Good Agricultural Practices and Carbon Sequestration

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A. R. Sharma and U. K. Behera

Abstract

Conservation agriculture (CA) technologies include minimum soil disturbance, permanent soil cover through crop residues or cover crops, and crop rotations for achieving higher productivity. Intensive agriculture and excessive use of external inputs have led to degradation of soil, water, and genetic resources, widespread soil erosion, nutrient mining, depleting water table, eroding biodiversity, high energy requirements, reduction in availability of protective foods, air and groundwater pollution, and stagnating farm incomes. To overcome this, CA is recognized as a potential tool. CA systems demand a total paradigm shift from conventional agriculture with regard to management of crops, soil, water, nutrients, weeds, and farm machinery. Reduction in cost of production, saving in water and nutrients, increased yields, more carbon sequestration, environmental benefits, crop diversification, and resource improvement are few prospects and opportunities lying with CA technologies. Laser land leveling, conservation tillage, direct-seeded rice, *Sesbania* brown manuring, residue management, integrated nutrient management, agroforestry, and use of biochar are important management practices for improving the carbon sequestration. There is need of developing policy frameworks and strategies for promotion of CA in the region. This article reviews the emerging concerns due to continuous adoption of conventional agriculture systems and analyzes the constraints, prospects, policy issues, and research needs for conservation agriculture and carbon sequestration.

Keywords

Carbon sequestration · Conservation agriculture · Management practices

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P. K. Ghosh et al. (eds.), *Carbon Management in Tropical and Sub-Tropical Terrestrial Systems*, https://doi.org/10.1007/978-981-13-9628-1_9

9.1 Introduction

Warming of the climate system is unequivocal, which is now evident from observations of increases in global average air and ocean temperatures. Eleven years from 1995 to 2006 rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906–2005) of 0.74 [0.56–0.92]°C is larger than the corresponding trend of 0.6 [0.4–0.8]°C (1901–2000), and over the twenty-first century, average temperature of earth surface is likely to go up by an additional of 1.8–4 °C (IPCC 2007). This temperature increase can be attributed to the altered energy balance of the climate system resulting from changes in atmospheric concentrations of the greenhouse gases (GHGs). Among the principal components of radiative forcing of climate change, CO_2 has the highest positive forcing leading to warming of climate (Fig. 9.1). CO_2 has the least global warming potential among the major greenhouse gases, but due to its much higher concentration in the atmosphere, it is the major contributor toward global warming and climate change.

