Challenges of soil quality of Indian soils *vis-á-vis* food security

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Soil quality (SQ) is the capacity of a specific kind of a soil to function, within natural and managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation[1]. In the mid-sixties due to introduction of dwarf varieties, which need high inputs in terms of fertilizers, water and pesticides increased agricultural production but discriminate and imbalanced use of fertilizer, deteriorated inherent capacity of the soil to supply plant nutrients. It examines spatial and temporal variations induced by land-use policy or management. Soil organic carbon (SOC) is the most reliable, versatile and easily assessable indicator, encompassing the interactive effect of several factors. Plataeuing or decreasing trend of crop yields at current levels of management indicates declining soil health (SH). Erosion, drought and desertification, irrigation induced salinity and sodicity, paradigm shift in land use, nutrient depletion and intensive cultivation are the causes of SH deterioration. Erratic rainfall and exploitation of land, water and vegetation resources by the ever increasing human and livestock populations further accentuate the problems of SH. Increasing salinity, residual carbonate, alkalinity and contamination of surface and groundwater through heavy metals, nitrates, fluoride and arsenic are the reflection of deteriorating SH.

SH is an indicator of good soil's physical, biological and chemical properties for maximum production. The challenges of growing population, industrialization and urbanization on qualities of diminishing resources are quite daunting especially in Asia, Africa and other developing nations. Soil, water and biodiversity are an integral part of sustainable production system in the era of resource degradation and heavy input depended agriculture. In the mid-sixties, our natural resources were not exploited; but now a high level of exploitation has been reached. The situation demands immediate attention. Enhancing productivity by input intensive agriculture has consolidated food and nutritional securities of developing nations with limited per capita availability of land, water and bioresources[2]. According to recommendations of the Proceedings of the International Conference on Soil, Water and Environmental Quality – Issues and Strategies (ICSWEQ), 28 January to 1 February 2005 held at New Delhi 'The shrinking capacity of soils to absorb any more abuse must be impressed in the public mind through appropriate changes in educational curriculum, mind set, awareness, mass media and it is the time for individual countries to act on the "World Soil Charter of FAO" and press for "UN Soils Convention" to accord the same high priority to soil preservation as is being currently given to climate change, biodiversity, etc.'. Soil organic matter (SOM) is the mainstay of SQ. Since balanced fertilization may meet crop productivity and maintain SOM, there is urgent need to improve the sequestration of carbon in all the soils by all available resources including recycling of crop residues, green manuring, composting, zero tillage, resource conserving technologies and other soil agrotechniques.

Challenges of SQ

The Mother Earth Day is celebrated every year on 22 April worldwide for creating awareness about the challenges of land degradation, soil pollution and climate change impact and for earth preservation. Against an annual depletion of 28 million tonnes (mt) of nutrients, against addition of 20 mt, leaving a net gap of 8 mt per annum, a deficiency which accumulating year after year, depleting SQ. A fact finding committee constituted by the Government of India in 1997 with the objective of analysing in-depth, the trend of productivity of important crops in Haryana and Punjab reported that there is decline in the organic-carbon content of the soils due to continuous cultivation of cereal-based cropping system, for instance rice–wheat, rice–rice and rice–maize, etc. The continuous nutrient depletion from the agricultural fields is a severe threat to the SH. Sub-optimal nutrient application together with poor quality water results in sparse plant cover and low vegetative inputs into the soils. In arid and rainfed areas, nutrition depletion by crop was far more than the benefits of the added fertilizers[2]. Alfisols, ultisols and oxisols with low cation exchange capacity (CEC) were the biggest losers. SOC loss ranged from 0.22% to 6.0% in different cropping sequences of India due to inadequate fertilization, whereas depletion of SOC was far less (0.22% to 2.92%) under balanced fertilization[3]. Inadequate fertilization with high RSC (residual sodium carbonate) depleted phosphorus and potassium by 7.7% and 13.4% respectively in arid soils of India from 1975 to 2002 (ref. 4). The abrupt change in land use by introducing high water requiring crops further heightens the problem of nutrient depletion. Traditional farming system was extensive with low yields, which was sustainable in harmony with the carrying capacity set by nature. Low productivity system has lost relevance in view of increasing demand of food, fibre and wood. Since 1951–52, there has been an increase of 36, 22 and 54 m ha irrigated, net sown and double-cropped area respectively on the cost of fallow, pastures and grazing lands and tree groves. High intensity farming system supports high productivity; it appears non-sustainable in the absence of holistic land management, which satisfies the needs of stakeholders in an economically favourable way and simultaneously contains curative action for preserving SH and prevents further soil degradation.

