Enhancing Soil Organic Carbon Sequestration in Agriculture: Plans and Policies

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Enhancing Soil Organic Carbon Sequestration in Agriculture: Plans and Policies

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Abstract

Soil organic carbon (SOC) is a vital factor that positively affects soil fertility, agricultural production, and food security. However, current farming practices, intensive tillage, increasing global warming, and climate change have created a risk of losses of SOC, affecting food supply. Therefore, various management strategies to build soil carbon accumulation and sequestration have been continuously adopted. Net soil carbon sequestration on agricultural lands has the potential to offset 4% of yearly worldwide human-induced greenhouse gas emissions for the remainder of the century, making a significant contribution to reaching the Paris Agreement's emissions reduction objectives. It is also pledged to adopt various plans and policies for building SOC in agriculture. By 2030, a carbon sink of 2.5–3 billion tons of CO_2 equivalent must be created. A package like this would contain restrictions to limit soil carbon loss and encourage sustainable development and "win-win" solutions to current issues and many other climate change risks.

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Keywords

Soil organic carbon · C sequestration · Carbon policy · Carbon management

Abbreviations

C	Carbon
CDM	Clean Development Mechanism
CER	Certified emission reduction
CO_2	Carbon dioxide
CSA	Climate-smart agriculture
EU	European Union
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
GIS	Geographic information system
Gt	Gigatons
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature and Natural Resources
LCA	Life cycle analysis
M ha	Million hectare
Mg	Megagrams
N	Nitrogen
NAPCC	National Mission for Sustainable Agriculture
NASS	National Academy of Agricultural Sciences
NMSA	National Mission on Sustainable Agriculture
NPOF	National Project on Organic Farming
Pg	Petagrams
PKVY	Paramparagat Krishi Vikas Yojana
SHM	Soil Health Management Scheme
SOC	Soil organic carbon
SOM	Soil organic matter
UNCCD	United Nations Convention to Combat Desertification
ZBNF	Zero-budget natural farming

1 Introduction

Soil organic carbon (SOC) is one of the essential factors which plays a significant role in the functions of soil and ecological services. SOC improves physicochemical properties of soil, particularly infiltration, water-holding capacity, and nutrient mineralization, and boosts microbial and enzymatic activity (Panda and Biswal 2018). Though the soil is primarying for carbon as it sequesters the carbon in the soil biomass, its evolution due to microbial decomposition contributes a considerable amount of carbon dioxide to the atmosphere (Frey et al. 2014). Thus, it has a dynamic role in the biogeochemical cycling of carbon and gains importance in climate change (Mehra et al. 2018). Furthermore, soil health mainly depends on the soil's organic matter content and biological activity, whereas both factors mostly rely on the soil's organic carbon (Turmel et al. 2015). Hence, it is essential to consider soil organic carbon in all the plans and policies related to soil health management.

A lot of research is continuously focused on the elucidation of soil organic carbon pool and its dynamics in soil. However, the role of soil in the mitigation of GHG emissions and climate change is still in the dark, and hence this aspect is lacking in the framework of soil health (Paustian et al. 2019). However, global countries have taken several initiatives toward soil health improvement via national or international frameworks, policy-making, and providing incentives/subsidies. Still, it is a long way to go to achieve progress in soil health, the evaluation of soil organic matter/organic carbon, the assessment of the adoption of technologies for soil health improvement, and the outcome at the field level. Hence, we need to integrate soil health with climate-smart agricultural practices (Roper et al. 2017; Bünemann et al. 2018; Stewart et al. 2018). Moreover, soil health assessment and the climate change perspective may increase its monetary value and gather political attention.

In India, many initiatives such as the National Mission on Sustainable Agriculture (NMSA), Paramparagat Krishi Vikas Yojana (PKVY), Soil Health Card Scheme, National Project on Organic Farming (NPOF), Soil Health Management (SHM) Scheme, etc. have been taken to manage soil health. Furthermore, raising interest toward climate-resilient agriculture and contribution of soil organic carbon for mitigation of climate change attracts the global countries toward soil health management through different initiatives such as the "4p1000" initiative, Recarbonization of Soil (RECSOIL), Global Assessment of SOC sequestration potential (GSOCseq) program, Save Organics in Soil (SOS), etc. These initiatives will ensure sustainable development through productive, climate-resilient, and more economical agriculture. This chapter aims to highlight the potential role of SOC, enhancing SOC sequestration in agriculture; gaps in research and practical policy and various plans and policies for SOC management in agriculture and allied sectors are also comprehensively discussed.

2 Potential Role of Soil Organic Carbon

SOC is one of the vital factors in the global carbon cycle (Nieder et al. 2018). Hence, the status of SOC should be maintained in equilibrium and to be enhanced in the low carbon-containing soil. Soil organic carbon plays a significant role in various ecosystem services, such as maintaining soil fertility, biodiversity, and food security (Bengtsson et al. 2019). SOC can play an influential role in climate change adaptation and mitigation and combat desertification, land degradation, and food insecurity.

2.1 Soil Organic Carbon in Climate Change Adaptation and Mitigation

Even though the changes in temperature and precipitation due to climate change are small, their impact on soil fertility is more pronounced. It affects soil processes and soil properties by changing soil macro- and microclimate. There are agricultural practices to adapt to climate change impacts. Several options such as zero-tillage, crop residue incorporation, fallow lands, diversified crop production, changing the pattern of irrigation and fertilization, and various agronomic practices are available to minimize the adverse impacts of climate change (Jat et al. 2016). In addition, there are different farming practices such as conservative agriculture, restoration of soil nutrients, and soil conservation strategies to enhance soil carbon stocks and encourage soil functional stability (Abbas et al. 2020).

Improving the SOC content is essential to maintain soil quality and mitigate the impacts of climate change. Therefore, monitoring SOC content is crucial for policymaking, and it ensures the improvement of SOC at the farm level to enable incentives (Minasny et al. 2017). Additionally, the adaptations had beneficial impacts on grain and biomass production soil functions. It also enhanced the soil's carbon sequestration potential, filtration, transformation, and recycling capacity. However, the impact of climate change on the biological activity and properties of the soil is not still appropriately elaborated. Therefore, the adaptation decisions in agriculture that could mitigate climate change would be impassible if farmers instigated properly (Aryal et al. 2020). Various physicochemical factors affecting the SOC are mentioned in Table 1.

