Soil Organic Carbon Sequestration in Rice-Based Cropping Systems: Estimation, Accounting and Valuation

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Abstract

Crop management practices largely govern the complex process of carbon (C) sequestration in agricultural soils. In rice-based systems, small alterations in cultivation practices can lead to increased soil organic carbon (SOC) contents in soil and reduced GHG emissions, thereby complementing the C sequestration. Due to enormous complexity of C sequestration process, monitoring soil C changes could be costly and extremely variable in C stocks on micro- and macro-scales. To assess the soil C change, the factors driving the driving soil C dynamics are accounted, and models are developed. However, it is worth notable that these modelling and measurement efforts are relatively new considering the history of C dynamics. It will be challenging to settle on annual-to-decadal target rates for rebuilding soil C based on the available modelling and measurement tools. Overall, change in soil C fraction is reported in many studies with choice of agronomic management practices in rice-based cropping systems. The combined application of inorganic fertilizers and organic manures seems to be the best option to increase rice yields while improving soil C accumulation. An attempt has been made in this chapter to compile and analyse all the available information

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related to the soil C sequestration potential of rice-based cropping system, particularly rice-wheat and rice-rice cropping system, in addition to the mechanism, measurement and valuation of C.

Keywords

Soil organic carbon · Agronomic management practices · Rice-based cropping system · Carbon sequestration measurement

Abbreviations

BD	Bulk density
C	Carbon
CDM	Clean Development Mechanism
SOC	Soil organic carbon

1 Introduction

Soil is the greatest carbon (C) reservoir, accounting for more than 80% of total C in the terrestrial biosphere. The transfer of C from the soil to the atmosphere is a continual process that is heavily impacted by various factors. Soil organic carbon (SOC) sequestration invariably refers to the process of restoration of SOC pool, through conversion of atmospheric CO_2 through the process of photosynthesis and humification. It can be increased by enhancing the soil C stocks through sustainable land management. Some of the agronomic management practices, viz. diversifying the cropping system by crop rotations, choice of crop establishment method, fallow period management, fertilizer and water management, have the potential to either reduce or increase soil C stocks (Baker et al. 2007). Increased C losses would arise if stored C is released into the atmosphere due to temperature-induced breakdown (Bradford et al. 2016). A reduced C loss is induced by a relative increase in the amount of contributed and/or plant-derived C over decomposition (Kallenbach et al. 2016; Paustian et al. 2016). The response is based on two factors: breakdown and soil C addition. Increasing the soil C stock has many advantages which are strongly tied to soil nutrient status, soil fertility, soil aeration, etc. In tropical soil, temperature-induced breakdown leads to decline in SOC levels; however, complete exhaustion of SOC in soil is not possible in nature. In general, a steady state is maintained in the SOC levels of cultivated soils which is referred to as a lower equilibrium limit (Buyanovsky et al. 1998). In an erosion-free environment, the fluctuation in SOC level depends on the management practice. Crop cultivation leads to SOC stabilization at the lower equilibrium level, but addition of organic inputs in addition to fertilizer applications tend to shift the equilibrium towards the upper limit (Nayak et al. 2012a). Extensive adoption of improved crop management practices is recommended with an aim to maintain or increase SOC levels, thereby improving soil fertility and mitigating climate change (Lessmann et al. 2021). The most recent scientific discussions accept that timely intervention is needed to rebuild SOC for sustainability.

Rice is staple in South and East Asian countries, and it also represents a fairly large fraction of global agriculture. It is established that transplanted rice have higher soil organic C storage. Organic C accumulation is faster owing to slower organic matter decomposition in low and shallow lowlands due to anaerobic/reduced condition created by flooding (Watanabe 1984). Microbial activity is slowed down under flooded conditions resulting in declined decomposition rate. However, the potential of C sequestration in rice-based cropping systems is not well recognized. In rice-based systems small interventions in cultivation practices could result in substantially modified SOC contents (Zhu et al. 2014). Heavy tillage operations and intensive agriculture with flawed nutrient management in rice ecosystems are mainly responsible for depletion of SOC pools. Ratnayake et al. (2017) reported significant reduction or no increase in the soil C stocks in rice-based cropping systems. Alternatively, Nayak et al. (2012b) reported potential of C sequestration in rice-based cropping system with appropriate residue retention and nutrient management.

