

Soil carbon management

in rainfed production systems

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Low input farming, under rainfed condition coincided with high temperature have adverse impact on soil organic carbon (SOC) through depletion of nutrient status, and low productivity. About 67% of the Indian soils are deficient in SOC. Increasing SOC stocks in dryland help in mitigating the increasing atmospheric carbon dioxide (CO₂) concentration; besides improving the soil quality attributes such as stability of aggregates, soil fertility and nutrient cycling etc. Therefore, this article aims on the present status of SOC and key reasons for its depletion in Indian soils and technological approaches to achieve the improved profile of SOC stocks in dryland areas. Use of FYM, vermi-compost, oilcakes, poultry manure, judicious fertilizer application, reduce/no tillage, utilization of crop residue, integrated nutrient management, use of bio-fertilizers, rotation with high-residue/high biomass crops, application of bio-char, use of cover crops, amelioration of degraded land with organic amendments, switch from single cropping to inter-cropping, pasture cropping and agroforestry with trees/shrubs with crops, introducing pulse crops in cropping system to promote atmospheric N₂ fixation, eliminating summer fallow periods, avoiding residue burning, use of technology for soil carbon monitoring etc are more or less effective for increasing carbon sequestration.

Keywords: Crop residues, Drought, Land degradation, Soil carbon stock, Soil health

MOST of the rainfed farmers are resource poor small and marginal but their share for the food production is almost 60% of the total food grain. Rainfed areas in the country support nearly 40% of the country's population and 60% of livestock with the production of 90% of millets, 80% of pulses and oilseeds, 60% of cotton. Among all the existing issues, food crisis remains the most unsolved problem around the globe until date as the human population growth is at an alarming rate. However, several critical challenges for the nation's food security, such as climate change induced droughts, cyclones, heatwaves, irregular rainfall pattern, etc coinciding with non-judicious management of natural resources are degrading the soil productivity and affecting the overall crop yields and environmental quality specifically in drylands, consequently impacting the income of small and marginal farmers. As per the estimations, by 2030, India needs to produce 304 million tonnes (MT) of food grains, 96 MT of fruits, 175 MT of vegetables, 21 MT of meat, eggs and fish and 170 MT of milk and by 2050,

the production must be enhanced by 65% to meet the requirement of ever-growing population. This has to be achieved in the face of shrinking arable land and farm size, low productivity, growing regional disparities in productivity and depletion of the natural resource base. Soil organic carbon (SOC) helps in maintaining the physico-chemical and biological properties of the soil which ultimately help in producing more biomass and food. Sustainable management of SOC specifically in rainfed areas is critical to sustain the food security and soil fertility without impairing the environmental quality. Therefore, it is the need of the hour for the humankind to realize the mistakes done since decades and transform the current agriculture system into sustainable production system using present innovative technologies in order to ensure the global food security and environmental safety.

SOC status of rainfed regions of India and causes for its depletion

The SOC is the biggest carbon pool in the terrestrial biosphere. It is estimated that 3.667 tonnes of CO₂

is emitted from 1 tonne of soil organic matter. The average concentration of SOC ranges from 0.30–1.05% in top 30 cm soil profile and accounts around 10% of the SOC stocks (140–170 Pg) in agriculture ecosystem and active fragments of terrestrial farmlands. In most of cultivated soils, the SOC is less than 5 g/kg in comparison to uncultivated soils i.e. 15–20 g/kg. About 67% of the Indian soils are deficient in SOC specifically, soils of arid, hot ecosystems are low in SOC stock as compared to those of semi-arid, sub-humid and coastal environments. The carbon (C) sequestration potential in Indian soils is estimated at 7–10, 5–7, 6–7 and 22–26 Tg C/y for restoration of degraded soils and ecosystems, erosion control, adoption of recommended management practices (RMPs) on agricultural soils, and for secondary carbonates, respectively. Thus, in India the total carbon sequestration potential is 39–49 (44 ± 5) Tg C/y.

The carbon depletion is associated with several factors such as disruption in soil aggregation, decomposition of SOM, accelerated aeration, alteration in plant productivity, biomass production and soil biological properties. The annual carbon sequestration rate could be increased by 20–75 g C/m² by changing the land-use pattern through the adoption of SOC enhancing technologies.

Proven strategies for enhancing SOC

Crop residue recycling: Soil organic matter (SOM) can be efficiently improved by the incorporation of crop residues such as stubbles, stem, leaves, husks, etc which also play a decisive role in improving soil quality and sequestering SOC as well as addressing several environmental issues. Residue incorporation changes the labile pool of SOC. Retention of sun hemp residues on soil surface significantly enhanced the SOC by 0.92% compared to control plots (no residue incorporation). Legume-based residue incorporation ensures the production of huge biomass that confirms the net gains of carbon stocks in comparison with cereals, which produces less biomass. Alternatively, crop residues can also be used to make a biochar (by-product of the pyrolysis: bio waste is heated at 400–600°C temperature in absence of oxygen). Agricultural wastes such as poultry litter, waste wood, manure, plant material,

bagasse, etc are used in making biochar, which then becomes a great source of carbon.