2.2 Soil Organic Carbon in Combating Land Degradation and Desertification

Due to intensive agriculture and urbanization, more than 70% of forest area in the world has been degraded in terms of SOC depletion. Tropical forests are critical since the area decreased at a 5.5 million ha yearly rate. Globally, one-fourth of land has been degraded, and it is predicted that by 2050, only below 10% of the earth's

Table 1 Biophysicochemical factors affecting SOC and influencing yield

Important factors	Effects of SOC
Biophysical, chemical	
Physical	Clay/carbonate
Parent material	Alkalinity, soil structures, precipitation
Climate	Temperature
Vegetation	Natural vegetation, peat/bogs
Anthropogenic	
Land management	Tillage system, irrigation, cropping system, fertilization
Land exploitation pollution	Sealing, mining, waste disposal, pollutant emission

land will be conserved without any impacts due to human activities (Arneth et al. 2021). The extensive land degradation will severely impact the soil organic carbon, which is mainly formed due to the decomposition of biomaterials. Soil organic carbon is essential and provides the biosphere of the Earth via food production, employment generation, poverty reduction, biodiversity maintenance, and, more importantly, one of the giant sinks for carbon after oceans (Laban et al. 2018). Thus, a slight change in soil organic carbon will affect sustainability, either quantitatively or qualitatively.

A global target is fixed in the Bonn Challenge launched by Germany and IUCN to restore 150 Mha of degraded land by 2020 and 350 Mha of land by 2030. The committee on science and technology formed by the UNCCD has issued a report on realizing the carbon benefits of sustainable land management practices. This report provides guidelines for estimating soil organic carbon in the context of "land degradation neutrality planning and monitoring" in COP 14 of UNCCD held in New Delhi. The report highlights the crucial role of SOC in the prevention of land degradation and desertification. Land Degradation Neutrality (LDN) is the optimum quantity and quality of land resources required for the ecosystem's practical functions and services and improved food security (Cowie et al. 2018). It should be remained unchanged or increased both temporally and spatially. It epitomizes the pattern of that change in the policies and practices of land management. It is an exceptional strategy to offer the expected land degradation and the restoration of degraded lands. It deliberately deals with land-use planning in conservation, sustainable management, and restoration of lands. Soil organic carbon was taken as one of the indicators of LDN. Generally, the LDN has been indicated by land cover changes and land productivity dynamics (net primary productivity). SOC is the basic indicator of soil health, and it also has multiple roles in land management. It is also related to missions of Rio conventions which mainly played a critical factor in selecting appropriate management options for land in a sustainable way to achieve LDN (Akhtar et al. 2017). Management of SOC is essential for enhancing the quality of soil and yield of crops and decreasing soil loss. Sequestering carbon improvements improve soil health and crop productivity, steadily maintain carbon cycling, and positively affect agriculture production (Ramesh et al. 2019). Due to the variety of roles and functions of SOC and its essentiality in land management, SOC has been considering one of the three indicators of Land Degradation Neutrality (LDN). Hence, predicting and monitoring the chain that occurs in SOC are crucial for achieving LDN targets.

2.3 Soil Organic Carbon and Global Food Security

SOC plays a significant role in enhancing food security for the global population. More than 3/4 of the world's population faces insufficient nutrient supply, which leads to malnutrition or hidden hunger. However, problems associated with soil, such as erosion, salinity, acidity, depletion of SOC, etc., are the major threats to food security. Among all the factors, soil organic carbon has special attention regarding food security. Improving the SOC content in soils of temperate and tropical regions is challenging. External application of carbon-containing inputs such as compost, manure, biochar, etc. is also considered the management strategy for SOC enhancement (Tiefenbacher et al. 2021). On-farm management methods such as incorporating crop residues, stubble retention, less or zero-tillage, and rotation of crops are the possible options for enhancing short-term SOC. Protecting, stabilizing, and building up the existing C stocks in soils through a balanced nutrient application, conservative agriculture, etc. improves nutrient use efficiency and increases productivity.

The National Policy on Crop Residue Management effectively converts biomass into SOC, improving agriculture and food systems inputs. The improved SOC will contribute to enhancing the food security of different crops. However, it is estimated that 116 Gt of soil organic carbon has been lost from the time when agriculture began. There are a few crucial problems associated with soil properties and ecosystem services due to the depletion of SOC. Generally, low SOC soil is described by its low content of nutrients, high rate of soil erosion and compaction, etc.

Furthermore, it contains common soil microbes, low water infiltration, retention capacities, etc. These soils can be restored through recarbonization practices such as adding organic inputs, reducing SOC loss by no-tillage, etc. These management practices will enhance food security through more fertile soils and climate-resilient agricultural practices (Rao et al. 2016). Many research proved that the enhancement of SOC would increase yield and agricultural productivity. Improvement in food products due to an increase in SOC stocks would be a prime advantage for small farmers. In addition, it may serve as a tool to overcome the hesitancy of farmers to change their regular farming practices.

3 Enhancing Soil Organic Carbon Sequestration in Agriculture

SOC-oriented farming system, adaptation of zero-tillage practices, organic farming, appropriate manure management, zero-budget natural farming, agroforestry, and soil erosion control practices are good options for SOC sequestration and promote soil fertility by promoting soil fertility, increasing the amount of soil organic matter in the soil. Many options for enhancing SOC sequestration in agriculture are shown in Fig. 1.