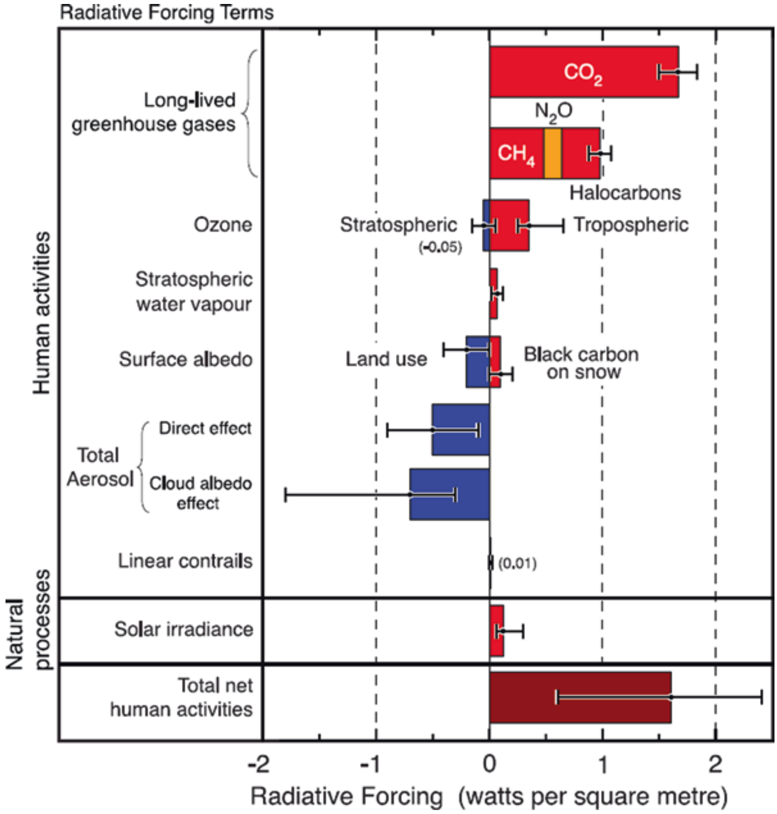


Fig. 9.1 Principal components of radiative forcing of climate change (IPCC 2007)

Carbon sequestration refers to storage of carbon in a stable solid form. It occurs through direct and indirect atmospheric CO_2 fixation processes. Direct soil carbon sequestration process occurs by inorganic chemical reactions that convert CO_2 into soil inorganic carbon compounds such as calcium and magnesium carbonates. Direct plant carbon sequestration occurs as plants photosynthesize atmospheric CO_2 into plant biomass; some of this plant biomass is indirectly sequestered as soil organic carbon (SOC) during decomposition processes. The amount of carbon sequestered at a site reflects the long-term balance between carbon uptake and release mechanisms. Many agronomic, forestry, and conservation practices, including best management practices, lead to a beneficial net gain in carbon fixation in soil. Soil gaining SOC is also generally gaining in other characteristics that enhance plant productivity and environmental quality. Increases in SOC generally improve soil structure, increase soil porosity and water holding capacity, as well as improve biological health for countless life forms present in soil. In general, there is a favorable interaction between carbon sequestration and various recommended land management practices related to soil fertility (e.g., adding mineral fertilizers, organic manures, sludges, and biosolids), tillage, grazing, and forestry.

9.2 Potential of Soil Carbon Sequestration in India

There is large number of options available for carbon sequestration in agroecosystems. Agricultural soil is a potential sink for sequestering atmospheric carbon. The carbon sequestration in soil is influenced by cropping systems and management practices. Rice-wheat is a dominant cropping system in the Indo-Gangetic plains which has positive as well as negative impacts on soil carbon sequestration. The implementation of effective land use and management practices, such as the conservation reserve program, forestry incentive program, integrated nutrient management and conservation tillage, and crop diversification, helps in increasing aboveground carbon sequestration and soil organic carbon.