In this chapter, an attempt has been made to compile and analyse all the available information related to the soil C sequestration potential of rice-based cropping system, particularly rice-wheat and rice-rice cropping system, in addition to the mechanism, estimation and valuation of C.

2 Potential of C Sequestration and Emission Reduction in Rice Soils

C sequestration potential varies from region to region even under the same type of management, due to difference in climate, soils, cropping systems and available technologies. Extensive efforts have been made to identify the agronomic management practices for soil C sequestration and emission reduction in rice soils. Table 1 lists several agricultural management practices and their role in either increasing C inputs to soils or reducing C losses from soils.

Long-term studies (Table 2) have shown that agricultural practices involving improved fertilizer management, application of manures, crop residue retention, crop diversification, green and brown manuring, optimum tillage, rationalized irrigation and agro-waste recycling enhance C storage. These agricultural practices are highly sustainable and help in mitigating climate change through C sequestration on one hand and reduction of GHGs emissions on the other.

It has been pointed out that a combination these practices may be required to effectively sequester C rather than depending on one particular practice. Higher C input through cropping system and soil management practices is likely to maintain the higher SOC level in soil (Mandal et al. 2007). For the past 15 years, calculated potential of SOC sequestration under different ecoregions in different cropping systems with diverse soil management options has been reported in India and abroad

Table 1 Agricultural management practices that can increase organic carbon storage and promote a net removal of CO_2 from the atmosphere

Management practice	Increased C inputs	Reduced C losses
Improved crop rotations and increased crop residues	√	
Cover crops and green manuring	√	
Manure and compost addition	√	
Improved grazing land management	√	
Improved crop rotation with legumes	√	√
Addition of biochar to croplands	√	√
No tillage and other conservation tillage		√
Rewetting peat and muck soils (organic soils)		√
Balanced fertilization		√

Modified: Paustian (2014)

Table 2 Agricultural practices for soil carbon sequestration in rice-based cropping systems reported in India

Technology	Cropping system	Region	References
Green manuring	Rice-wheat	North-west India	Aulakh et al. (2001)
	Rice-wheat	North and Eastern India	Nayak et al. (2012b)
	Rice-rice	Tropical India	Singh et al. (1991)
	Rice-rice	Tropical India	Kumar and Goh (1999)
Mulch farming/conservation tillage	Rice-wheat	North-west India	Aulakh et al. (2001)
INM	Rice-rice	Northern India	Dinesh et al. (1998)
	Rice-wheat	North-west India	Yadav et al. (2000a)
	Rice-wheat	Northern India	Singh and Dwivedi (1996)
Residue incorporation in rice with barley straw	Rice-barley	Tropical dryland	Kushwaha et al. (2001)
Residue incorporation in rice with wheat straw	Rice-wheat	North and Eastern India	Nayak et al. (2012b)
Restoration of sodic land	Rice-wheat	Central India	Nayak et al. (2008)
Addition of FYM	Rice-rice	Eastern India	Mohanty et al. (2013)
	Rice-rice	Eastern India	Shahid et al. (2017)
	Rice-wheat	North and Eastern India	Nayak et al. (2012b)

(Table 3). Globally, 40 to 80 billion tonnes of C is estimated to be sequestered in agricultural soils over a period of 100 years (Cole et al. 1997) with appropriate management practices. In India, the total potential of C sequestration is 12.7 Tg C year^{-1} to 16.5 Tg C year^{-1} which includes about 8.5 Tg C year^{-1} from restored soils

Table 3 Effects of agronomic management techniques on percent increase in SOC content over RMP