3.1 Carbon Farming

Carbon farming aims to increase carbon sequestration in soil and plants and create a net carbon loss from the atmosphere. Some practices, such as reduced tillage, longer-rooted crops, and organic matter, encourage the captured carbon to remain in the soil and become carbon neutral (Marks 2019). In addition, improving yield and soil management can reverse net CO_2 emissions into the atmosphere. Indeed, increasing

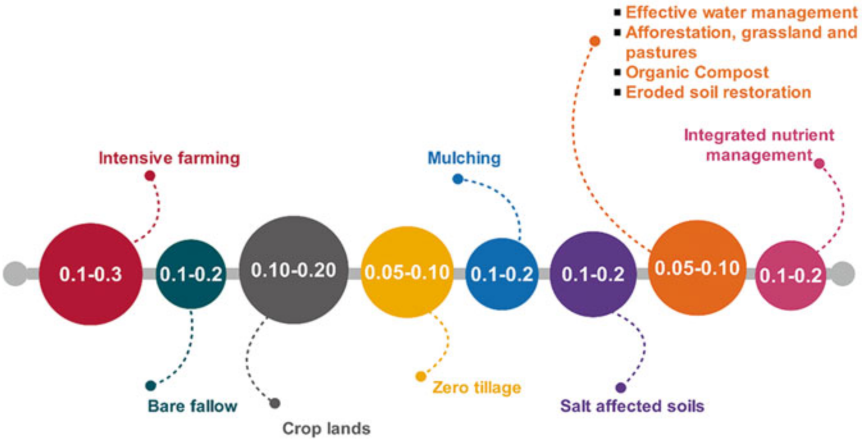

Fig. 1 SOC sequestration potential of various technological options (tons C/ha/year) (Data source: Lal et al. 2018; NAAS 2021)

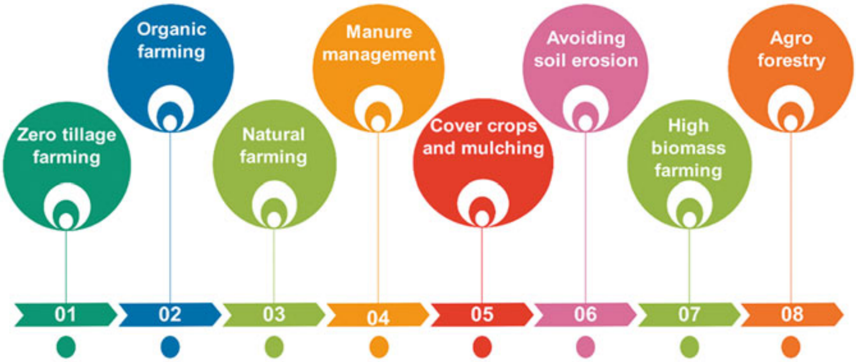

Fig. 2 Options for enhancing SOC sequestration in agriculture

the soil's capacity to absorb and store significant quantities of atmospheric carbon in a stable form provides a realistic and immediate answer to some of humanity's most severe issues, i.e., global warming and climate change. Many options for enhancing SOC sequestration in agriculture are shown in Fig. 2.

Natural ecosystems are depleted in conversion to agroecosystems due to reduced biomass C return, increased losses of SOC due to erosion and leaching, and significant variations in temperature and moisture regime. Carbon accumulated in the soil is 2–4 times that of the atmosphere and 4 times that of plants (Hussain et al. 2021). The organic carbon stock of various physiographic regions of India is mentioned in Table 2.

Table 2 Soil OC stock – physiographic region of India

S. no	Physiographic regions	Organic carbon	Pollutant	Medium	Vegetation
			0–30 cm	0–150 cm	
1.	Northern Mountains	0.40–2.75	7.89	18.31	Dry temperature, coniferous forest, moist temperature
2.	The Great Plains	0.40–2.8	3.28	10.53	Tropical mixed deciduous forest
3.	Peninsular plateau	0.3–3.40	3.62	10.11	Tropical dry deciduous thorn forest
4.	Peninsular India	0.04–2.31	3.64	13.34	Mixed deciduous thorn forest
5.	Plains of the islands and coastal plains	0.28–1.70	2.24	10.90	Littoral and swamps

Source: Modified from Bhattacharyya et al. (2000), Mandal and Sharda (2011)

Table 3 Land and soil management practices and their effect on SOC

Practice	Effect of SOC	Positive environmental effects	Carbon stock (Mg C ha^{-1} year^{-1})	References
No-tillage	Reduced carbon level	Erosion control reduced fuel consumption	0.07–0.33	Robertson et al. (2000), Arrouays et al. (2002)
Addition of organic amendment (compost, manure)	Increase carbon input	Increase soil respiration	0.05–0.15	Arrouays et al. (2002)
Use of cover crops	Reduced/ increased carbon loss	Increase soil respiration	0.15–0.25	Arrouays et al. (2002)
Crop rotation	Increase on inputs	Increased soil respiration	0.05–0.25	Lal (2004)

Source: Modified from Komatsuzaki and Ohta (2007)

The technical potential of C sequestration in cropland soil is 0.4–1.2 Pg C (Lal 2015). However, land-use changes such as agricultural output have resulted in considerable soil carbon (C) losses. Therefore, constantly increasing the C stock of farming soils is suggested to counterbalance or decrease the warming impact of C emissions (Luo et al. 2010). Various soil and land management practices that impact SOC are mentioned in Table 3.

Techniques include zero-tillage farming, organic farming, natural farming, manure management, cover crops, mulching, soil erosion, high biomass farming, and agroforestry systems (Mattila et al. 2022). Ecosystem-based options for carbon sequestration in India are mentioned in Table 4.

Table 4 Ecosystem-based options for carbon sequestration in India

Agroecosystem	Cropping management				Land and water management	
Himalayan	Agroforestry	Land covers/mulching	Agri-horticultural system	Perennial crops	Contouring	–
North-Eastern Hill regions	Arial seeding	Relay cropping system	–	–	Zoom land rehabilitation/riverbank stabilization	Contouring
Indo-Gangetic Plains	Zero-tillage	Utilization of crop residue	Agri-horticultural system	–	Salt-affected soil reclamation	Minimized soil-based brick industry
Eastern	Integrated farming system	Organic farming	Site-specific nutrient management	Crop diversification	Reclamation of deteriorated lands	–
Central	Sustainable intensification	Organic farming	Intercropping	Crop diversification with legumes	Reducing water erosion	–
Rainfed	Agroforestry	Organic manuring	Rainfed horticulture and intercrops	Cover crops/live mulching	Pond and tank restoration and desilting	–
Arid	Integrated farming system	Agroforestry	Water management by farm ponds	Crop diversification with legumes	Dune stabilization	–
Island	Integrated farming system	Organic manures	Composting local organics		Contouring	Seabank stabilization

Source: Modified from NAAS (2021)

3.2 Organic Farming

Organic farming is thought to promote soil fertility by increasing the amount of soil organic matter (SOM) in the soil. As a result, the sequestration of carbon dioxide from the atmosphere would significantly benefit agriculture and the allied system. According to the study's findings, soil carbon content (SOC) grew by 2.2% each year after practicing organic farming systems (Leifeld et al. 2013). The organic farming system enhances soil C growth compared to traditional agriculture (Gattinger et al. 2012). Soils under this system had higher C stocks than soils under conventional farming. In addition, they found that organic farming got more external (manure, slurry, compost) C inputs (1.20 Mg C ha^{-1} per year) than CF (0.29 Mg C ha^{-1} per year). High and frequent external organic inputs have been linked to higher soil C concentrations in the organic farming system (Leifeld et al. 2013).