Different processes are available for sequestering the atmospheric carbon. The potentiality of these different processes is varying in terms of the carbon sequestration. Soil carbon, atmosphere, and biotic pool contain 2500 Pg, 650 Pg, and 560 Pg, respectively. Soil erosion-controlling measures improve the soil carbon pool. Decline in soil quality, depleting soil organic carbon (SOC), and degradation of land resources due to erosion are the major impediments for future global food security. The productivity of some lands has declined by 50% due to soil erosion and desertification. In South Asia, annual loss in productivity is estimated at 36 million tons of cereal by water erosion. Eroded lands left unprotected lead to further erosion on-site and have greater off-site impacts. On the other hand, rehabilitation of eroded lands with conservation measures not only reverses the process of soil degradation but also improves the soil quality and converts these lands to potential carbon sinks (Lenka et al. 2012). In India, 146.82 million ha (about 45% of the land area) area is under various forms of land degradation. Degradation is particularly severe in regions with sloping and hilly terrains and those affected by unsustainable land management practices such as shifting cultivation. The sloping and hilly region of eastern India, called Eastern Ghats region, with a geographical area of 19.8 million ha is such an erosion-prone zone, having characteristic link of poor lands with people's poverty. For instance, the share of good quality soil in Orissa is one of the lowest, merely 10.4% of the land area of the state (Kumar 2011). It also happens to be the most backward Indian state with 46.4% of the population below poverty line. Shifting cultivation is prevalent in the hill slopes of the region. However, reduction in restoration or fallow cycle from 15 to 20 years to the current level of 2–3 years due to population pressure resulted in reduced farm output and increased land denudation. Mechanical measures for controlling soil erosion are not affordable by individual farmers because of extreme poverty condition. On the contrary, vegetative measures involving hedgerows and grasses are cost-effective and durable and find people's acceptance in this region as they offer multiple benefits such as for fodder and fuel wood. They are effective in low- to medium-slope ranges of arable lands. The species generally used are vegetative barriers of grass species or shrubs, and their performance for soil and moisture conservation depends upon their hedge-forming ability. Hedgerow intercropping though initially developed to restore the fertility of degraded soils in the tropics has been adopted in other regions not only for soil amelioration but also to provide additional products (e.g., fodder) and services (e.g., erosion control). Contour hedgerows are reported to promote the SOC storage because of a local effect under the hedge and also due to their anti-erosive effect (Walter et al. 2003). They are also effective in maintaining soil fertility and reducing the soil and nutrient losses in sloping lands. As the cultivated lands are scarce and fragmented, systems such as alley cropping are not popular in arable lands of the study region. The most acceptable measures are modification to field bunds through strengthening with vegetative measures with shrubs or grass species. Management practices such as conservation tillage and erosion control measures can improve the SOC stock and net C sink potential of sloping arable lands. Keeping in view the finite C sink capacity of soil (Chung et al. 2010), eroded lands, if put under erosion control measures, can be potential C sinks. Certain soil management practices such as application of manures and fertilizers and irrigation of semiarid and marginal lands for crop production, though increase the SOC status, are not net C sinks for CO_2 emission and do not contribute to the Kyoto Protocol because of the associated carbon costs. Even the advantages of no-till system over conventional tillage for SOC sequestration are questioned in recent studies; SOC buildup may be higher where the land cover is fully changed to pasture or agroforestry. But, subsistence farming, as prevalent in the region, may not permit pasture or agroforestry in agricultural lands used for growing food crops, even if they are eroded. On the other hand, keeping the land use unaltered, eroded lands can be treated with conservation measures to offset the on-site and off-site impacts on soil and environment.

In India different cropping systems are predominant and among them rice-wheat (RW) cropping system occupies 10.5 mha in Indo-Gangetic plain. Now, the productivity and sustainability of the RW system are threatened because of (a) the inefficient use of inputs (fertilizer, water, labor); (b) increasing scarcity of resources, especially water and labor; (c) changing climate; and (d) socioeconomic changes (urbanization, labor migration, preference of nonagricultural work, concerns about farm-related pollution, etc.). Therefore, there is a need for appropriate resource-conserving technologies (RCTs) to overcome these emerging constraints and to enhance system productivity, input use efficiency, and farm profitability on a sustainable basis. Besides this rice-wheat cropping system, several other cropping systems are available which can mitigate the problem arising from rice-wheat cropping system.

9.3 Processes Affecting Soil Organic Carbon Dynamics

- Aggregation: Increase in stable microaggregates due to the formation of organo-mineral complexes which encapsulate C and protect it against microbial activities (Fig. 9.2)
- Humification: To sequester 10,000 kg of C in humus, 833 kg of N, 200 kg of P, and 143 kg of S are needed
- Translocation into the subsoil: Transfer of SOC into the subsoil
- Formation of secondary carbonates
- Burial of SOC-laden sediments: Transport of SOC-enriched sediments to various depressional sites and/or aquatic ecosystems
- Plantation of deep-rooted plants

