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Assessment, Monitoring and Managing Soil Organic Carbon (SOC) for Climate Change Mitigation and Adaptation : An Indian Perspective

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Abstract

Soils are the largest terrestrial reservoir of organic carbon, yet great uncertainty remains in estimates of soil organic carbon (SOC) at global, continental, regional and local scales. SOC is an unique indicator which exerts major influence on a number of soil physical, chemical and biological attributes. Soil monitoring involves the systematic measurement of soil properties to record their spatial and temporal changes. The assessment of SOC stock at a given site or for a given region will require analyses of OC concentration, bulk density, content of coarse fragments (>2 mm) and soil depth. Spatial representation of the SOC is considered very essential for regional planning and management. Geospatial modelling approach would help in monitoring SOC stocks as a function of change in climate, land use and can be linked to global models to understand the organic carbon dynamics besides helping in developing necessary management interventions to reduce CO2 emissions from soils. The management practices that increase soil C sequestration and mitigate C loss include improved water and nutrient management, adoption of diversified crop rotation, adoption of resource conserving technologies, crop residue recycling, soil and water conservation, application of organic materials (compost, green manure, biochar) and adoption of agroforestry systems.

Keywords: Soil organic carbon, Assessment and monitoring, Soil carbon sequestration, GHGs emission, Management of SOC, Policy initiatives

Introduction, scope and main objectives

Globally, the soil carbon pool is estimated at 2,500 Gt up to a 2-m depth; out of this, the soil organic carbon pool comprises 1,550 Gt (Batjes 1996). Soils are critically important in determining global carbon cycle dynamics because they serve as the link between the atmosphere and vegetation. Though soil C pool constitutes only 3.5 % of the global C cycle, it comprises the most actively cycling C in terrestrial ecosystems.

Soils in tropical regions like India are low in SOC as they fall under the influence of arid, semiarid and sub-humid climates and this is a major factor contributing to their poor productivity (Katyal *et al*. 2001). Indeed, an increase of SOC stock by 1 Mg C ha^{-1}in the root zone can raise the crop yield by 15-33 kg ha^{-1} for wheat (Benbi and Chand 2007), 160 for kg ha^{-1} for rice, 170 kg ha^{-1} for pearl millet, 13 kg $ha^{-1}$for groundnut and 145 kg ha^{-1} for soybean, (Srinivasarao *et al*. 2013). Therefore, greater SOC content can result in higher foodgrain production in the country.

Soil organic carbon (SOC*)* provides energy to soil biota which act as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission, modifying soil physical structure and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation and enhancing plant health (Benbi 2015). Assessing spatial distribution of SOC, thereby, is important for improving soil quality and SOC sequestration.

Methodology

Soil carbon assessment methods can be broadly classified into direct and indirect methods, depending on whether carbon content in soil samples is directly measured or inferred through a proxy variable. The most established type of direct soil carbon assessment entails collecting soil samples in the field and analyzing them in the laboratory using combustion techniques. Field sampling is technically challenging, but most of its challenges can be addressed through an appropriate design that accounts for soil spatial variation. Direct methods are more precise and accurate but also more time and labor intensive as well as very expensive.

The *in situ* soil carbon analytical methods include mid-infrared (IR) spectroscopy, near-IR spectroscopy, Visible and near-infrared (VIS/NIR) spectroscopy, laser-induced breakdown spectroscopy (LIBS), and inelastic neutron scattering (INS). While LIBS and INS technologies are still in their infancy, IR spectroscopy has proven valuable in developing soil spectral libraries and for rapid characterization of soil properties for soil quality monitoring and other agricultural applications in developed and developing countries.

Remote sensing and GIS play vital roles in the preparation of spatial illustration. The prediction of topsoil SOC content from remotely acquired spectral data is generally based on an empirical approach. Reference soil analyses of samples collected in the field are related to the spectral information through a multivariate calibration model used to predict the SOC values at locations .

Results

The first report on SOC stock in India made by Gupta and Rao (1994) was 24.3 Pg (1 Pg = 10^{15} g) using a database of 48 soil series for soil depths ranging between 44 and 186 cm. However, this estimate was based on a hypothesis of enhancement of OC level judging by success stories of afforestation programmes on certain unproductive soils.

Based on the geographical distribution of soils throughout the country, SOC stock in different physiographic regions of India was estimated to be 21 Gt (1 Gt = 1 billion tons) up to 0.3 m depth and 63.2 Gt up to 1.5 m depth using 1800 soil samples (Bhattacharyya *et al*. 2010).