Many studies have examined the environmental benefits of organic farming, including improved soil quality, decreased nutrient production, and lower energy consumption (Pimentel and Burgess 2014). However, the findings vary by farm activities (Sharma et al. 2021). For example, organic farming emits more ammonia, nitrogen, and N_2O per unit product than conventional farming (Clark and Tilman 2017). In addition, organic farming conducted using dairy and pig farm manure had typically higher GHG per unit area than traditional farming (Cederberg et al. 2013). However, it improves the soil carbon from the external organic outputs and has a lower carbon footprint than conventional farming (Adewale et al. 2018).

3.3 Natural Farming

Natural farming has been advocated as a more eco-friendly and zero-budget system in India, since it has four major components, i.e., *jeevamrutham*, *beejamrutham*, *acchadana* (mulching), and *whapasa* (soil aeration), which has been claimed to boost microbial activity, increase soil carbon, provide nitrogen through green mulching, and increase the availability of existing topsoil nitrogen (Smith et al. 2020). Comparative life cycle analysis (LCA) indicated that zero-budget natural farming ZBNF systems consume 50–60% less water and 45–70% less energy and produce 55–85% fewer greenhouse gases (Rose et al. 2021). However, it should be highlighted that the LCA sample size was small and did not consider soil carbon sequestration. Hence, ZBNF had a research gap on carbon sequestration; more scientific studies need to be done for policy options.

Permaculture is a natural farming technique, a modified Masanobu Fukuoka natural farming (Fukuoka 1985; Krebs and Bach 2018). Organic manuring is an essential principle in permaculture, but unfortunately, farm cattle and animals are believed to emit more GHG than tractors. Contrasting the above view, some findings show that cattle plowing uses less energy than tractors (Spugnoli and Dainelli 2013; Krebs and Bach 2018). The excessive use of animal manure causes environmental issues such as eutrophication of groundwater and freshwater, heavy metal deposition in soil, ammonia emissions, and greenhouse gas emissions (Jongbloed and Lenis 1998; Bolan et al. 2010). Recent research shows that soil organic matter and carbon storage are improved by organic manure (Bolan et al. 2010; Maillard and Angers 2014). Hence, permaculture with less organic inputs is a good option for soil carbon sequestration.

3.4 Manure Management

Appropriate manure management is an important option to improve the carbon sequestration in the soil. Several long-term European trials have proven that organic manures sequester more SOC than chemical fertilizers (Smith et al. 1997; Powlson et al. 2013). Long-term usage of manure increased the SOC pool at the 0–30 cm depth by 10% in Denmark, 22% in Germany (90 years), 100% in Rothamsted, UK (over 144 years) (Jenkinson 1990), and 44% in Sweden (more than 31 decades) (Powlson et al. 2013). The yearly growth in manure nitrogen production leaped from 21.4 Tg N year in 1860 to 131.0 Tg N year in 2014 (Zhang et al. 2017). Cattle produced 44% of total manure nitrogen output in 2014, followed by goats, sheep, swine, and chickens. Application of manure nitrogen to farmland amounts to less than one-fifth of total production (Gross and Glaser 2021).

Organic manure degrades quickly as it is rich in nitrogen content and has a low C:N ratio. Hence, manure may also enhance soil carbon levels due to its high carbon concentration. Many research examined the influence of manure application on SOC stocks; few studies reported increases in carbon, while others found relatively minor or negative impacts on SOC stocks (Gross and Glaser 2021). Due to manure application, studies are needed to understand parameters that govern the degree of change in SOC stocks. According to the recent findings by Gross and Glaser (2021), the increasing impact of manure on carbon is complex and variable. Soil texture, SOC content, and tillage intensity should also be considered to increase carbon content. More long-term SOC field data must be studied to understand carbon dynamics better, and new comprehensive approaches in carbon dynamics assessment methodologies are also needed.

3.5 Cover Crops and Mulching

Growing cover crops and mulching practices have advantages over other management methods that enhance soil organic carbon (SOC) and crop yields. Around the world, farmers, scientists, and policymakers are interested in the potential contribution of cover crops to soil carbon sequestration (Lal 2015). Though research on the regional, national, and international impacts of cover crops on carbon sequestration is widely made (Franzluebbers 2010; Poeplau and Don 2015; Ruis and Blanco-Canqui 2017), the policy-making and implementation for cover crops and mulching is lacking (Tellin and Myers 2018). The influence of cover crop green manuring on SOC stocks, on the other hand, is often underestimated. SOC stock changes occur due to an imbalance between carbon inputs, mainly in dead plant material or manure, and outputs, primarily due to decomposition, leaching, and erosion (Poeplau and Don 2015). In addition, global food consumption increases due to the growing worldwide population and rising affluence in emerging nations, limiting the amount of farmland converted to natural vegetation or grassland (Tilman et al. 2011). As a result, effective strategies such as cover crops and mulching for raising SOC stocks while maintaining high agricultural output are essential.