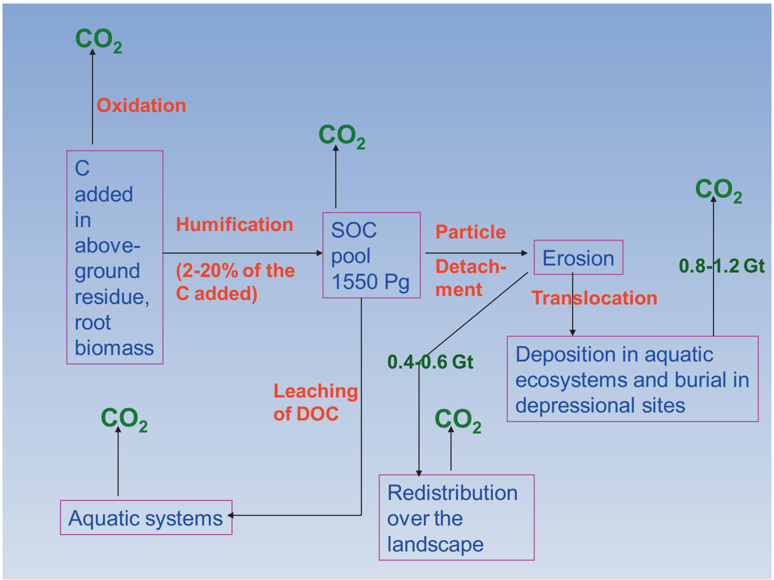


Fig. 9.2 Processes involved in soil organic carbon dynamics

9.4 Management of Soil for Increasing the Carbon Sequestration

There are different strategies for improving carbon sequestration and those are described below.

9.4.1 Laser Land Leveling

Laser land leveling (Fig. 9.3) alters fields having a constant slope of 0–0.2% using laser-equipped drag buckets and gives a smooth land surface (± 2 cm). Large horsepower tractors and soil movers equipped with global positioning systems (GPS) and/or laser-guided instrumentation help to move soil either by cutting or filling to create the desired slope. Laser leveling provides a very accurate, smooth, and graded field, which helps in saving of irrigation water up to 20% and improves the use efficiency of applied N.

9.4.2 Conservation Tillage (Zero/Minimal Tillage)

Conservation tillage (Fig. 9.4) is the collective umbrella term, commonly given to no-tillage, direct-drilling, minimum-tillage, and/or ridge-tillage, to denote that the specific practice has a conservation goal of some nature. Usually, the retention of 30% surface cover by residues characterizes the lower limit of classification for conservation tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients.

9.4.3 Bed Planting (Narrow/Broad Beds)

In bed planting (Fig. 9.5), crops are grown on the raised beds alternated by furrows. Beds are usually made at 0.6–1.0 m wide, and two to three rows of crops are sown on the beds. The furrow-irrigated raised-bed system (FIRBS) of wheat cultivation

Fig. 9.3 Laser land leveler

Fig. 9.4 Zero-tilled sowing

Fig. 9.5 Bed planting

has been shown to result in saving of seed by 25–40%, water by 25–40%, and nutrients by 25%, without affecting the grain yield (Das 2012).

9.4.4 Direct-Seeded Rice

Direct dry seeding of rice (Fig. 9.6) with subsequent aerobic soil conditions reduces overall water demand; saves labor, fuel, and time; and gives similar yield to transplanted rice, if weeds are effectively controlled. The technology does not affect rice quality and can be practiced in different ecologies such as upland, medium, and lowland and deepwater and irrigated areas (Pathak et al. 2012). Soil health is maintained or improved, and fertilizer and water use efficiencies increase. Therefore, it can be a feasible alternative to conventional puddled transplanted rice.

Fig. 9.6 Direct-seeded rice

Fig. 9.7 Brown manuring with *Sesbania*

9.4.5 *Sesbania* Brown Manuring

In brown manuring (Fig. 9.7), rice and *Sesbania* are sown together and allowed to grow for 25–30 days before knocking down *Sesbania* crop with 2,4-D ester salt at a rate of 0.40–0.50 kg ha^{-1}. The technology smothers weed, reduces herbicide use, lowers irrigation application, supplies 15–20 kg N ha^{-1} with a fresh biomass of 10–12 t ha^{-1}, facilitates better emergence of rice where soil crusting occurs, conserves moisture with brown mulch, improves soil C content, and increases farmers' income.