Agronomic management	Cropping system	Average increase in SOC content over control (%)	Place	References
Residue incorporation	Rice-rice	10	Iksan City, South Korea	Ku et al. (2019)
	Rice-wheat	20	Ludhiana, India	Singh et al. (1994)
		18	Kanpur, India	Tiwari et al. (1998)
		34	Sabour, India	Yadav et al. (2000a); Singh et al. (2019)
		14	Kalyani, India	Majumder et al. (2008)
Manure application to both the rice crops	Rice-rice-fallow	28	Dhaka, Bangladesh	Naher et al. (2020)
Green manure incorporation before rice planting	Rice-wheat	16	Ludhiana, India	Singh et al. (1994)
		11	Kanpur, India	Yadav et al. (2000b)
		32	Sabour, India	Yadav et al. (2000a), Singh et al. (2019)
FYM addition to both the rice crops	Rice-rice	80	Assam, India	Gogoi et al. (2021)
		18	Cuttack, India	Mohanty et al. (2013)
		11	Cuttack, India	Shahid et al. (2017)
	Rice-wheat	14	Kalyani, India	Majumder et al. (2008)
		33	Ludhiana, India	Singh et al. (1994)
		15	Kanpur, India	Tiwari et al. (1998)
		38	Sabour, India	Yadav et al. 2000b
Biochar addition to both the rice crops	Rice-rice	169	Cuttack, India	Munda et al. (2018)
Plastic mulching in ridge and furrow system of planting in rice	Rice-fallow	86	Sichuan Province, China	Zhang et al. (2013)
Double zero tillage, i.e. zero-tillage DSR followed by zero-tillage wheat	Rice-wheat	23	Chitwan, Nepal	Paudel et al. (2014)

and 6 Tg C year^{-1} to 7 Tg C year^{-1} from advanced agronomic management practices (Lal 2004).

2.1 Potential of SOC Sequestration in Rice-Rice Cropping System

Stagnation in rice productivity in rice-rice cropping systems has been an outcome of extensive use of inorganic fertilizers. Moreover, the rice-rice system has become associated with reduced fertility and overall decline in soil health. In fact, reports from long-term fertilizer experiments throughout the world suggest deterioration in physical, chemical and biological soil attributes for crop production with continuous application of inorganic fertilizer in rice-rice system (Basak et al. 2016). Globally, cultivation of double rice over the years have led to the destruction of soil structure, as a result of which stability of soil aggregates have been disturbed and the C content of soils have declined. Relatively lower magnitude of depletions in SOC is reported in areas with continuous submergence (8–9 months in a year) of soils under rice-rice system. Higher SOC concentration in lowland rice soils is generally observed compared to upland soil. Swarup (1998) reported substantial increase of about 60% in SOC concentration over a period of 20 years with INM in rice-rice cropping system. Possible explanation for lower SOC depletion may be lower inherent C concentration in the studied soil.

Studies suggest that sole application of FYM and combination with FYM and 100% NPK both increased C content in soils significantly. This can be explained in relation to increased biomass of crops (root biomass and root exudates) with complementary and sometimes additive effect of organic and inorganic fertilizers. An increase in SOC stock was reported by Majumder et al. (2008) and Chaudhary et al. (2017) and attributed it to the combined application of fertilizers and FYM. Similarly, Srinivasarao et al. (2012) reported increased SOC stock with sole application of FYM. At a long-term study at Cuttack, India, SOC concentration and stocks had increased substantially with combined application of chemical fertilizers and manure as compared to untreated control in rice-rice cropping system (Shahid et al. 2017; Mohanty et al. 2013). The SOC stock of surface soil increased in all treatments as compared to the initial value recorded 41 years ago. The differences in the SOC stock were non-significant in the greater depths of soil profile. It was also established from the study that crop residue in the form of rice roots and stubbles is sufficient to counter the C loss through decomposition of organic matter. C sequestration potential can further be improved with combined application of chemical fertilizers and manure.