3.6 Avoiding Soil Erosion

Agricultural soils are prone to erosion due to removing most vegetation by conventional tillage. Erosion is a selective process that preferentially removes the light organic fraction (1.8 Mg/m^3) (Malhi et al. 1994). As a result, the SOC pool is impacted (Lal 2019). Total C moved by erosion is estimated to be 4.0–6.0 Pg/year, assuming a 10% delivery ratio and a 2–3% SOC content (Du et al. 2019). Traditional tillage methods, such as deep plowing, harm agricultural soils and contribute to global land degradation (Bai et al. 2008). According to the World Resources Institute, 60–90 Pg of soil organic carbon (SOC) was lost worldwide in the preceding decades due to excessive and continuous tillage methods.

Furthermore, since 1750, misusing agricultural technology has led to a 66–90 Pg C loss in soil carbon stores, while deforestation has contributed to a 22% loss (Lal 1999). As a result, conserving natural resources and ensuring food security while reducing environmental impact are critical to alleviating the issues associated with land degradation. In addition, the degradation of biomass and soil C stock has been a significant source of CO_2 emissions (Hussain et al. 2021). Hence, ecologically appropriate strategies may reduce C emissions and sequester them in soil and biota.

3.7 High Biomass Farming

The idea of carbon sinks, credits, and trading boomed the interest in herbaceous bunch-type grasses and woody perennials which can be used as energy crops and feedstock for biofuels. Biomass and biofuel crops generate vast quantities of biomass, have great energy potential, and grow on all types of soils. C sequestration rates range from 0.6 to 3.0 Mg C ha^{-1} $year^{-1}$ for bioenergy crops grown in deteriorated soils and 1631 Tg per year globally from 757 M ha of land. It has a vast carbon offsetting potential, 1 kg through biomass and 0.6 kg through fossil fuel reduction. Plants like *Panicum virgatum* L., *Pennisetum purpureum* Schum., *Populus Salix*, and *Prosopis* are among the most crucial short-rotation woody perennials used for biomass farming (Lemus and Lal 2005). Carbon sinks alone cannot reduce GHG emissions; a significant decrease in fossil fuel usage is required. This is an essential part of a prospective society's reaction to a GHG emission reduction strategy.

3.8 Agroforestry

Agroforestry includes many carbon-trapping practices like agrisilviculture systems that can help mitigate climate change. However, soil type determines the efficacy of soil C sequestration in the agroforestry system. Crop leftovers and tree litter restore vast amounts of organic C to the soil in sustainable agroforestry systems. Those inputs may help stabilize soil organic matter (SOM), slow biomass degradation, and improve SOC stocks (Oelbermann et al. 2004; De Stefano and Jacobson 2018). The meta-analysis notably shows that agroforestry systems and shelterbelts are effective strategies to raise SOC stocks in top- and subsoils, especially in subtropical climates (Hübner et al. 2021). From another meta-analysis study, SOC stocks decreased by 26% and 24% when land use changed from forest to agroforestry at 0–15 and 0–30 cm, respectively. Changing from agriculture to agroforestry increased SOC stock by 26, 40, and 34% at 0–15, 15–30, and 100 cm. Agroforestry boosted SOC by 25% at 0–30 cm but decreased 23% at 0–60 cm (De Stefano and Jacobson 2018). If the land use evolved from simpler systems like agriculture to agroforestry, SOC stocks would rise. Hence, agroforestry is an effective technique to sequester the soil's organic carbon.

4 Gaps in Research for an Effective Policy

According to Pathak et al. (2014), many research gaps need to address and promote:

1. Agricultural residue management practices and business models that minimize residue burning and improve SOC.
2. Local organic resources for SOC enhancement identification and inventorying.
3. Determination of long-term trials with crop-fodder-grassland-agroforestry systems in various agroclimatic regions.
4. Creating a national SOC monitoring network with multi-ministerial R & D institutes.
5. Quick, cost-effective, and practical monitoring of GHG emissions and SOC changes in various ecosystems.
6. Developing regional GHG emission-mitigation and SOC simulation models using remote sensing and GIS tools.
7. Developing low C and N technologies and evaluating their GHG reduction potential.
8. Developing methods for reducing cattle GHG emissions via improved feeding and waste management (Pathak et al. 2014; NAAS 2021).

Pathak et al. (2014) also indicated important points in policy-making that need to address:

1. Linking fertilizer, water, and other agri-input subsidies to GHG reduction and establishing the notion of "green budgeting" at the state-federal levels.

2. Adopting adaptation technology with mitigation advantages in national and state climate action programs.
3. Encourage farmer and community-based holistic land management.
4. Developing novel payment for ecosystem services and mitigation assistance for smallholder farmers.
5. Ensuring soil quality, regulating climate, and conserving biodiversity are SOC-based policies and initiatives.
6. Focus on combining multi-ministerial projects like NAPCC and SAPCC.
7. Subsidize the development of excellent organic fertilizer (low-volume, high nutritional products) with chemical fertilizers.
8. Motivate private (corporate/industry) farmers to engage in regenerative farming methods for SOC improvement and awareness and capacity development on management practices in GHG reduction and carbon sequestration.

5 Policy Options in Soil Carbon Management

Policies can help to define the goals and provide guidance about how to achieve the objectives of soil carbon management through various options. For example, according to the World Bank, 2012 farmers need to be encouraged to increase carbon sequestration. Policies and measures that promote sequestration of carbon include, as shown in Fig. 3, (i) boosting the adoption and investment more in climate-smart agriculture, (ii) multinational global cooperation agreements, (iii) incentives and payment of ecosystem services, (iv) motivating public-private participation in carbon management, (v) long-term policy building based on scientific evidence, and (vi) emission reduction, mitigation, and adaptation planning.

Boosting the adoption and investing more in climate-smart agriculture is very important in the current scenario. Climate-smart agriculture (CSA) is climate-friendly agriculture that includes practices that enhance SOC sequestration, reduce GHG emissions, improve crop yields and nutrient use efficiencies, and promote climate resilience. It helps to strengthen capacities to implement a climate-friendly agricultural policy (Magaudda et al. 2020). National policies, strategies, and investment plans should be changed to recent developments and trends in carbon policy and management. It is possible that better guidance and training for farmers on land management may result in more carbon sequestration and more environmentally friendly agricultural policy-making (Kløve et al. 2017).