9.4.6 Leaf Color Chart (LCC)

Leaf color chart (LCC) (Fig. 9.8) is an easy-to-use and inexpensive tool for site-specific N management in crops/plants. Use of the LCC would promote timely and efficient use of N fertilizer in rice and wheat to save costly fertilizer and minimize the fertilizer-related pollution of surface and groundwater. It is a promising eco-friendly and inexpensive tool in the hands of the farmers.

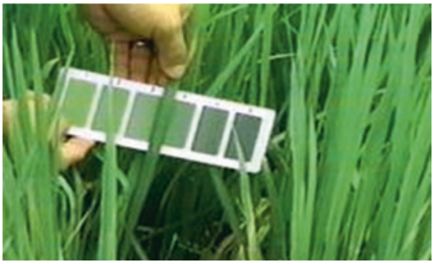


Fig. 9.8 Leaf color chart

Fig. 9.9 Zero-till wheat with rice residues

9.4.7 Residue Retention for Mulch

Cropland offers a huge potential for sequestering C, especially when crop residues are managed properly. Permanent or semipermanent crop/plant residue cover on soil, which can be a growing crop or dead mulch, has a role to protect soil physically from the sun, rain, and wind and to feed soil biota/microorganisms that take over the tillage function and soil nutrient balancing. Crop residues (Fig. 9.9) significantly influence soil physical, chemical, and biological properties. It helps in water conservation through enhanced water infiltration, and reducing evaporation, and wind and water erosion.

9.4.8 Integrated Nutrient Management

The common recommended management practices leading to improve soil C sequestration under integrated nutrient management include the use of manures, compost, crop residues, and biosolids, mulch farming, conversation tillage, agroforestry, diverse cropping systems, and cover crops (Lal 2004). All these practices have the potential to alter C storage capacity of agricultural soil. The addition of fertilizer on a regular basis leads to an increase in SOC and soil microbial biomass and also alters soil C and N dynamics. Soil organic carbon is reported to increase by the continuous application of different combinations of N, P, and K, whereas it decreased in unfertilized soils. Accordingly, integrated use of FYM and fertilizers either maintained or improved SOC. The beneficial effect of incorporation of crops residues is more as compared to its burning or removal. The use of FYM/GM along with incorporation with crop residues has been found to be even more beneficial (Singh et al. 2007). The incorporation of organic manures and crop residues to soil on long-term basis helps in C sequestration, but the rate of C sequestration can vary with the type and nature of organic manure. The rate of change in SOM in agricultural soils is very slow and can take decades to centuries. The change in SOC fractions like labile carbon, water-soluble carbon, and microbial biomass C can be promptly influenced by changes in C inputs. Labile C is the fraction of total C that declines faster and is restored faster and is sensitive to best management practices.

9.4.9 Agroforestry in Carbon Sequestration

- *Direct role*: Carbon sequestration rates ranging from 1.5 to 3.5 Mg C ha^{-1} $year^{-1}$ in agroforestry systems.
- *Indirect role*: Agroforestry has also some indirect effects on C sequestration since it helps to reduce pressure on natural forests.

9.4.10 Arbuscular Mycorrhizal Fungi in Carbon Sequestration

It increases the surface area of roots and releases some organic acids. Mycorrhiza is responsible for better soil aggregation and improves the carbon sequestration in soil (Fig. 9.10).

