

Farmer's Perception towards Mitigating Climate Change through Adoption of Soil Carbon Sequestration Practices– A Review Analysis

ABSTRACT

Climate change is one of the most severe global environmental issues. Carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases (F) are the principal greenhouse gases (GHGs) whose atmospheric concentrations are escalating. According to [1], agricultural soils have the ability to mitigate GHG emissions by 89% through the sequestration of carbon and an additional 2% and 9% through the mitigation of N₂O and CH₄, respectively. The process of capturing and long-term stabilisation of CO₂ in the soil is known as soil carbon sequestration. Increased food production, better soil health, diversified ecosystem services, and reduced environmental footprints are all the benefits of practices increasing soil organic carbon (SOC). These techniques include planting woods, managing nutrients by using compost, sludge and green manure, and mulching [2]. Additionally, they have the ability to reduce GHG emissions by up to 8% by mitigating around 18 Mg C ha⁻¹ C year⁻¹ (0-15 cm soil layer). Farmers and society as a whole may benefit from this approach [3]. Supporting campaigns and initiatives to boost soil C sequestration is crucial, both on a policy level and through programmes. Additional studies needs to be done to determine the benefits of C sequestration on soil quality precisely, which encourages farmers to adopt more C-positive agricultural practices that improve productivity, as well as water and air quality [4].

Keywords: Soil carbon sequestration; Carbon sequestration practices; Green House Gas (GHG); Mitigation; Perception, Adoption

1. INTRODUCTION

Since majority of the population directly rely on agriculture and natural ecosystems for their livelihoods, developing nations like India are more vulnerable to climate change. Through the implementation of mitigation strategies including the addition of biomass to soils, minimal soil disturbance, and soil conservation, agro-ecosystems can reduce carbon emissions by one third globally [5]. According to [6], agricultural soils may account for around 89% of the GHG mitigation potential through C sequestration and have an additional 2% and 9% mitigation potential for N₂O and CH₄. This leads to an estimated 5–14% reduction in emissions over the course of 5–10 decades (with agricultural systems having the ability to store up to 1400–2900 Mt CO₂ equivalent annually [7]. Because of their capacity to store substantial quantities of organic C, soils have been a primary focus of increasing soil C storage [8]. According to [7], this leads to an estimated 5–14% reduction in emissions over the course of 5–10 decades, with agricultural systems having the ability to store up to 1400–2900 Mt CO₂ equivalents annually. Because of their capacity to store substantial quantities of organic C, soils have been a primary focus of increasing soil C storage [8].

Additionally, ongoing efforts have been made to encourage sustainable land use through the adoption of practices that could boost agricultural output, income, and the sustainable use of natural resources [9]; for instance, through establishing Sustainable Land management (SLM) practices and restoring deteriorated land [10] [11]. However, despite the use of such measures, a considerable improvement in agricultural productivity has not noticed since the agricultural land continues to be degraded. Because SLM practices have not been fully adopted and, when they have, they have not been properly carried out [11]. One of the low cost SLM technologies that have several advantages, including improving soil fertility and raising farm output, is the adoption of soil carbon enhancing practices [12]. Hence these practices increase farmer income and ensure food security.

2. SOIL CARBON SEQUESTRATION PRACTICES FOR FARMER'S ADOPTION

The technique of capturing and permanently storing CO₂ in a stable form inside the soil is known as soil carbon sequestration. The following six soil C management strategies were suggested by [13] to increase SOC: (1) minimal soil disturbance; (2) maintenance of permanent ground cover; (3) intensification of nutrient recycling mechanisms; (4) creation of a positive nutrient balance; (5) enhancement of biodiversity; and (6) reduction in losses of water and nutrients. He felt that a C-management strategy should have potential for lowering GHG emissions in addition to being able to boost SOC content. Carbon management practices are aimed at increasing the ecosystem C balance by applying more carbon into the soil (for example, by planting crops), increasing below- and above-ground biomass (for example, through forestry and agroforestry), sequestering SOC (for all ecosystems), and also lowering C losses from the soil [14], SOC stocks in soil can be maintained by avoiding poor land use, using management strategies, and restoring degraded land [14] [15].