A multinational global cooperation agreement is crucial for policies and measures that promote carbon sequestration. The IPCC encourages carbon sequestration through international global cooperation agreements, where food security and climate change adaptation and mitigation are significant concerns. Agricultural adaptation and mitigation must be adequate for long-term policy-making about carbon sequestration. This will lead to a greater understanding of the role of agriculture in ongoing global climate talks.

Incentives and payment of ecosystem services must be part of policies that promote carbon sequestration. The worldwide government and institutions need to

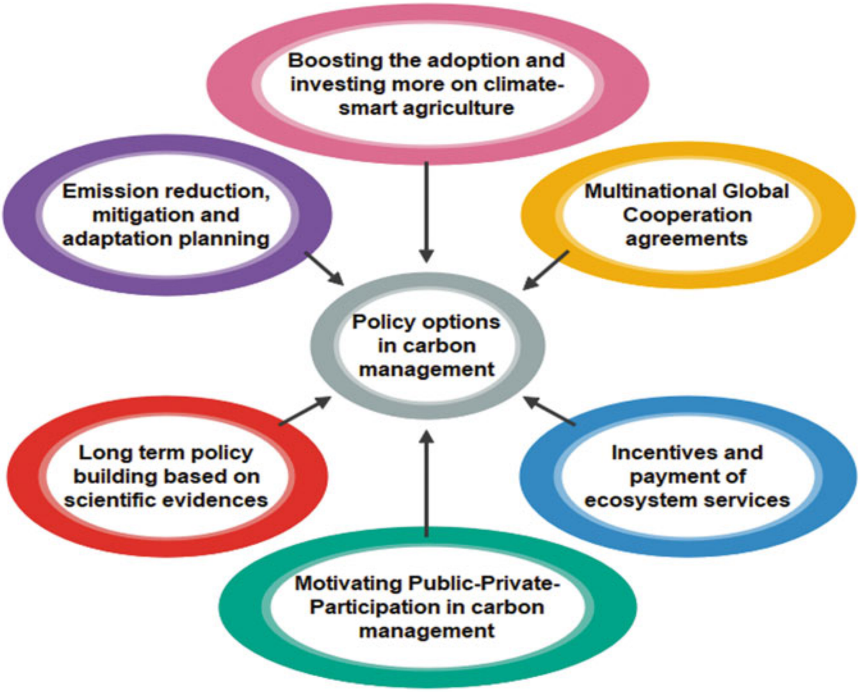

Fig. 3 Policies and measures that promote sequestration of carbon

increase funds and develop the financing mechanism for farmers who act early to mitigate carbon and adopt carbon management practices (Stringer et al. 2012). Better agricultural practices will require public, private, and corpus funds. Combining climate finance with food security is one of the most promising ways to fund climate-smart agriculture. Payments for ecosystem services (PES) might help farmers embrace conservation agriculture, natural farming, and chemical-free organic farming, requiring specialized equipment and significant upfront investments (Devi et al. 2017; Kumar et al. 2019). In addition, PES for early-stage agroforestry producers may profit from carbon financing (Idol et al. 2011).

Motivating public-private participation in carbon management is very important given changing climate scenarios. Its adaptation can help to avoid many climate change-related future problems (IPCC 2014). This platform can include developing social and ecological infrastructure, policies, process technology, and resource management in planning carbon management through agriculture (Lebel et al. 2007). Currently, government commitment and financial investment are the only carbon management source. So, the private sector’s commitment to climate-friendly agriculture is critical to sound policy-making. A public subsidy may entice private investment in R & D, tree planting, and seed and seedling production. Incentives from commercial and financial service providers should encourage farmers to employ sustainable land management to overcome the constraints above. Public policy and public-private partnerships may stimulate private investments such as agriculture finance and insurance bundling and alternative risk management like index-based weather insurance or weather derivatives.

Long-term strong policy building based on scientific evidence can play a significant role in carbon management and climate change mitigation plan from a long-term perspective (Moss et al. 2010). Greenhouse gas emission reduction and adaptation of mitigation strategies must be effectively supported by institutions, governance, innovation, and investments in environmentally friendly technology, infrastructure, and sustainable livelihoods. Innovative infrastructure and technologies and assets in low-carbon and carbon-neutral energy technology, which are environmentally friendly, may help decrease greenhouse gas (GHG) emissions and increase climate change resilience (IPCC 2014).

6 International Plans and Policies Frameworks for Soil Organic Carbon Management

The United Nations Framework Convention on Climate Change (UNFCCC) came into effect on 21 March 1994. The convention aims to prevent harmful human meddling in the climate system (Gao et al. 2017). The Convention on Biological Diversity (CBD) also plays a vital role in biodiversity conservation, particularly active soil biodiversity that drives the dynamic equilibrium of SOC under unchanged land use. Midgley et al. (2010) demonstrated that high C levels corresponded to a high biodiversity system in tropical latitudes. Organic matter decomposition, nutrient cycling, soil structure development, and climate regulation are essential activities and services performed by the soil biota (Dominati et al. 2010; Pulleman et al. 2012).

The United Nations Convention to Combat Desertification (UNCCD) plays a vital role in sustainable land management (Kutter 2015). Globally, arid, semiarid, and dryland areas are prone to loss of organic C due to severe erosion. Consequently, SOC content in drylands (usually smaller than 1%) is recognized as a parameter reflecting degradation and desertification trends. However, despite the importance of SOC in monitoring and assessing desertification, current policy analyses have paid little attention to this measure. Incorporating SOC as a meaningful indicator into the UNCCD's regular reporting system will undoubtedly increase soils' prominence in the convention's negotiation process and synergize with the CBD and UNFCCC (Lorenz et al. 2019). The potential for such synergies has already been well recognized within the Millennium Ecosystem Assessment (2005). In addition, the UNCCD is working on preventing desertification/land degradation and mitigating the effects of such losses toward achieving environmental sustainability and tackling land degradation (Ma and Zhao 1994; Prăvălie 2021).

