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Soil carbon sequestration in rainfed production systems in the semiarid tropics of India

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HIGHLIGHTS

- Soil organic carbon (SOC) is a strong determinant of soil quality and productivity.
- High temperatures and low soil moisture are causes of SOC depletion in the tropics.
- Application of chemical fertilizer and organic amendments improve the SOC stock.
- Improvement of SOC stock increase the crop yields even in rainfed conditions.
- National level policy interventions needed to promote measures for C sequestration.

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ABSTRACT

Severe soil organic carbon (SOC) depletion is a major constraint in rainfed agroecosystems in India because it directly influences soil quality, crop productivity and sustainability. The magnitude of soil organic, inorganic and total carbon stocks in the semi-arid bioclimate is estimated at 2.9, 1.9 and 4.8 Pg respectively. Sorghum, finger millet, pearl millet, maize, rice, groundnut, soybean, cotton, food legumes etc. are predominant crop production systems with a little, if any, recycling of organic matter. Data from the long term experiments on major rainfed production systems in India show that higher amount of crop residue C input (Mg/ha/y) return back to soil in soybean–safflower (3.37) system practiced in Vertisol region of central India. Long term addition of chemical fertilizer and organic amendments improved the SOC stock. For every Mg/ha increase in SOC stock in the root zone, there occurs an increase in grain yield (kg/ha) of 13, 101, 90, 170, 145, 18 and 160 for groundnut, finger millet, sorghum, pearl millet, soybean and rice, respectively. Long-term cropping without using any organic amendment and/or mineral fertilizers can severely deplete the SOC stock which is the highest in groundnut–finger millet system (0.92 Mg C/ha/y) in Alfisols. Some agroforestry systems also have a huge potential of C sequestration to the extent of 10 Mg/ha/y in short rotation eucalyptus and *Leucaena* plantations. The critical level of C input requirements for maintaining SOC at the antecedent level ranges from 1.1 to 3.5 Mg C/ha/y and differs among soil type and production systems. National level policy interventions needed to promote sustainable use of soil and water resources include prohibiting residue burning, reducing deforestation, promoting integrated farming systems and facilitating payments for ecosystem services. A wide spread adoption of these measures can improve soil quality through increase in SOC sequestration and improvement in agronomic productivity of rainfed agroecosystems.

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1. Introduction

India is still a predominantly agrarian economy. Of the total geographical area of 328.7 million ha (Mha), 141 Mha is the net cultivated area devoted to agriculture, of which only 63 Mha or 44% is the net irrigated area producing more than 56% of the total food grains (FAI, 2011). While generating only 44% of the total food, rainfed agriculture is critical as it contributes significantly to the production of coarse cereals (90%), pulses (87%), and oil seeds (74%). These commodities, produced under rainfed agro-ecosystems, are vital for ensuring food and nutrition security for the ever-growing population. Because of the large diversity in rainfall patterns, temperature regimes, parent materials, vegetation and relief or topography, India is endowed with a wide range of soil types. Inceptisols (95.8 Mha) are the predominant soil types in India followed by

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Entisols (80.1 Mha), Alfisols (79.7 Mha), Vertisols (26.3 Mha), Aridisols (14.6 Mha), Mollisols (8.0 Mha), Ultisols (0.8 Mha), Oxisols (0.3 Mha) and miscellaneous soils (23.1 Mha).

Soil degradation is one of the major constraints threatening food security of the country. Out of 328.7 Mha of total land area, 120.72 Mha (36.70%) is degraded to some degree. Among principal degradation processes, 73.27 Mha (60.27%) is affected by water erosion, 12.40 Mha (10.30%) by wind erosion, 17.45 Mha (14.50%) by chemical degradation, and 1.07 Mha (0.9%) by physical degradation (ICAR, 2010). Another 18.2 Mha (5.5%) of land area is not suitable for agriculture because of the limitations of ice caps, salt flats, arid mountains, and rocky physiography (Sehgal and Abrol, 1994). Because of the long-term use of extractive farming practices in rainfed regions, most soils are degraded to varying degrees and are characterized by low soil organic matter (SOM) concentration, unfavorable soil structure and tilth, low nutrient reserves, and marginal productivity (Sharma et al., 1999). Land scarcity and low per capita land area necessitate cultivation of marginal lands, albeit at high economic, ecological and environmental costs.

The semiarid tropics (SAT) include those regions of the world where rainfall exceeds potential evapotranspiration for only 2 ± 4.5 months of the year (dry SAT) or 4.5 ± 7 months (wet SAT) with a mean annual temperature in either case of >18 °C (Troll, 1965). Semi-arid or dryland tropics cover almost 6.5 million km^2 of land in 55 countries in the world and are inhabited by more than 2 billion people (ICRISAT, 2010). Approximately 60% of these drylands are in developing countries. Around 170 million ha of the SAT area is located in India (Fig. 1). Average grain yields in these areas of developing countries are 1.5 Mg/ha which is about half of those in irrigated areas (3.1 Mg/ha). Uncertainty in rainfall,