2.2 Potential of SOC Sequestration in Rice–Wheat Cropping System

A perceived threat to rice-wheat cropping system is the reduction in SOC stock and the associated reduction in nutrient supplying capacity of soil. Long-term studies in

India showed a decline in SOC content in treatments without addition of organic input (Ladha et al. 2003). From the same studies, it is reported that applications of FYM before rice in a rice wheat rotation resulted in SOC build-up and higher grain production. Rice crop residues (agro-wastes) are burnt on field in huge quantities particularly in North-west India. The burnt agro-wastes (19.6 million tonnes of straw of rice and wheat) in India are equivalent to 3.85 million tonnes of SOC, 59,000 tonnes of nitrogen, 2000 tonnes of phosphorous and 34,000 tonnes of potassium. The agro-wastes could be one of the alternatives to improve the SOC stocks in addition to supplementation of plant nutrients. The combined use of organic input (residue from rice or wheat) and inorganic fertilizer in rice-wheat systems may work complementarily and increase the crop yield and SOC build-up.

Studies in Indo-Gangetic Plains (IGP) suggest that the application of chemical fertilizers over a period of 23–26 years in cereal-cereal (rice-wheat) cropping systems has positively influenced the SOC of surface soil. However, a decrease of 2 and 35% of SOC concentration was reported with no fertilizer application in middle and lower IGP, respectively, whereas at trans- and upper IGP, it has more or less maintained the SOC level (Nayak et al. 2012b). Because of low SOC concentration initially, trans- and upper IGP could maintain their SOC level with no fertilizer application despite a declining yield trend. The higher stubble and root biomass in response to fertilizer application in turn results in higher yield. The SOC increased in surface soil along the IGP except at lower IGP where initial SOC value was comparatively higher than others. Most of the reports from long-term experiments suggested that optimum application of inorganic fertilizers helped in increasing SOC stocks (Purakayastha et al. 2008) or maintaining the SOIC stocks (Biswas and Benbi 1997). Brar et al. (2013) even reported C sequestration in rice-wheat system without any external organic input. Some other reports suggest that substitution of part of fertilizers through FYM or crop residue or green manure has also enhanced the SOC considerably. The combination of organic and inorganic sources improves the organic C content of soil over that achieved with fertilizers alone, due to the additive effect of organic and inorganic sources and their interaction thereof (Nayak et al. 2012a). Similarly, SOC build-up in response to cropping system management, addition of manures with chemical fertilizers and incorporation of paddy stubbles and green manures have been widely reported from long-term studies (Yadav et al. 2000b).

In many of long-term experiments on rice-wheat system conducted in diverse agro-climatic zones of India, application of 50% of N through FYM along with 50% recommended dose of NPK in rice and application of 100% recommended dose of NPK in wheat-sequestered 0.39, 0.50, 0.51 and 0.62 Mg C ha^{-1} year^{-1} over untreated plots, respectively, at Ludhiana (Trans-Gangetic Plains), Kanpur (Upper Gangetic Plains), Sabour (Middle Gangetic Plains) and Kalyani (Lower Gangetic Plains), (Table 3). In China, Hao et al. (2008) reported that combined input of chemical fertilizers and manures sequestered C in soils. Nayak et al. (2012b) reported a very wide range of C sequestration (0.08 to 0.98 t ha^{-1} year^{-1}) in IGP with different organic inputs (FYM, crop residue, green manure) along with NPK in rice-wheat system, which are similar reports from other studies (Causarano et al.

2008; Kundu et al. 2007). A C stock budgeting was reported by Bronson et al. (1998) from different agroecosystems of Asia. It was reported that increase in C stock in soil is possible even in tropical lowlands, even though very high temperatures prevail in tropical region round the year. They opined that C mineralization was relatively slow due to anaerobiosis. Addition of large quantities of organic C from photosynthetic algal communities in the rice-based ecosystems is also responsible for slow mineralization of C. Similarly, it was also observed that clayey soils have more potential to sequester C than sandy and silty soils in the lowland tropics, due to mineral coating on SOC giving a physical protection (Matus et al. 2008). It also explains the reason for higher SOC sequestration rate at lower IGP which is characterized by higher soil clay content.

Overall, the SOC enrichment (C sequestration) in soil with organic input is largely established; however, the extent of SOC enrichment is dependent on many other factors such as cropping systems and choice of crop management practices.