Table 1 Comparison between Traditional and Recommended Management Practices (RMP's) in relation to Soil Organic Carbon Sequestration [2]

S. No	Traditional methods	Recommended management practices
1	Biomass burning and residue removal	Residue returned as surface mulch
2	Conventional tillage and clean cultivation	Conservation tillage, no till and mulch farming
3	Bare/idle fallow	Growing cover crops during the off season
4	Continuous monoculture	Crop diversions with high diversity
5	Low input subsistence farming and soil fertility mining	Judicious use of farm input
6	Intensive use of chemical fertilizers	Integrated nutrient management with compost, bio-solids and nutrient cycling, precision farming
7	Intensive cropping	Integrating trees and livestock with crop production
8	Surface flood irrigation	Drip, furrow or sub irrigation
9	Indiscriminate use of pesticides	Integrated Pest Management

3. CARBON SEQUESTRATION PRACTICES BY FARMERS - REVIEW AND RESULTS

3.1 TILLAGE AND LAND LEVELLING

The possibility of zero tillage to increase soil carbon storage has been frequently reported [16][17][18]. Zero tillage and reduced tillage demand less energy, which results in less GHG emissions [19][20]. In Zero tillage-based wheat and maize systems, GHG emissions were decreased by 1.5 Mg CO₂-e ha⁻¹ year⁻¹ [19] [21]. Due to traditional land-levelling practices, the majority of agricultural areas in South Asia are not properly levelled [22] [23]. The effect is felt for a long period of time, although soil aggregates are stabilised under reduced and zero tillage practices, which physically prevent C from mineralization [24][25][26]. According to [27], proper land levelling increases crop growth and yield, as well as the effectiveness of input utilization. By enhancing water and nitrogen use efficiency, Precision Land Levelling (PLL) is known to reduce GHG emissions [28]. Due to less time required for pumping irrigation water and cultivation, PLL could, in Indian conditions, reduce GHG emissions by around 0.15 Mg CO₂-e ha⁻¹ year⁻¹ [29].

3.2 CROP RESIDUE AND IRRIGATION MANAGEMENT

Crop residue return, or the biomass that is returned after harvesting, has beneficial effects on SOC, yet the degree to which it is effective depends on the tillage practices used [30][31]. The soil carbon sequestration is increased when residues are left on the soil surface [32][33][34]. According to [32], the C sequestration is positively correlated with the amount of residue return. Improved crop cultivars, paddy-upland rotation, employing legumes in rotation, and optimum fertilizer application are few of the management practices for increasing crop residue return to the soil [15] [35]. Retaining crops can lower the need for fertilizer [36][37], which may minimize GHG emissions. Since biochar can prevent the release of CO₂ by stabilizing decaying organic matter and can last in soil for hundreds or even thousands of years, it has the potential to reduce global GHG emissions by 12% [38]. Biochar is a synthetic product made from crop residues and other organic sources. By improving Net Primary Productivity (NPP) and by ensuring addition of biomass to soil, improved water management improves C sequestration [15] [39]. According to estimates by [40], better water management might reduce greenhouse gas emissions by 1.14 t CO₂-e ha⁻¹ year⁻¹. Through increased microbial activity, drip irrigation with repeated wetting-drying cycles may encourage soil CO₂ emission [41]. Micro-irrigation/fertigation lowers the Global Warming Potential (GWP) by reducing N losses as well [42]. The C footprint of pumping water is reduced through reduced irrigation [43].

3.3 MANURE AND NUTRIENT MANAGEMENT

From 70% of the total manure generated in the early 1970s to 30% in the early 1990s, India's availability of manure as a source of nutrients and C in agricultural practices has decreased [44]. In India, dung production totals 335 Mt annually, of which 225 Mt remain for agriculture usage. According to [45], this only represents one-third of the FYM that the nation needs to have in order to fully realize its total C sequestration potential. Compost and other

organic manures can improve soil C stocks [14], but they may also raise CO₂ emissions [46]. By providing enzyme-producing microbes such as C and N substrates, organic manure application can promote SOM [47], thus enhancing the structure and diversity of the microbial community [48]. NPK treatment alone sequestered C at a rate of 0.16 Mg C ha⁻¹ year⁻¹, whereas application of NPK along with FYM sequestered C at a rate of 0.33 Mg C ha⁻¹ year⁻¹ [45]. Even in a hot, semi-arid region, FYM combined with Integrated Nutrient Management (INM) may enhance soil SOC [49]. In an extensive study, [50] observed soil C accumulation in a triple-cereal cropping system (rice, rice, and wheat) with organic (FYM or compost) amendment. The addition of organic material raised SOC in a rice-wheat cropping system by 18 to 62% as compared to NPK [51]. Similar results were found by [52] who found that adding FYM to rice-wheat cropping systems in India and Nepal increased SOC accumulation from 0.08 to 0.98 Mg C ha⁻¹ yr⁻¹. When manures were added to various types of soil, some researchers observed greater GHG fluxes (CH₄ and N₂O emissions) [53] [54]. [55] found that a soybean-wheat cropping system with an organic amendment increased SOC stocks, N₂O and CO₂ emissions, but the yearly GWP was reduced.