The FAO's Global Soil Partnership (GSP) was created in 2012 to promote sustainable soil management (SSM) and improve soil governance to ensure healthy and productive soils. Besides these supporting and provisioning ecosystem services for food security and improved nutrition, climate change adaptation and mitigation and long-term development must be addressed (Rodríguez Eugenio 2021). GSP has five pillars which are directly or indirectly associated with SOC management and combat climate and sustainability:

1. Promote protection, conservation, and management of long-term soil productivity.
2. Promote soil education, extension, and policy.
3. Promote soil research and identify gaps, priorities, and synergies with environmental and social initiatives.
4. Furthermore increase the availability of information and data quality on the soil by collecting, validating, monitoring, and integrating with other disciplines.
5. Harmonization of methods, measurements, and indicators for the sustainable management and protection of soil resources.

SOC is a cross-cutting issue entering many different EU policy frameworks. The EU promotes practices that favor maintaining or even increasing SOM levels (Sočo and Kalembkiewicz 2009). However, in many regions of the EU, the soil is irreversibly eroded or has a low organic matter content. The EU's agriculture, energy, transportation, and cohesion policy changes provide the opportunity to build the framework and the necessary incentives to achieve this goal. In addition, EU policies consider their direct and indirect effects on land use targeted to reach no net land taken by 2050. That would help reduce soil erosion and enhance soil organic matter buildup (Montanarella and Panagos 2021).

The IPCC provides scientific assessments on climate change, its implications, and potential future risks and adopts adaptation and mitigation options (Junk et al. 2013). According to the IPCC, markets will effectively stimulate carbon sequestration only if the monetary worth of carbon stocks and sinks is recognized and paid. Some developing countries see the need for carbon offsets to facilitate cash inflows to finance conservation and other efforts (McAfee 2016). The tradable emissions permit is a new instrument that has the potential to have a significant impact on carbon sequestration (Kauppi and Sedjo 2018).

Companies with surplus emissions permits can sell them to companies that need more. As a result, total emissions are no longer accessible but come at a cost to the company. Therefore, firms with surplus permits can either sell them or sacrifice the potential to get paid – this is known as an opportunity cost. As a result of this method, the market can reallocate emission permits, hence emissions, to the users who get the best return on the licenses, allocating carbon emissions permits to the most efficient users (Bayer and Aklin 2020).

Under the Kyoto Protocol, the CDM is a project-based GHG offset method. The scheme intends to help Annex-I nations (those with binding emission reduction objectives) lower global GHG emissions more cost-effectively by letting them invest in offset projects in non-Annex I countries (low- and middle-income countries without binding targets). The CDM, as the world's most important regulatory project-based mechanism, allows high-income countries' public and private sectors to buy carbon credits from low- and middle-income countries' offset projects (Ba et al. 2018).

The CDM enables nations to satisfy a portion of their Kyoto obligations by funding carbon emission reduction projects in low- and middle-income countries. Because lower-income countries have lower energy efficiencies, cheaper labor costs, weaker regulatory requirements, and less advanced technologies, such projects are arguably more cost-effective than projects executed in higher-income countries (Steel and Harris 2020). The CDM is also intended to benefit the host country's long-term development. CDM projects provide emissions credits known as certified emission reductions (CERs), which can be purchased and exchanged (Boyd et al. 2009). Visit the Paris Agreement website for more international carbon trading under the current climate policy system.

The Clean Development Mechanism (CDM), as specified in Article 12 of the Protocol, allows a nation with a Kyoto Protocol (Annex B Party) emission-reduction or emission-limitation commitment to implement an emission-reduction project in developing countries. These projects can yield saleable certified emission reduction (CER) credits, one ton of CO_2 equivalent. Many consider the mechanism to be a game-changer. It is the world's first worldwide environmental investment and credit system, offering CERs, a standardized emissions offset mechanism. A CDM project activity could include, for example, a solar panel-powered rural electrification project or the construction of more energy-efficient boilers. The method promotes sustainable development and emissions reductions while allowing industrialized countries considerable flexibility in meeting their emission reduction or limitation commitments.

7 India Plans and Policies Frameworks for Soil Organic Carbon Management in Agriculture

In India, various plans and policy frameworks have been initiated to manage SOC in agriculture and climate change-related issues (Liu et al. 2016). The National Mission for Sustainable Agriculture (NAPCC) India intends to help agriculture adapt to climate change by developing climate-resilient crops, expanding weather insurance mechanisms, changing agricultural practices, and emphasizing waste management and recycling to use it as an organic carbon source. Many policies and legal framework plans for soil organic carbon conservation, land planning, and other regulatory measures that efficiently comply with soil and organic carbon improvement at the national level have been initiated.

In order to meet India's commitments under the UNFCCC and Paris Climate Change Agreement in 2015, various ICAR institutes and universities are involved in estimating and monitoring the soil organic carbon stocks in widespread diverse landscapes. India is also involved in bringing different plans and policies, including the National Mission on Sustainable Agriculture (NMSA), National Project on Organic Farming (NPOF), National Adaptation Fund for Climate Change (NAFCC), National Action Plan on Climate Change (NAPCC), etc., for the concern toward carbon sequestration through soil management practices. In addition, many multi-ministerial policies encourage the farmers to implement SOC-based sustainable procedures and enhance the farm managing ability toward climate regulation (Smith et al. 2008; Fulton and Benjamin 2011).

The Government of India emphasizes the thrust on adopting climate-smart agriculture, especially on conservation agriculture principles. Nowadays, this is popularizing among the farmers as an act to coincide with extreme weather events. Adaptation, mitigation, and productivity are the pillars of climate-smart agriculture. Crop diversification, residue retention, water management, nutrient management, zero-tillage, and information and communication tools (ICTS) are considered management practices under climate-smart agriculture to achieve greater sustainability. Climate-smart agriculture-based practices are all done because the soil will be the potential sequester and sink of atmospheric carbon dioxide in the form of soil organic carbon (Pathak et al. 2014). Studies found that this conservation agriculture sequester nearly 24–40 MT of carbon per year. Therefore, the total soil quality would also improve. Some techniques like zero-tillage direct-seeded rice (DSR) and alternate cropping increased SOC stocks. The negative impacts could be decreased by improving these agricultural practices, especially the soil's biological activities and soil properties (Bhattacharyya et al. 2015). Soil quality can be studied by the disobedience and liability indices which provide information about the stable carbon in the soil. Climate-smart agriculture practices were found to elevate the overall sustainability of the earth.