3 Estimation of SOC Sequestration

The variations in the SOC sequestration arise even under same management practices because of various factors, viz. soil and climate type, cropping system, etc. Under such scenario, estimations of soil C sequestration are being made using measurement and monitoring technologies, to remunerate the C sequestration achieved, through so-called moving baselines. Various analytical tools to assess C sequestration/storage have been developed and available in the existing literature (Paustian et al. 2019; Falloon and Smith 2000; Gulde et al. 2008; van Wesemael et al. 2019; Wiesmeier et al. 2019). The measurement standards and procedures for soil C sequestration are still evolving. Rapid and cost-effective measurements of soil C concentration on a large scale, i.e. at the landscape and regional level, and on a vertical scale at profile level are being tested for making recommendations (Lobsey and Viscarra 2016; Ramifehiarivo et al. 2017). New technologies like eddy covariance flux towers are being used to estimate C sequestration at the ecosystem level (Nayak et al. 2019). For accurate estimation of SOC, some of the pre-estimation parameters need to be considered along with the suitable methods of SOC estimation.

3.1 Critical Pre-estimation Parameters for Accurate Assessment of SOC

Establishing the Baseline

As mentioned earlier in the chapter, the SOC sequestration varies with choice of management practice in a particular agricultural system, and it is influenced by soil type and climatic factors. Many of the earlier researchers have calculated and reported C sequestration on the basis of difference in SOC in the treated plot and non-treated plot while considering the non-treated as the baseline without considering the SOC stock before treatment implementation (Shahid et al. 2017). Some researchers believe that this may give erroneous information (Nayak et al. 2019) because both the treated as well as non-treated plots are losing SOC, though at a different rate. Hence, initial SOC level must be taken into account before imposing the treatment so that a boundary line is fixed to correctly assess the SOC change, be it steady state, retention, loss or gain of SOC (Olson 2013).

Fixing a Timeline

Fixing a timeline is necessary for measuring the SOC sequestration as SOC changes take place very slowly which support a higher inconsistency at spatial scale and inconsistently lower instance of variability at a temporal scale. Detecting the SOC in terms of absolute quantity compared to real initial value is difficult. Sometimes, it is argued that less than 20 years is a very short time to establish equilibrium in SOC in soil with high clay content. Similarly, in soils exposed to convention management practices, loss of SOC continues for 50–100 years (Sanderman and Baldock 2010). Therefore, Kumar et al. (2012) suggested that spatial variability and rate of SOC change are the key factors for correct assessment of SOC sequestration. In light of the above discussion, long-term field experiments lasting many years or decades are recommended for assessing SOC sequestration within various agroecosystems and crop management options.

Determination of the Frequency of Measurement

Soil C stocks are relatively stable in undisturbed soil; nevertheless, any disturbance to topsoil causes SOC stocks to be lost. SOC is lost when grasslands and forests are converted to other uses that involve soil disturbance. Apart from land-use change, management methods, particularly in cropping systems and grasslands, can have a considerable impact on SOC stocks. The frequency with which soil C stocks are measured varies, depending on the land use and soil management system in practice. The frequency has implications for the method used to prepare a C inventory as well as expenses and can range from once a year for land-use change operations to once every 5 years for long-term projects.

Sampling Method

The method for sample collection should be based on the objective (i.e. short- or long-term storage change). Several methods are being used traditionally, viz. digging open pits, core sampling with a punch core, core drill method, etc. However, sampling method should be chosen on the basis of objective of the study. For example, augers should be used to take undisturbed cores, however, in a soil with coarse roots, auger sampling should be replaced with rotary core device (Rau et al. 2011). Comparison studies are suggested to make a reasonable decision on choice of sampling. Methodologies that combine soil pit and auger sampling techniques under different soil, topography and cropping system should be tested and compared for more comprehensive information related to choice of sampling method.

Bulk Density Corrections

The calculation of SOC stock at a given depth is done with the help of SOC concentration, bulk density (BD) and soil depth. Any error in the measurement of BD across the depth of sampling in treated and non-treated plots would magnify the bias and may result in complete wrong information on SOC stock. So, in order to reduce the error, corrections in the BD should be made before calculation of SOC concentration.