Due to concerns about soil degradation and the need for sustainable soil management in agroecosystems, much scientific attention has been focused on characterizing SQ. The Soil Science Society of America (SSSA, 1995) defines SQ as 'it is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance soil and water quality, and support human health and habitation'. In simplest terms, SQ or SH can be defined as 'the fitness of soil for use'. In agricultural systems, high quality soil provides for the sustained and productive growth of crops with minimal impact on the environment. There are two components of SQ, viz. inherent and dynamic. Inherent SQ refers to the characteristics that define a soil's inherent capacity for plant production. These are usually static, changing little over short-time frames (years to decades). Soil texture and soil mineralogy are commonly included as properties of inherent SQ. Other soil properties such as total soil carbon, CEC and exchangeable sodium percentage may also be defined as inherent properties, where broad soil types or regional comparisons are of interest at one point of time, even though they may be altered by management over longer time frames. Inherent soil properties are the basis of many land-use capabilities or suitability assessments that are key components of land-use planning and policy development in many regions. Most were undertaken with the primary aim of evaluating potential soil productivity. Thus, the inherent quality of a soil should be viewed in light of its intended agricultural use. Properties of dynamic SQ are those that change in response to human use and management normally over relatively short-time frames (years to decades). Agricultural soils of high dynamic SQ maintain high nutrient availability, permit adequate infiltration of water and air, have relatively stable structure and maintain a functionally diverse community of soil organisms that support a relatively high level of plant productivity. These processes are reflected in specific physical, chemical and biological properties of soils. The terms dynamic SQ and SH are often used interchangeably. Two soils may be equally 'healthy' but achieve different levels of plant productivity because of differences in their inherent quality.

Challenges of food security

The food that an individual eats fundamentally affects his health, strength, stamina, nervous condition, moral and mental functioning. It is of paramount importance in the normal growth, development and health of humans. The access to food by all is still unachieved but a cherished goal. Widely accepted food security comprises three parts. Every individual has a physical, economic, social and environmental access to a balanced diet that includes necessary macro- and micronutrients, safe drinking water, sanitation, environmental hygiene, primary health care and education so as to lead a healthy life. Food is produced from efficient and environmental friendly technologies that conserve and enhance the natural resource base of crops, animal husbandry, forestry, inland and marine fisheries, etc. The ultimate composition of a food is expressed in terms of 19 chemical elements. Every human being has a fundamental right to balanced and nutritious diet in required quantity every day for sustaining his life. Food security is a distant goal, but achievable. Projections made by the Food and Agriculture Organization on trends in agriculture, food and forestry (*World Agriculture: Towards 2015/2030*) indicated that low income countries with high dependence on agriculture will encounter challenges of food security, sustainability and rural poverty. In the past, the increasing needs of expanding population for food, fuel and fibre were met through cultivating progressively larger areas of land and by intensifying the use of existing cultivated land. Under the circumstances when no more additional good quality land is available and the crop yields are stagnated, the food requirement of added population in future has to come from the reclamation and management of degraded lands, which include the salt-affected lands also. India has the world's 2.4% land and 4% fresh water resources of which nearly 6.73 million ha lands are salt affected and a sizeable area is underlain by poor quality water. With these limited resources, we have to support 16% of the global population. Owing to higher allocation of good quality water to other remunerative sectors, the availability of fresh water to agriculture which is the largest user, is diminishing rapidly and has to largely depend upon the low-quality water resources[5]. Therefore, another important component to achieve higher productivity could be the optimum utilization of surface waters as well as low-quality groundwater and waste waters, which are still usable. The injudicious use of water is often associated with the development of water logging, salinity, sodicity and many other environmental problems. Adequate knowledge in diagnosis and management technologies for saline and alkali lands/waters and wastewater generated from municipalities and industries is essential to obtain maximum crop production from these resources for achieving the goal of 300 mt

Table 1. Post harvest buildup of SOC by use of different organic residues under different cropping sequences[9]