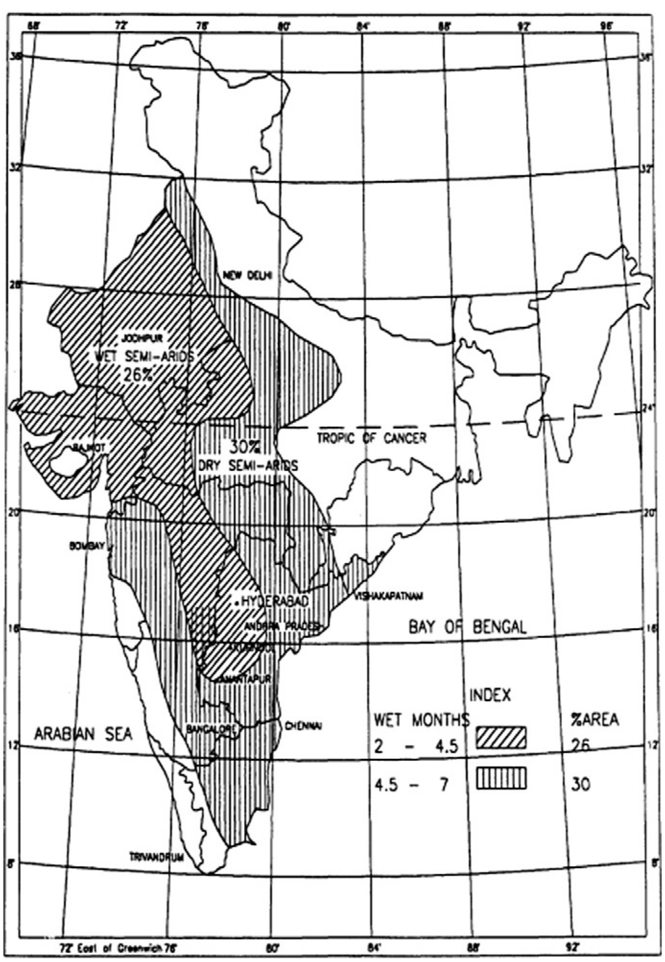

Fig. 1. Semiarid tropics of India (Source: Adopted from Troll, 1965; World Maps of Climatology).

degraded lands, low input application, biotic stress, poor crop management, lack of focused extension program and appropriate policy support are the main causes of such a low productivity (Rockstrom et al., 2010). Most soils are severely depleted in SOC reserves.

Soil organic carbon (SOC) concentration is a key indicator of soil quality and productivity. Thus, restoring quality of degraded soils necessitates increasing SOC concentration in the root zone. The term "soil C sequestration" implies removal of atmospheric CO_2 by plants through photosynthesis and transfer of the biomass C into soil as humus. The strategy is to increase SOC density, improve depth distribution of SOC and stabilize SOC by encapsulating it within stable micro-aggregates so that C is protected from microbial processes and has a long mean residence time (MRT). In this context, adopting recommended management practices (RMPs) in agroecosystems, and those which create a positive soil C budget, is an important strategy for SOC/terrestrial sequestration. Thus, land use change can be an important instrument for SOC sequestration. Whereas land misuse and soil mismanagement have caused depletion of SOC with an attendant emission of CO_2 and other green house gases (GHGs) into the atmosphere, there is a strong case that enhancing SOC pool could substantially offset fossil fuel emissions (Kaupppi et al., 2001) and also improve soil quality as well as generate ecosystem services. However, the SOC sink capacity depends on the antecedent level of SOC, climate, profile characteristics and management. The SOC sink capacity for atmospheric CO_2 can be greatly enhanced when degraded soils and ecosystems are restored, and marginal agricultural soils are converted to a restorative land use or replanted to perennial vegetation. Incorporation of SOC into the sub-soil by establishing plants with a deep tap root system or illuviation through bioturbation and pedogenesis can increase its MRT. Converting agricultural land to a more natural or restorative land use essentially reverses some of the effects responsible for SOC depletion that occurred upon conversion of natural to managed ecosystems. Applying ecological concepts to the management of natural resources (e.g., nutrient cycling, favorable C budget, soil mixing by macro invertebrates and enhanced soil biodiversity) may be an important factor to improving soil quality and SOC sequestration (Lavelle, 2000). The SOC concentration in the surface layer usually increases with increasing inputs of biosolids (Graham et al., 2002), although the specific empirical relation depends on soil moisture and temperature regimes, nutrient availability (N, P, K, S), texture and climate. In addition to the quantity of input, quality of biomass can also be important in determining the SOC pool. Most of the research done thus far on SOC sequestration in soils of agroecosystems is confined to cold and temperate regions. There is little research information available on this theme in the tropical and sub tropical regions of India (Velayutham et al., 2000; Lal, 2004a; Srinivasarao et al., 2011a, 2012a,b,c,d,e,f, 2013a,b). The objective of this chapter is to synthesize the available information on carbon stocks in different soil types and agro-climatic zones, carbon sequestration scenarios in major rainfed production systems, minimal carbon input requirement for zero change in C stock, and important management practices and strategies which influence C sequestration and large scale policy interventions required in Indian context.

2. Carbon stocks in soil types and agro-climatic zones

2.1. Carbon stocks in various soil orders and different types of soils

Vertisols, Inceptisols and Alfisols comprise a major share of soil organic carbon (SOC) stocks in the top 30 cm depth. For similar depth, Aridisols have low SOC but high (33%) soil inorganic carbon (SIC) stocks. For the purpose of this synthesis, Indian soils are broadly classified into five groups. The data in Fig. 2 show SOC and SIC stocks in five major soils of India. The maximum SOC stocks are observed in red soils (Alfisols and Ultisols), alluvial soils (Entisols and Inceptisols) and black soils (Vertisols). Since total carbon (TC) stock in soil is determined by C concentration and the areal extent of soils, high stocks must have both

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