In India, about 500 MT of crop residue is produced every year as per the report of the Ministry of New and Renewable Energy of which domestic and industrial sector consume a big share. Apart from these, a huge portion of residues is still left in the field. In some places, it is also burnt in the field itself. On-site burning of crop residues produces huge amount greenhouse gases (GHGs) i.e. majorly methane (CH₄) and nitrous oxide (N₂O) gases that harm the soil quality by depleting SOC and environment.

Cover crops: Cover crops are well known for atmospheric-nitrogen (N₂) fixation that improve N recycling in the soil-plant system. Integrating cover crop into crop rotations highly benefits the soil by enhancing the soil C sequestration and organic matter. Incorporation of the roots and stubbles of leguminous cover crops grown for short periods helps in maintaining the high levels of SOM in some soils. Incorporation of short duration legume cover crops at the stage of flowering would enhance the soil organic matter that ultimately improves the nutrient cycling besides protecting the soil from erosion. Additionally, soil biological factors such as arbuscular mycorrhizal fungi (AMF) and microbial population and its activity would be efficiently promoted by cover crop, which have a large effect on soil aggregation.

Integrated nutrient management: Integrated nutrient management (INM), whereby both organic manures/amendments and inorganic chemical fertilizers are combinedly used is an efficient technique for attaining sustainability in crop production. INM is one of the best strategies that would help in restoring the depleted SOC, while improving the degraded soils and crop yields. Per cent increase in SOC stock over inorganic or recommended dose of fertilizer (RDF) treatment under various INM treatment combinations in different cropping systems have been illustrated in Table 1. From this study, it was noticed that INM practices in pearl millet cropping significantly improved the profile SOC stock by 110–112% over the 100% inorganic treatment. Also, the INM in pearl millet-cluster bean-castor, groundnut, finger millet and post monsoon



Recycling of crop residue



Horsegram and greengram cover crop

sorghum crops enhanced the profile SOC stock by 32%, 43–47% and 16–22% and 16–22% respectively against the inorganic treatment.

Table 1. Profile SOC stock and per cent increase over inorganic treatment under different INM treatment combinations

Crop /cropping system	INM treatment combination	Profile SOC stock (mg/ha)	SOC stock increased over inorganic/ RDF treatment (%)
Pearlmillet-cluster bean-castor	50% RDN (F) + 50% RDN (FYM)	25.5	32
Groundnut	50% RDF + 4 mg/ha FYM	45.9	43
	50% RDF + 4 mg/ha GNS	47.2	47
Finger millet	FYM 10 mg/ha + 100% NPK	85.7	22
	FYM 10 mg/ha + 50% NPK	81.6	16
Post monsoon sorghum	25 kg N (FYM) + 25 kg N (Urea)	62.6	16
	25 kg N (CR) + 25 kg N (Urea)	65.8	22
Groundnut-finger millet	FYM + 50% NPK	72.9	9.6
	FYM + 100% NPK	73.0	9.7
Soybean-safflower	6 Mg FYM _{N₂₀} P ₁₃ /ha	69.9	7.2
	5 Mg CR _{N₂₀} P ₁₃ /ha	68.7	6
Rice-lentil	50% organic (FYM) + 50% RDF	24.0	3.5
Groundnut	50% RDF + 6 mg/ha compost (farm yard manure (FYM) + bio-fertilizers (BF)	71.6	8.4
Pearlmillet	50% N-Fertilizer + 50% N-crop residue	44.2	110.4
	50% N-Fertilizer + 50% N-FYM	44.6	112.3

Values in the parenthesis are profile SOC stock in the inorganic treatment. CR; crop residue.

Tank silt application

Tank silt is topsoil eroded with high intensive rains which contain fine soil particles (silt + clay) and organic materials that accumulate in farm or village tanks. It is a rich source of nutrients and SOC. The tank silt

collected from some tanks of eight districts of Andhra Pradesh showed the nutrient content (range) as: organic C (%) from 0.4–2.0; mineral N (mg/kg) from 200–1400; available P (mg/kg) from 8.0–35.2; K (mg/kg) from 400–600; S (mg/kg) from 12–50; Zn (mg/kg) from 0.7–2.2 and B (mg/kg) from 0.3–1.0. Being rich in SOC and other nutrients, its application in rainfed agriculture can enhance water holding capacity (WHC). Tank silt application has improved the organic carbon from 0.30–0.38%.



Tank silt application

Balanced nutrition: Balanced fertilization/nutrition is the supplement of plant nutrients in the right proportion, in the right method and at the right time for a specific crop and agro-climatic situation, which improves soil health and nutrient use efficiency. Government of India launched Soil Health Card (SHC) in 2015 to ensure the farmland's nutrient status and decided the recommended dose of fertilizers to reduce the burden on agriculture soils. Implementation of site specific nutrient management (SSNM) package (tested the individual fields for nutrient deficiencies and recommended the particular nutrient requirement of the crop) in 8 clusters of Telangana and Andhra Pradesh resulted in increased yield by 25% in major rainfed crops in comparison with farmers' practices. Combining these techniques with carbon biomass addition in the form of manures, crop residues, or with any other organic amendments would be effective in enhancing the SOC status of the soils.