9.4.11 Biochar in Carbon Sequestration

Biochar is a fine-grained and porous charcoal-like material produced by pyrolysis of biomass in an oxygen-limited condition. It acts as atmospheric carbon sink. A

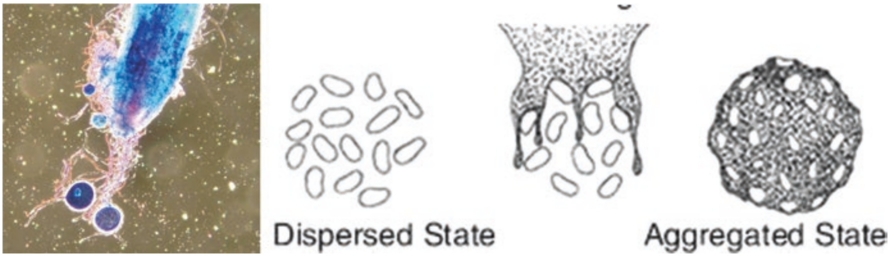
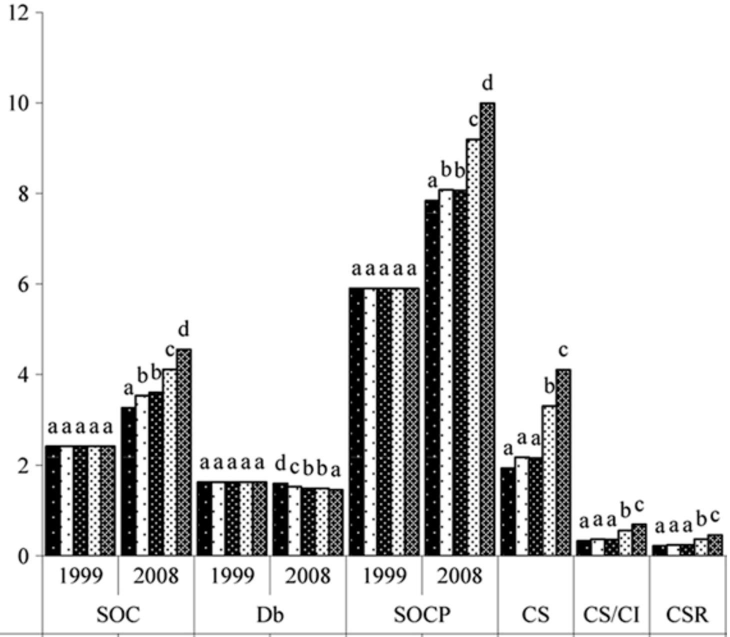


Fig. 9.10 Arbuscular mycorrhiza

significant portion of biochar is found in the organo-mineral fraction of soil suggesting that biochar forms interactions with minerals. Direct spectroscopic evidence for large particles showed biochar to be embedded within the mineral matrix.

The soil organic carbon pools and rate of carbon sequestration (Fig. 9.11) were significantly increased through balanced fertilization (100% NPK) when farmyard manure was applied in conjunction with 100% NPK in rice-wheat cropping system (Brar et al. 2012).

The bulk density of soil decreased with fertilization. This decreased was nonsignificant with imbalanced fertilizer application. However, balance fertilizer application (100% NPK) integrated with organic manure (FYM) proved best among all the treatments which significantly decreased the bulk density of surface soil (0–15 cm) over the imbalanced fertilizer treatments. The decrease in bulk density over the years could be attributed to the addition of root and plant biomass and to the conversion of some micropores into macropores due to cementing action of organic acids and polysaccharides formed during the decomposition of organic residues by higher microbial activities.



	SOC		Db		SOCP		CS	CS/CI	CSR
	1999	2008	1999	2008	1999	2008			
■ Control	2.42	3.26	1.63	1.60	5.90	7.84	1.94	0.33	0.22
□ 100% N	2.42	3.53	1.63	1.53	5.90	8.08	2.18	0.37	0.24
▣ 100% NP	2.42	3.60	1.63	1.49	5.90	8.06	2.16	0.37	0.24
⊡ 100% NPK	2.42	4.11	1.63	1.49	5.90	9.19	3.30	0.56	0.37
▩ 100% NPK+FYM	2.42	4.55	1.63	1.46	5.90	9.99	4.10	0.69	0.46