3.2 Measurement Techniques

There are numerous methods for estimating SOC, ranging from simple laboratory techniques to a more complicated diffuse reflectance spectroscopy. The examples are (1) Walkley and Black method or wet digestion or titrimetric determination, (2) colorimetry, (3) direct estimation of organic matter by loss-on-ignition, (4) CHN analyser, (5) diffuse reflectance spectroscopy and (6) modelling.

Wet digestion or titrimetric determination is the most popular approach utilized in the field, and it is also a cost-effective procedure. Despite its high accuracy, the C, hydrogen and nitrogen (CHN) analyser is rarely utilized in field investigations due to its high cost. Diffused reflectance spectroscopy is also costly, and it has yet to be widely adopted in the field. The availability of models and data to represent local situations limits modelling. The remote sensing method can only be utilized for large projects, and it still requires modelling and validation using data from other sources. It is necessary to enhance the accuracy and affordability of soil C collection and measuring methodology in order to monitor C changes in the soil and biotic pool. SOC stocks are calculated using two variables: SOC concentration and bulk density.

Wet oxidation Walkley and Black (1934) or dry combustion is the most used method for determining SOC concentration (Wang and Anderson 1998). The amount of organic C in most samples is known to be underestimated by the wet oxidation method; hence a correction factor must be applied. The adjustment factor's magnitude is known to vary by soil type. Despite the availability of more reliable procedures, the Walkley-Black method is still employed in some laboratories, particularly in India. Over the last 10 years, significant work has been made in refining, improving, and adapting the approach for measuring and monitoring soil C sequestration at field and regional scales. It is currently possible to monitor changes in soil C as tiny as 1 Mg C ha^{-1} or estimate them using simple or elaborate simulation models (Paustian et al. 1997; Smith et al. 2007). More accurate measurements will be more widely accepted if measurement errors are addressed and the measurement procedure is unbiased. When monitoring C sink operations, "uncertainties, transparency in reporting, and verifiability" should all be taken into account, according to Article 3.4 of the Kyoto Protocol (Smith 2004). In situ measurements can be done using laser-induced breakdown spectroscopy (Cremers et al. 2001), inelastic neutron scattering (Wielopolski et al. 2000) and diffuse reflectance IR spectroscopy (Christy et al. 2006).

On some dynamic and geographically relevant basis, measurement and monitoring procedures employing current or new methodologies must be integrated to field-level and regional scales using computer simulation and remote sensing (Paustian et al. 1997; Smith et al. 2007). When monitoring C sink for trading purposes, uncertainty in measurement, transparency in reporting and verifiability should be taken into account. Due to various pools and tiny incremental changes expected, monitoring soil C changes at the project level could be costly and extremely variable in C stocks on micro- and macroscales. SOC change could be estimated in one of three ways: (1) using SOC stock change values for specific practices reported in the literature based on research studies, (2) using process-based models of SOC dynamics, parameterized from experimental data and (3) using a combination of baseline measurements to assess the vulnerability of SOC pools and modelling informed by baseline measurements and understanding of the factors driving soil C dynamics. It is worth notable that these modelling and measurement efforts are relatively new considering the history of C dynamics. It will be challenging to settle on annual-to-decadal target rates for rebuilding SOC based on the available modelling and measurement tools.

4 Policy for Protection of SOC Sequestration

4.1 Economic and Political Will for SOC Sequestration

In the developing countries, the policymakers are not forthcoming to incentivize C sequestration measures because of permanence issues of SOC stocks, difficulty in quantifying contribution of C sequestration towards yield increase and other co-benefits. In the developing countries, the need for yield increase is prioritized over soil C sequestration. It is agreed that the most effective way to accumulate SOC is to increase C inputs, which implies that high organic C levels can be maintained with improved management and C input, irrespective of climate, soil type and cropping system. However, it is still difficult to quantify the contribution sequestered C towards improvement in crop yields, which makes it difficult to convince the policymakers for incentivizing the technologies related to enhancement of C sequestration. It is even more tedious to quantify the value of co benefits, viz. improvement in soil biodiversity, reduction in pollution, erosion reduction or other societal benefits. These co-benefits also vary spatially and temporally. Presently, SOC is not taken into account in market-based policy, primarily for two reasons: (1) expenses for ecosystem services (ES), as ES are difficult to measure and till now not standardized, and (2) the priority of farmers is higher crop production and not the C sequestration. Thus, new incentives for farmers to sequester extra SOC are required. Amelung et al. (2020) proposed establishment of seven-point soil information system for proper implementation of C sequestration policies:

