rich in carbon. According to Amonette and Joseph (2009), biochar is created when plant biomass is subjected to pyrolysis, a thermochemical conversion process, at temperatures between 350 and 600°C in an environment with either little or no oxygen. In contrast, only around 3% and 10%–20% of the initial carbon is retained by burning or decomposition, respectively (El-Naggar *et al.* 2018b). Therefore, biochar functions in the soil as a source and a sink of carbon.

Afforestation

Since the 1990s, reforestation has expanded the area of planted woods by around 1.05×10^8 ha (Payn *et al.* 2015). However, whether afforestation can meet mitigation goals will depend on its area and potential for sequestering carbon. It has been demonstrated that broad-leaved deciduous forests sequester more carbon than coniferous forests, and that wet cold temperatures store more carbon than moist warm ones. The top 0–20 cm of soil had a significantly higher SOC content in forests under 20 years old, while the top 100 cm of soil had a much higher SOC content in forests older than 20 years (Doelman *et al.* 2020). The impact of afforestation on soil carbon dynamics, however, is poorly understood.

Methane reduction

Carbon credits are available for sustainable techniques that lower methane emissions in rice cultivation and animals, such as better manure handling and rice field water management (Chen *et al.* 2024).

Water-efficient irrigation

Greenhouse gas (GHG) emissions can be reduced using water-skilled irrigation techniques such as drip irrigation and variable rate irrigation. By conserving water, this technology reduces the energy cost related to pumping and water treatment, which reduces carbon dioxide (CO₂) emissions. They can also reduce emissions of other greenhouse gases, such as nitrous oxide (N₂O) and methane (CH₄), by reducing excessive soil moisture and by improving irrigation techniques.

How Carbon credit and sequestration help us

Smallholder farmers have a unique chance to diversify their income and incentivize permanent agriculture through carbon finance. They can boost their earnings by applying carbon-eligible farm practices and collecting more revenue than carbon credit. These earnings assist them:

Farmers can purchase good quality seeds, soil amendments and machinery that enhance crop yields for carbon income.

The plots are safeguarded from unwanted weather conditions and dry spells like protection plowing and perennial practices like plowing and agroporesstra, which enhance soil health and water holding capacity (Sauer *et al.* 2021).

Carbon credit is another source of income, which comes in handy for marginal farmers since it lessens reliance on seasonal crops and market fluctuations.

The use of permanent farming practices over a period of time enhances fertility, water holding capacity and climatic resistance of the soil. It is estimated from research that zero plowing alone can raise the soil carbon stock from 10% to 15% in a span of ten years (Brown *et al.* 2021). Farmers can enhance their production and support for world carbon sequence effort by enhancing the fertility of their soil.

Commodity has the potential to make \$10 to \$30 per hectare per annum through commodity carbon credit markets depending on smolhews sequence capacity and carbon price (Kumar *et al.* 2023). Complementary can be a vital source of revenue, considering the economic dislocation by most marginal farmers.

Reduce pollution

Carbon credits reduce pollution by limiting or offsetting the quantity of greenhouse gases, particularly carbon dioxide (CO₂), that a person or business can emit. Since an organization has to purchase credits from other companies that have lowered their emissions when their emissions exceed the permitted level, there is an economic incentive to lower pollution.

This market-based method encourages investment in renewable energy, energy efficiency and clean technologies, eventually resulting in fewer air pollutants and toxic emissions (Jia and Wen 2024). Further, most carbon offset schemes, such as reforestation drives and clean cookstove campaigns, reduce local pollutants and prevent or displace carbon emissions, enhancing the environment and public health.

Reduce global warming

Carbon credits help in combating global warming by limiting the amount of greenhouse gases, especially carbon dioxide (CO₂), continued in the environment (Gupta 2011). By giving emissions a value, carbon credit encourages companies and countries to reduce their carbon footprint. By assisting with carbon offset initiatives such as adopting permanent energy sources, increasing energy efficiency, or with methane collections, renewable energy and redistribution, they can achieve it. These efforts help reduce the increase in global temperature by reducing the amount of greenhouse gases in the atmosphere (Barzagli and Mani 2019). Therefore, international efforts to slow down climate change and promote a more durable future depend a lot on carbon credit.

Problems associated with carbon sequestration and carbon credit

One significant problem is the soil's poor capacity to store carbon. When soil reaches its saturation range, extra carbon can no longer be absorbed, hence effective control of carbon intake is required. It is possible to reverse the indexed carbon; Any disruptions, including shifting land uses, deforestation, or erratic farming methods, can release stored carbon back into the atmosphere and hinder attempts to slow down climate change; Additionally, environmental factors including erratic rainfall, warming temperatures, and extreme weather events lower risks and hasten the release of carbon through microbial activity or soil erosion (Goldstein *et al.* 2020).

While carbon credits are supposed to reduce the emission of greenhouse gases, they also have several major shortcomings, such as the lack of standardization and transparency in the certification,

and marketing of credits, which can lead to over- or false statements of reduced emissions (Marchant *et al.* 2022). Carbon credits can be exploited by some companies as a way of avoiding real changes to their operations, thus buying the right to pollute without decreasing their actual emissions—a technique of “greenwashing.”

The accurate measurement and monitoring of carbon sequestration and carbon credit is challenging. Traditional methods, such as soil samples and dry combustion, are labor-intensive and provide limited snapshots of dynamic processes (Oldfield *et al.* 2022). Policy intervals, including standardized incentives or a lack of carbon credit system, also obstructs comprehensive participation in sequestration initiative.

CONCLUSION

Carbon credits have enormous potential in India's agricultural industry, and small and marginal farmers stand to gain just as much. These farmers can take part in the carbon market by implementing sustainable practices, joining FPOs, and utilizing technology to detect carbon accurately. In addition to helping India achieve its climate goals, this gives farmers a new source of income, increasing their ability to withstand economic and climate shocks. India's agriculture industry may set the standard for sustainable carbon finance and serve as a template for poor countries around the world if it has the right institutional framework.

Reducing the quantity of CO₂ that harmed coastal ecosystems contributes to global emissions requires the use of negative emission strategies. Activities aimed toward conservation and restoration can accomplish this. Adoption rates of biochar, agroforestry, and conservation agriculture have been steadily increasing due to their benefits for soil protection. Because there are so many factors involved, it is challenging to evaluate the impacts of conservation agriculture and the application of biochar as a mitigation approach on SOC stocks, even though their potential has been thoroughly researched. Standardization of soil and crops is necessary before widespread use.

Although the rates of SOC sequestration in agroforestry also vary, all reports show that it has positive consequences.

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Author contribution

Kousik Samanta developed and led the overall study, conducted the data reviews and the analysis, and was involved in draft preparation—original draft; Madhurima Banik conducted the data reviews and the analysis, and critically read the manuscript—original draft; Aminul Islam participated in preparing the manuscript and critically read the manuscript.

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