An estimation of status and spatial variability of SOC for surface soils across six states of NER (viz. Assam, Manipur, Meghalaya, Nagaland, Sikkim and Tripura covering a geographical area of 15.61 m ha) in Geographical Information System (GIS) environment revealed that the soils were very high in SOC content – 98.54% area had >1% and 14.4% area had > 2.5% SOC content (Choudhury *et. al*. 2013). While 76.5% area had SOC density of 20– 40 Mg/ha, 8% area had very high SOC density of 40–60 Mg/ha. A total of 339.8 Tg (1 Tg = 10^{12} g) SOC stocks was estimated on an area of 10.10 m ha surface soils representing all major land-use systems, with a major share (>50%) coming from forest soils. Tiwari et. al. (2015) through pedometric mapping of soil organic carbon loss using soil erosion maps worked out a threshold limit of 150 kg ha^{-1} $year^{-1}$ SOC loss above which the areas are to be considered as susceptible demanding immediate conservation measures.

In India, first spatially explicit 250m map of soil organic carbon stock was generated through Random forest(RF) based digital soil mapping technique using a large number of remote sensing derived data layers and data mining approach (Sreenivas *et al*. 2016). For modelling with RF algorithm, about 898 soil profile observations were used, while the rest of 300 were used for validation. The soil organic carbon pool size of India has been estimated at 22.72 ± 0.93 Pg, which is comparable to previous studies.

Sarathjith *et al*. (2016) reported a R^2 value of 0.81 for SOC with VisNIR DRS which has been proven valuable in developing soil spectral libraries enabling rapid characterization of SOC and other soil properties for soil quality monitoring and other agricultural applications in developed and developing countries.

Discussion

There are considerable opportunities to build up soil organic carbon through C sequestration for enhancing the soil quality. C sequestration potential of different nutrient management practices across various agro-climatic zones of India is estimated to range between 2.1 and 4.8 Mg C ha-1 with a total potential of 300 to 620 Mt (Pathak *et al.* 2011). In India, balanced application of fertilizers can enhance SOC concentration by 6 to 100% and C sequestration by 20-600 kg ha^{-1} yr^{-1}, while integrated nutrient management practices is estimated at 100-1200 kg C ha^{-1} yr^{-1} with an enhance SOC concentration of 17-132 % under various soil, crop and climatic conditions (Benbi 2013). Carbon-sequestration potential of rainfed production systems under different nutrient management practices ranges between 0.04-o 0.45 Mg ha^{-1} yr^{-1} (Srinivasarao *et al*. 2014).

C sequestration potential of agro-forestry systems very widely (1.3-173.0 Mg C ha^{-1}) depending on tree species, climatic conditions and age of plantation (Nair *et al*. 2009). Total potential of SOC sequestration through restoration of degraded and desertified soils in India has been put at 10-14 Tg C yr^{-1}(Pathak *et al*. 2015) Raising Jatropha on degraded lands can increase C content in surface soil by 19 % resulting in about 2500 kg C ha^{-1} sequestered over a 4 year period (Wani *et al*. 2012). Besides C sequestration and rehabilitation of degraded lands, Jatropha has the biodiesel C replacement potential of 230 kg ha^{-1} yr^{-1}.

Zero tillage (ZT) agriculture can enhance soil-C sequestration by reducing the degree of soil disturbance and C turnover. In wheat based cropping systems in India, conversion from CT to ZT resulted in net C sequestration rates ranges from 219-359 kg C ha^{-1} yr^{-1} (Grace *et al*. 2012).

In India, agriculture contributes nearly 18% of total GHGs emission in the country. Crop residues burning is a potential source of Green House Gases (GHGs) causing global warming. In India, an estimated 141 Tg crop residues are surplus most of which are burnt *in situ*. The crop residues on an average contain 45% C and assuming a humification rate 10% the incorporation of surplus crop residues can result in C sequestration of 6.3 Tg C annually (NAAS, 2012).

Adoption of improved water management such as alternate wetting and drying, direct-seeding of rice (DSR) and System of Rice Intensification (SRI) in place of submerge rice reduce or totally eliminate methane emission. The DSR and SRI have potential to reduce the global warming potential (GWP) by about 25-50% compare to the conventional puddled transplanted rice (Pathak *et al*. 2015).

Conclusions

SOC is sensitive to impact of human activities, viz. deforestation, biomass burning, land use changes and environmental pollution. Sustainable land management delivers carbon benefits in three important ways namely carbon conservation, carbon sequestration and reduction of GHGs emissions. The triple imperatives provide resilience to agricultural ecosystems in terms of increasing climate change adaptation and mitigation with higher crop productivity.

In order to improve SOC and enhance soil C sequestration, the Government of India has taken several initiatives namely National Mission of Sustainable Agriculture for promotion of integrated nutrient management and production of organic fertilizers, Nutrient Based Subsidy scheme to ensure balanced fertilization, promotion of organic farming, National Biogas and Manure Management Programme, promotion of City/urban compost, Watershed Development programme for soil & water conservation and National Food Security Mission for promotion of conservation agriculture. Recently National Mission on Soil Health Cards has been launched to provide every farmers soil test based fertilizer recommendations. This will ensure assessment, mapping, monitoring of SOC at village level under actual field conditions.

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