1. Soil information systems for many parts of the world, including yield gap analyses and soil deterioration status.

2. Realistic forecasts of local and regional yield growth per tonne of sequestered C.
3. Requirement of additional fertilizer for long-term C sequestration.
4. Accounting for greenhouse gas emissions throughout the life cycle of C sequestering farming systems.
5. Regional and national maps showing soil C sequestration potential.
6. Accounting for organic material shift that may minimize stored C elsewhere.
7. Farmers' incentives, social standards and initiatives to scale up adoption of C sequestering practices.

Policies should evaluate both direct and indirect advantages, as well as local skills for long-term site-specific soil management. These activities are expected to be more effective throughout the world, tackling the common job of SOC sequestration on a scale and at a level that is appropriate for the difficult problem of land management.

Clean Development Mechanism

The unwise exploitation of soil organic matter can be devastating if not conserved and protected. It is the need of the hour to make regulation policies for conservation and protection of soil organic matter/SOC. Proper valuation should be done for protection of SOC as commodity, so that SOC can be traded like any other agricultural commodity. Valuation in terms of C credits is one such international attempt to sequester C and arrest the growth of GHGs emissions.

The Clean Development Mechanism (CDM) is one of the Kyoto Protocol's Flexible Mechanisms, as stated in Article 12. The rationale of the CDM is to promote cleaner environment by implantation of energy efficient projects which help in reduction in emission. The CDM is one of the Protocol's "project-based" mechanisms, in which commodities and services are created and catered with reduced emissions. The CDM is sometimes referred to as production-based mechanism as the CDM project produces an emission cut and it is subtracted against a hypothetical baseline of emissions. The baseline emissions are the hypothetical emissions that are predicted to occur in under conventional production system without CDM intervention.

The logic behind the implementation of these projects in developing countries only is mainly the substantially lesser expenditure incurred on emissions cut compared to developed countries. Such as, according to Sathaye et al. (2001), environmental regulation in developing countries is often lower than in developed countries. As a result, it is often assumed that developing nations have more capacity to cut their emissions than industrialized countries. The CDM was intended to meet two objectives:

1. To help non-Annex I parties (the developed nations) in contributing to the UNFCCC's ultimate goal.
2. To help Annex I countries in meeting their quantifiable emission restriction and reduction obligations (GHG emission ceilings).

Article 3.4 of Kyoto Protocol recognizes agricultural land as a potential C source that should be included in the UNFCCC Parties' regular emission inventories. The Protocol, on the other hand, makes no provision for national credits for C sequestration in agricultural soils. Afforestation and reforestation projects will be eligible for CDM credits throughout the Kyoto Protocol's first 5-year commitment period (2008–2012). Other sink activities will be ineligible, such as forest protection and soil C sequestration. Nonetheless, soil C sequestration may be eligible for CDM credits in future commitment periods (Gupta and Ringius 2001).

Baseline, Permanence and Leakage Related to CDM

In the absence of the CDM project, one of the major criteria is to create a baseline, which includes C emission by sources or decrease by sinks. The baseline might be the most expected land usage at the start of the project. The amount of sequestration that happens as a result of project execution above and beyond the estimated sequestration that would occur if the project was not completed is referred to as additionally.

It is generally suggested that over a period of time, schemes for soil C reaccumulation would be needed. This again raises the question of whether C stocks can actually be permanent. It is well understood that below-ground C is relatively more protected than above-ground C, i.e. plant biomass. So, forests might be felled at a later point to add to the below-ground C; however, agriculture is unlikely to be converted back to forests in emerging nations like India. Neither is it likely that farmers who benefit economically from conservation agriculture will go back to conventional agriculture. Therefore, question of permanence of soil C sequestration remains unanswered.