The application of N fertilizer from the right source, at the right dose, right time, and in the right place enhances crop yield, N use efficiency, and SOC storage, and mitigates GHG emissions [56]. Optimum and balanced doses of nutrients maximize crop yields, resulting in relatively more C inputs from both above and below-ground plant biomass to the soil [4]. 'Nutrient Expert'-based management reduced on average 13% of GHG emissions from rice, wheat, and maize compared with farmer's fertilizer practices [57] [21]. Enhanced fertility management can improve SOC content at the rate of 0.05–0.15 Mg ha⁻¹ year⁻¹ [2]. Crop production, N use efficiency, SOC storage, and GHG emissions are all improved by administering N fertilizer from the appropriate source, at the right dose, at the right time, and in the right place [56]. Maximising crop yields with optimal and balanced nutrient dosages causes significantly greater C inputs from both above- and below-ground plant biomass to the soil. [4]. When compared to farmer's fertilizer practices, "Nutrient Expert"-based management decreased GHG emissions from rice, wheat, and maize by an average of 13% emissions from rice, wheat, and maize compared with farmer's fertilizer practices [Improved fertility control can raise SOC content by 0.05-0.15 Mg ha⁻¹ year⁻¹ [2]. According to a meta-analysis by [58], N fertilization encourages SOC storage in agricultural soils everywhere over the world. In the opinion of [59], the impacts of balanced fertilization on crop development resulted in a favourable influence on soil C sequestration. Due to the higher C input associated with increased primary production and crop residues returned to the soil, balanced fertilization (N120 P30 K30) improved SOC concentration in rice-wheat and maize-wheat cropping systems [60]. The Government of India has launched a "Soil Health Management (SHM)" programme under the National Mission for Sustainable Agriculture [61] to enhance soil health and soil productivity through balanced fertilization. Through the careful use of chemical fertilizers, including secondary- and micro-nutrients, along with organic manures and bio-fertilizers, the SHM programme seeks to achieve Integrated Nutrient Management (INM). According to the SHC-based suggestions, crop yield increased by 5-6% and chemical fertilizer use was reduced by 8–10% [62].

3.4 CROP VARIETY AND PEST MANAGEMENT

In lower soil profiles, crops and crop cultivars with deep roots can store more [63]. Growing deep-rooted crops also improves SOC stocks [4] [39], reduces nitrate leaching to groundwater and thereby reduces N₂O emission [64][65], and extracts nutrients and moisture from deeper soil layers [66]. The need for tillage may be greatly reduced by deep-

rooted perennial crops as well [39]. According to [67], plants that possess improved root architecture can enhance soil structure, hydrology, drought tolerance, and N usage efficiency [68][69] are more examples of plants with enhanced root design. [70] contrasted the amount of assimilated C from traditional and new wheat varieties that were transmitted underground and stabilized in the soil. According to the authors, older wheat cultivars containing greater root biomass transferred more assimilated C down the soil profile than more recent cultivars. A new "Rhizo-Engine framework" stressing a comprehensive strategy for exploring plant root impacts on SOC sequestration and the vulnerability of SOC stocks to climate and land-use changes was recently developed by [71]. According to [72], the mycorrhizal fungi can boost C sequestration by "enhanced weathering" of silicate rocks via vigorous interactions. While the use of pesticides improves the amount of carbon dioxide (CO₂) capture via higher crop yield, it also increases the amount of greenhouse gases (GHGs) emitted during the manufacturing, distribution, and application of synthetic pesticides [73]. According to [28], Integrated Pest Management (IPM) can boost crop yields while reducing pesticide usage. IPM can increase agricultural yields by more than 40% while lowering the requirement for pesticides by 31%, according to [74]. According to research, any pest management techniques that minimize foliar spraying are capable of lowering greenhouse gas emissions [75]. Climate-Smart Pest Management (CSPM) is a cross-sectoral approach to managing pests [76]. Its aim is to decrease crop losses brought on by pests, enhances ecosystem services, lowers GHG emissions, and increases the resilience of the agricultural system [77].