Fig. 9.11 Effect of INM on soil organic carbon pool and sequestration rate

Table 9.1 Impact of tillage on SOC and greenhouse gas emissions in IGP

Region/state	Gross SOC stock (Mg C ha^{-1})		Associated GHGs (Mg C ha^{-1})	
Rice-wheat	Conv. till	No-till	Conv. till	No-till
Bihar	27.25	**33.52**	23.29	**23.33**
Haryana	24.14	**28.25**	32.10	**30.84**
Punjab	26.22	**30.68**	34.67	**33.52**
Uttar Pradesh	26.22	**30.68**	26.52	**25.17**
West Bengal	37.69	**46.35**	25.67	**24.76**
Maize-wheat				
Uttar Pradesh	24.14	**28.25**	8.65	**8.14**
Cotton-wheat				
Haryana	21.39	**25.03**	11.62	**10.87**
Punjab	24.14	**28.25**	13.16	**12.42**

A switch over from conventional to conservation tillage reduces carbon oxidation and thus emissions of CO_2. Grace et al. (2011) reported (Table 9.1) that the C sequestration potential of rice-wheat systems of India on conversion to no tillage is estimated to be 44.1 Mt. C over 20 years. Implementing no-tillage practices in maize-wheat and cotton-wheat production systems would yield an additional 6.6 Mt C. This offset is equivalent to 9.6% of India's annual greenhouse gas emissions. So long-term use of zero tillage improves the carbon sequestration in soil, and the three pillars of conservation agriculture – (1) minimum disturbance of soil, (2) permanent soil cover, and (3) crop rotations – are responsible for carbon sequestration.

Contour hedgerows and grass filter strips are important toward enhancing and sustaining productivity of sloping agricultural lands in medium- to high-rainfall regions. Averaged over 3 years of observation, the efficacy of *Indigofera* + grass filter strip was found superior (Table 9.2) with lowest runoff (8.9%) and soil loss (5.0 Mg ha^{-1}), followed by *Gliricidia* + grass filter strip (10.7% runoff and 6.3 Mg ha^{-1} soil loss). A consistently lower runoff and soil loss under *Indigofera* + grass filter strip was observed as compared to sole *Gliricidia* (Lenka et al. 2012). Higher SOC buildup is possible with complete land cover change with pastures or agroforestry systems due to increased rate of organic matter addition and retention. A SOC buildup rate of 3.5–4.5 Mg ha^{-1} year^{-1} could be possible with *Stylosanthes* and grass cover in degraded hillock sites as reported by Lenka et al. (2012). If lands are degraded, the response to restorative measures may be higher, and thus the C sequestration rate may be higher in the initial years before reaching a plateau, as compared to crop fields cultivated with management practices. For instance, the rate of change in SOC stock observed after 21 years in a rice-lentil cropping system varied from 0.043 to 0.462 Mg ha^{-1} year^{-1} (Srinivasarao et al. 2011), which is relatively lower as compared to the findings of this study. Agroforestry systems have the potential to sequester atmospheric carbon in trees and soil for maintaining sustainable productivity.

Pathak and Aggarwal (2012) reported some potential low carbon agricultural technologies (Table 9.3) for wheat production in the upper IGP. In case of wheat

Table 9.2 SOC sequestration rate potential of hedgerows and grass filter strips

	SOC sequestration rate (Mg ha^{-1} year^{-1})		
Treatments	1 m	2 m	Plot
Indigofera	0.416	0.258	0.21
Indigofera + GFS	1.346	0.642	0.39
Gliricidia	0.942	0.692	0.336
***Gliricidia* + GFS**	**1.418**	**0.818**	**0.412**
Control	–	–	–
Sole GFS	0.318	0.19	0.128
Initial	0.046	0.112	0.088
CD ($P = 0.05$)	0.07	0.12	0.06

Table 9.3 Potential low carbon agricultural technologies for wheat production in upper IGP