By minimizing leakage issues, some forms of contracts can assist to limit the probability of C sequestration reversal (Marland et al. 2001; Ellis 2001). The word "leakage" describes a situation in which a project accidentally moves an unwanted activity from one location to another, such as a forest conservation project that reduces deforestation inside the project area but promotes deforestation elsewhere. However, because soil C sequestration techniques are often more desirable than other land-use systems, they are less likely to have leakage consequences.

4.2 Costs and Valuation of C

Tonne of C dioxide equivalent, or $tCO2^e$, is used to calculate and express C trading. The intricacies of the method for determining costs and valuation are still being negotiated many years after the Kyoto Protocol was signed. In general, the polluting entity must pay for inputs that are directly related to pollution, such as gasoline costs. There are arguments in favour of accounting for all social costs (human health impacts from global warming), which will not only account for all expenses but also affect the polluting entity's decisions and actions. To assess the societal cost, value assessments on the significance of future climate impacts are required (Smith et al. 2001). Because not all commodities and services have a market price, valuations can be challenging. Inferring pricing for "non-market" products and services is possible. These appraisals, for example, of human health impacts or ecosystem impacts, are still being developed (Smith et al. 2001). There is an increasing recognition that possible good effects of climate change in some areas, such as tourism, do not compensate for negative effects in other areas, such as lower food production (Smith et al. 2001). The fundamental benefit of economic analysis in this field is that it enables for a thorough and uniform treatment of climate change implications. It also allows for a comparison of the advantages of climate change policy decisions to other feasible environmental policies. One C credit is equal to one tonne of CO_2, or CO_2 equivalent gases in some markets. CERs are a form of emissions unit (or C credit) awarded by the CDM Executive Board for emission reductions. Under the Kyoto Protocol, greenhouse gas accounting for soil C in agriculture is based on the rate of change in C stock. As a result, credit can be gained if the old approach produces a drop and the new activity minimizes the rate of loss.

4.3 Challenges Associated with Valuation of C

The Kyoto Protocol does not include provisions for national crediting for C sequestration in agricultural soils. However, many countries and multinational companies have made investment in C sequestration projects in agricultural soil outside Kyoto Protocol. This necessitates a strong corporate social responsibility and also legislation for fair valuation of sequestered C. Robust legislation is essential to guarantee that additionality, leakage and transaction costs are all loosened. It is anticipated that converting all croplands in the United States to conservation tillage may sequester 25 Gt C over the next 50 years. Some farmers, for example, are earning money from coal-burning fields through a C trading agreement negotiated through the Chicago Climate Exchange (Baker et al. 2007). Payments are based on the adoption of conservation tillage practices, which are estimated to sequester 0.5 t CO_2 ha^{-1} $year^{-1}$ of CO_2.

Farmers in India often have modest land holdings, making it difficult to aggregate these small land holdings (1–5 acre farm size) into a major transaction for purchasing C credits. However, reputable organizations may verify C sequestration or emission reduction activities and grant VERs (verified emission reductions), which can then be sold. As mentioned earlier in the chapter, the need for yield increase is prioritized over soil C sequestration in India, and it will be a difficult task to convince the farmers to adopt technologies for C sequestration even with higher transaction costs. Many questions must be answered before soil C trading becomes a reality in agriculture, including whether agricultural soils will be approved as a means of meeting GHG emission commitments, whether incentives can be designed to avoid countervailing C losses and how emissions reduction targets will be integrated into farmers' activities at the grass-root level.

5 Conclusion

In order to understand the method, estimate and valuation of C, as well as the soil C sequestration capacity of rice-based cropping systems, namely, rice-wheat and rice-rice cropping systems, it has been attempted to consolidate and evaluate all the material currently accessible. Likewise, to understand the method, estimate and valuation of C, as well as the soil C sequestration capacity of rice-based cropping systems, namely, rice-wheat and rice-rice cropping systems, it has been attempted to consolidate and evaluate all the material currently accessible.

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