Soil restoration by minimizing degradation: Loss of SOC pool driven by erosion, acidification, salinization, elemental imbalance etc through physico-chemical, biological and ecological degradation leads to decline in soil quality. This can only be minimized through the adoption of recommended management practices. Enhancing the SOC pool to above critical level (10–15 g/kg) is highly required to set-in-motion the restorative trends. India joined the global commitment “Bonn Challenge” and pledged a total of 21 million hectares (ha) to be restored by 2030 (13 mha by 2020 and an additional 8 mha by 2030). This mainly focusses on restoring land productivity and ecosystem services of 26 million hectares of most degraded and vulnerable land by adopting a landscape restoration approach.

Mulch cum manuring: Mulching has been considered as an effective practice for conserving soil health specifically under rainfed condition. In rainfed regions, soil moisture protection and reduction of C losses is a great challenge. Crop residues of rainfed crops such as cotton, castor, pigeon pea, maize, etc left on the surface and a legume residue can be utilized as a mulch-cum-manure that contributes to improve crop productivity and soil fertility. Decomposition of mulches leads to addition of nutrients and organic carbon to the soil. Mulches reduce evaporation losses, insulate soil against extreme heat and cold by moderating soil temperature, reduce soil compaction, and control the wind and water erosion.

Green manuring: Incorporation of green manure biomass into the soil helps in the accumulation of organic matter and recycling of plant available nutrients. Especially, leguminous green manures are recognized to be a promising nutrient source that improves the soil nutrient accumulation. Because of its lowest C:N ratio than cereal crops, it promotes a faster mineralization of nitrogen which significantly increases enzymatic activities (urease and dehydrogenase) in the soil. Green manuring/green leaf manuring improves soil biological health and enhances soil moisture storage, which helps in coping with intermittent droughts.

Growing short duration legume crops such as horsegram, greengram, cowpea etc and incorporating into the soil at flowering stage would add huge amount of organic matter to the soil that helps in increasing crop yields. Green manure crops such as greengram, cowpea, and *sesbania* used for *in situ* manuring for five consecutive years helped in enhancing total organic carbon (TOC) stocks significantly ($P < 0.05$) compared

Table 2. Effect of different green manuring on depth-wise TOC stocks (Source: Ansari *et al.* 2022)

Treatment	TOC stocks (mg/ha)		
	0–15 cm	15–30 cm	30–45 cm
No green manuring	19.0	15.4	13.1
Greengram green manuring	21.4	17.2	14.1
Cowpea green manuring	23.4	18.5	15.1
<i>Sesbania</i> green manuring	24.6	19.2	15.1
LSD ($P < 0.05$)	1.06	0.88	0.69

to non-green manured soils (Table 2). Forest tree crops such as *Gliricidia* spp., *Pongamia glabra*, *Cassia fistula*, *Calotropis gigantea*, *Delonix regia*, *Azadirachta indica* etc can be utilized for green leaf manuring.

Composting: Composts are bulky in nature for e.g. farm yard manure, vermicompost, kitchen waste composts, sheep manure, poultry litter, bio-enriched composts, market waste compost, and night soils (urban composts). Organic manures substantially increase the SOC content that proliferate the soil microbial activity ultimately resulting in retaining soil moisture and nutrients besides imparting drought tolerance during dry spells.

Programmes and policies

Government of India has initiated several policies and programs for promoting the buildup of SOC, which facilitated the farmers to improve their land fertility status through some innovative technologies. National Mission for Sustainable Agriculture (NMSA), Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Soil Health Card (SHC), National Policy for Management of Crop Residue (NPMCR), Customized Fertilizers, National Biogas and Manure Management Programme (NBMMP), Neem Coated Urea Scheme, Rehabilitation of Degraded Lands Targets and Land Degradation Neutrality, Nano Fertilizers and India’s commitment for Net Zero Emissions are some of the steps for improving soil health.

SUMMARY

In Indian soils, the soil C stock in the upper 40 cm soil horizon is depleted at the rate of 0.1–1.0% per year due to prolonged intensive cultivation. Additionally, climate change and other key factors are further worsening the status of cultivating lands specifically in dry regions of India. In rainfed agriculture, among all extreme events, temperature is being one of the key factors for destroying soil organic matter that leads to decline in the crop yields and productivity of lands at greater extent. Almost about 63% of areas are prone to some degree of desertification in dryland areas. Soil management practices that aid in provision of adding high C biomass inputs or balanced plant nutrient input/output for sustaining the SOC levels or for protecting/improving the residual profile SOC stocks specifically in dryland situations help in achieving the land degradation neutrality (LDN) and sustainable developmental goals (SDGs) in India.

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Farmyard manure and vermicompost