Technology	GWP (CO_2 eq. ha^{-1})	Change in GWP over conventional practices (%)	B:C ratio with carbon credit	Area required for 1000 t CO_2 mitigation (ha)
Conventional	1808	–	–	–
Sprinkler	1519	−15.98	1.92	3460.2
Zero tillage	111	−93.86	2.26	589.3
INM	−171	−109.46	1.98	505.3
Organic	−1880	−203.98	2.01	271.2
Nitrification inhibitors	1663	−8.02	2.01	6896.6
SSNM	1696	−6.19	1.91	8928.6

crop, GWP reduction strength of the technologies ranged from 6% to 204% in the upper IGP. The GWP reduction was maximum with organic management and minimum with SSNM in wheat crop. But the B:C ratio of organic management was less than conventional management. Zero tillage and nitrification inhibitor technologies have shown higher values of B:C ratio than the conventional practice in the wheat crop.

9.5 Future Aspects

Detailed study about the interaction mechanisms of different GHGs should be evaluated.

- Long-term impacts of conservation agricultural practices on soil quality still need to be assessed.
- Future research should try to optimize the production of biochar and bio-oil by varying the feed stock quality and pyrolysis temperature to obtain the best possible combination for the purpose of carbon sequestration.

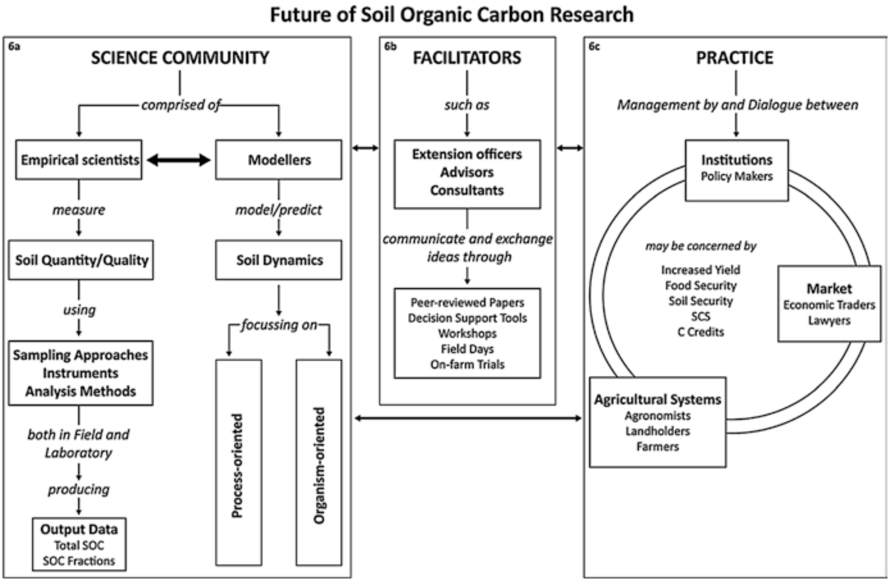


Fig. 9.12 Interdisciplinary approaches in carbon sequestration

- Any single process cannot improve the carbon sequestration in soil. There is need of multidisciplinary approach with scientist, farmers, and policy-makers to come together for mitigating this gravest threat.

Further research (Fig. 9.12) evaluating investment certainty is needed before recommending wide-scale dissemination of new technology for carbon sequestration and climate change mitigation.

9.6 Conclusion

- Soil carbon sequestration is an important cost-effective tool in climate change mitigation program.
- Conservation agriculture, organic farming, agroforestry, and biochar application can easily be adopted, and these practices have a positive impact on soil carbon sequestration and crop productivity.
- Crop diversification and intercropping could be viable options for enhancing carbon sequestration in changing climatic scenario.
- For sequestering the atmospheric carbon and for maintaining sustainability, integrated nutrient management has a pivotal role.
- Successful carbon sequestration in major production system in India requires knowledge, thorough understanding, proper channel to disseminate the technology, financial backup, and government efforts.

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