3.5 CROP ROTATION AND FALLOW MANAGEMENT

According to studies by [78] and [50], the inclusion of a dual- or multi-purpose legume (grain, green manure, and forage) in a rotation is likely to balance the inputs of organic and inorganic fertilizers and its impact on SOC stocks. In legume-cereal crop rotations, legumes with the ability to fix atmospheric nitrogen increase biomass production, crop residue inputs, and ultimately the total SOC [79][80]. SOC in agricultural soils can be improved by reducing overgrazing (which reduces Net Primary Production and increases CH₄ flow and animal respiration), balancing SOM decomposition through manures, crop residues, and litter, and increasing the mean annual Net Primary Production (NPP) [81]. Increasing soil biodiversity can result in higher SOC stocks and more stabilised SOC [82] [83] [84]. According to [85], the incorporation of grain sorghum, instead of continuous soybean farming boosted soil organic C and N levels and that cultivating high residue crops coupled with minimal tillage could increase production. In accordance with [86], a cover crop used to cover the ground surface during the fallow season prevents nutrients leaching from the soil profile and supplies nutrients to the primary crops. According to [86], by using cover crops, SOC loss was decreased. To increase soil fertility, especially soil C, in intensive double-cropping areas, a short-duration cover crop like *Sesbania* can be cultivated [87]. According to [86], growing cover crops on 25% of the world's farmland could reduce greenhouse gas emissions in agriculture by 8%. A decrease in N₂O emissions has also been attributed to cover crops [88] [89]. In warm and humid areas, cover crops and fallow rotation may mitigate a net loss of 0.98 Mg C ha⁻¹ during a 7-year period, according to [40]. Creating borders of permanent vegetation along the edges of the field is another way to provide continuing live cover for agricultural soils [86]. When cover cropping is incorporated into the system, the potential impact of no-tillage on boosting SOC increases significantly [82]. According to [90] and [91], rhizodeposition and the addition of root litter boost SOC stocks, and this is greater with perennial crops than with annuals. In opinion of [92] agroforestry, in which crop cultivation is blended with growing trees and occasionally with grazing cattle, has the largest capacity to hold carbon, ranging from 4.3 to 6.3 MT CO₂-e ha⁻¹ year⁻¹.

4. CARBON SEQUESTRATION PRACTICES – FARMER’S PERCEPTION

Farmers choose carbon pathways because they also have other benefits, most notably improving soil structure. They want to enhance soil health and, as a bonus, maybe sequester carbon. According to [93], the farmers would require localized models that could address their management issues and assess complicated mixtures of practices. Less than 35% of respondents in an Australian survey believed that carbon farming is a suitable method of lowering Australia's greenhouse gas emissions. The study also indicated that experience with the negative effects of climate change had an impact on respondent's chances of adopting carbon farming [94]. Another study that looked at the adoption of climate-mitigative practices in Alberta found that beliefs about climate change had no bearing on adoption choices and that many farmers had already adopted these practices due to co-benefits rather than because they agreed with the climate science. Although the authors acknowledge that some members of this population are skeptical about man-made global warming, they warn that attempts to convince them to embrace legislative requirements related to climate change could cause cognitive dissonance and cause them to reject the mandates [95]. However, some research has connected concern about climate change to readiness of adopting conservation agriculture habits [96]. There has never been a prior evaluation of farmer's stated preferences for a particular carbon payment scheme. Prior to the establishment of government conservation programmes that encourage the adoption of practices that ameliorate climate change or well-developed carbon commodity markets for carbon, it will not be possible to evaluate revealed preferences for such payment systems [97].

5. CONCLUSION

Around 18 Mg C ha⁻¹ year⁻¹ (0–15 cm soil layer) might be mitigated by soil management practices, which could make up for an 8% reduction in GHG emissions [4]. When farmers adopt soil carbon enhancing agricultural practices, development and innovation occur frequently [98]. In order to increase food security, it is necessary to accelerate the adoption of land management practices that improve SOC. The farmers require a lot of support because the current methods for providing them with knowledge, resources, and incentives to encourage the adoption of sound technical practices are insufficient [4]. The improvement of knowledge and abilities through training and the provision of extension services could provide farmers with the necessary skills and raise the necessary awareness of a wide range of practices and technologies that sequester carbon. Therefore, knowledge and understanding of the issues that limit small-scale farmer's decisions to embrace these practices are necessary. Farmers certainly require more information about these practices, and the best way to solve this is through collaborative efforts by researchers, agents from the private sector, policymakers, extensionists, traders, and other stakeholders [99]. The productivity effects of carbon farming practices must be efficiently promoted and practices must be simple to incorporate into current agricultural systems, in order to boost involvement [100]. To expand our understanding, we require a new generation of research to evaluate the potential of novel management strategies for C sequestration and its long-term stabilization. Additionally, it is necessary to pursue both short-term and long-term policy efforts that can provide incentives through the corresponding government initiatives and the involvement of the farming community [99].

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