According to the National Bureau of Soil Survey and Land Use Planning (NBSS and LUP), soil in India has 20–25 Gt of organic carbon. The primary cause of soil organic carbon declining pool is accelerated soil erosion (Gama-Rodrigues 2011). The recurrent droughts also result in a decline in biomass production and a decrease in the organic carbon content in the soil, leading to land degradation, especially in the northwestern region of India. It was also found that the carbon sink capacity has been reduced (Jat et al. 2019). The practice of conservation tillage, majorly in western Indian regions, enhances the development of soil organic carbon. However, various features in the Indian conditions may not apply these strategies in all areas. In order to elevate the sequestration of carbon, submission on agroforestry systems under the National Mission on Sustainable Agriculture (NMSA) emphasized enlarging the tree cover area, thus enriching the soil organic carbon. This enhances the proper risk management toward climate resilience (van Wesemael et al. 2011). Presently, this mission is being implemented in 20 states and 2 union territories.

The National Policy on crop Residue Management is working to elevate SOC by making crop residues available and converting biomass into a source of SOC to enhance crop growth, ultimately resulting in enhanced carbon sequestration (Monfreda et al. 2008). Other management under in situ strategies like zero-tillage, nitrogen-fixing legumes, and crop rotation helps increase existing carbon stocks in the soil. The national program of sequestering carbon was recently initiated, including:

1. National Mission for Green India: As forests sequester billion tons of carbon as soil organic carbon stock and biomass and thus act as effective carbon sinks, thereby enhancing the ecosystem services.
2. National Mission for Sustainable Agriculture: The Indian Ministry of Agriculture has channelized the need-based knowledge to boost productivity in farm practices. This paved the way for land-use planning and regional soil and water databases. It also allowed the biotechnological approaches of sequestering carbon, drought resilience, and increased crop productivity.

The application of farmyard manure and organic manure usage potentially enhances the SOC (Lal 2019). Significant policies and technological options such as agriculture intensification, mulch farming, and composting lead to increased organic carbon stocks in soil (van Wesemael et al. 2011). According to COP 21–22 report, agroecology, agroforestry, conservation agriculture practices, and landscape management can play an essential role in achieving India's SOC management and carbon sequestration goal. The Soil Health Card program provides information to farmers about soil nutrient status and recommends dosages of nutrients. The Paramparagat Krishi Vikas Yojana is a centrally sponsored scheme in the NEH region to facilitate organic farming produce, which enhances SOC and increases soil sustainability (Aayog 2020). Agriculture-related policies are directed toward reducing net GHG emissions. Carbon sequestration strategies need multidimensional research and policies to inspire carbon sequestration (Soussana et al. 2019). Area-specific priorities need to be comprised of various state and central government programs, and the technology implementation is vital to public contribution. A country like India with a tropical agroecosystem should make scientific efforts to understand the dynamics of SOC both spatially and temporally (Deffner et al. 2020).

For the quick, inexpensive, and authentic monitoring of the changes in the status of SOC in diverse ecosystems, we may require scientific interventions:

1. Monitoring SOC at the national level.
2. Measuring the interaction of SOC and productivity of agriculture.
3. Identification of resources, which can be effectively utilized for SOC improvement.
4. Promotion of crop residue management, with zero burning of residues.
5. Through long-term experiments on SOC in various agroecosystems, crop diversification, and cropping systems.
6. Development of SOC-based programs and policies for sustainable soil quality and regulation of climate change.
7. Linking of multi-department programs toward sustainable SOC enhancement.
8. Promotion of holistic land management approaches with farmer/community participation.
9. Providing incentives to farmers for the ecosystem services, particularly SOC management practices.
10. Encouraging the production of quality organic manure with appropriate subsidy support instead of chemical fertilizers.

11. Promoting corporate-farmer partnership with particular attention to SOC improvement with incentives.
12. Conducting SOC management awareness programs on a large scale against burning crop residues.
13. Strengthening existing programs at the state and national level by incorporating SOC improvement interventions
14. Establishing the national mission on carbon sequestration at the farmer's level and scientists' levels
15. Promoting legume-based cover crops to improve land cover, soil carbon, nitrogen, etc.

8 Future Scope and Perspectives

Soil is a dynamic system that provides several ecosystem services like water quality, crop productivity, biogeochemical cycles, and climate change impacts. Soil health is connected with sustainable agricultural practices since soil biota and its activity are the crucial components of soil health. Soil organic carbon (SOC) administers the inherent productivity of soils. It controls climate change and ecosystem services that are significant for a sustainable enhancement of crop productivity and supply of food. India has enormous potential for carbon sequestration in sustainable agriculture and productivity. However, inappropriate practices or management leads to the acceleration of greenhouse gas emissions into the atmosphere, affecting climate change. Intensive agriculture and improper management of natural resources affect soil health and food quality and worsen other environmental issues. In several states (e.g., Punjab Haryana, Uttar Pradesh, Madhya Pradesh, West Bengal, Tamil Nadu), SOC has declined ~0.2–0.4%. So, it is time to focus on restoring the SOC pool through appropriate land-use and farming practices, soil conservation, sustainable food production, and environmental security. The government has taken a few initiatives to enhance C sequestration by launching different schemes in agriculture and various other allied sectors. But on practical aspects, much more attention and motivation from the farmers are still required to successfully implement these plans and policies to fulfill the required target of soil C restoration.

9 Conclusion

Soil organic carbon management primarily focused on meeting India's particular food grain production objectives in the agricultural research and development paradigm. Policy options in soil organic management provide a new paradigm for food security, agricultural research, and development. The need for a paradigm change has become imperative in light of the pervasive issues of resource degradation that have followed earlier attempts to increase output while paying little attention to the integrity of natural resources. In order to achieve continuous productivity increase, it is necessary to integrate concerns about productivity, resource conservation, soil quality, and environmental considerations. Scientists will need a much-increased ability to approach challenges to formulate long-term plans and policies, collaborate closely with farmers and other stakeholders, and significantly improve knowledge and information-sharing processes. Considering the importance of SOC, focused practical plans and policies in agriculture will eventually make the country more secure against climate change and soil sickness. It will also support the aims of Sustainable Development Goals for a better country and the planet in general.

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