Land use systems	Material added	Organic carbon (%)
Maize–wheat (25 yrs)	Control	0.51
	Farm yard manure	2.49
Cotton–sorghum (45 yrs)	Control	0.56
	Farm yard manure	1.14
Ragi–cowpea–maize (3 yrs)	Control	0.30
	Farm yard manure	0.64
Rice–rice (10 yrs)	Control	0.43
	50% from inorganic + 50% through green manuring (*Sesbania aculeate*)	0.90
Rice–wheat (3 yrs)	Control	0.44
	Farm yard manure	0.54
Rice–wheat (7 yrs)	Fellow	0.23
	Green manuring (*Sesbania aculeate*)	0.37

Table 2. Changes in soil properties (0–30 cm) under different tree–crop combinations in five years[9]

Land use system	Organic carbon (%)	Available N (kg ha^{-1})
Crop based system	+0.07	+10
Eucalyptus based system	+0.12	+21
Acacia based system	+0.20	+31
Populus based system	+0.17	+25

food grains by 2020 from 145 mha Indian arable lands.

Enhancing SOC stock

The SOM consists of living organisms (bacteria, fungi, earthworms, nematodes, insects and plant roots), active organic matter (fresh/partially decomposed, labile) and humus (well decomposed and relatively stable). The sources of SOM are plant and animal residues and the products synthesized by them and microorganisms. The SOM and humus serve as reservoirs of living organisms and these living organisms participate in the mobilization of plant nutrients and facilitate to build soil structure besides providing other benefits[6]. Nutritional value of organic matter lies in its dynamic nature. Organic carbon is the energy source for soil organisms, and it is the activity of these organisms and the processes they are involved in rather than the absolute-organic matter level, which is most important. Increasing SOC in tropical climate is not easy. However, continuous application of lingocellulotic crop residue helps in building SOM temporarily. There are evidences in the literature, as shown through long-term experiments, that application of farm yard manure (FYM) + mineral nutrient (nitrogen, phosphorus, potash and sulphur) and micronutrient increases the crop yield and builds the SOC content[7]. Integrated use of manure and fertilizers helps in building SOC residues and plays a major role in maintaining SOM content. Soil microorganisms grow rapidly during early phases of decomposition when plant materials are subjected to transformation and decomposition processes by the heterotrophic microflora immediately after incorporation into the soil, and as a result, the population of bacteria fungi and actinomycetes increases with application of plant residues and FYM. It was also observed that exhaustion of the available carbon led to decrease in microbial biomass. Many crop management practices such as manuring including green manuring, crop residue application, mulching have shown improvement in SOM and microbial population[8].

Soil carbon sequestration refers to the storage of carbon in stable solid form. It occurs through direct and indirect fixation of atmospheric CO_2. Direct soil carbon sequestration occurs by inorganic chemical reaction that converts CO_2 into soil inorganic carbon compounds such as Ca and Mg carbonates. Indirect plant carbon sequestration occurs as plants photosynthesize atmospheric CO_2 into plant biomass; subsequently some of the plant biomass is indirectly sequestered as SOC during the decomposition process. The amount of carbon sequestered at a site reflects the long-term balance between carbon uptake and release mechanism. Many best management practices have been proven to help in sequestering soil carbon as in: restoration of degraded soils and ecosystems, and the adoption of recommended agricultural practices on prime land and retiring marginal agricultural lands to restorative land uses or converting to natural ecosystems. Rapidly increasing population restoration of degraded soils and ecosystems is an important strategy. This strategy of restoration of degraded soils and ecosystems can enhance biomass production, improve SQ and increase the SOC pool. Many soils of the tropics, especially those in densely populated regions of Asia, have lost a large proportion of their original SOC pool because of practices of mining soil fertility. There is a large potential of restoration of degraded soils in South East Asia, which ranges from 18.3 to 35.0 teragram carbon per year (TgC/yr). These estimates are attainable potentials provided that regional governments adopt appropriate policies and implement plans to restore degraded soils through forestation, establishing planted fallows and improving grazing lands. It is a major challenge that must be addressed in a coordinated and planned manner.

The SOM is extremely important for productivity, and particularly so for the poorer soils of arid and semi-arid areas. Its direct contributions to nitrogen and sulphur nutrition of crops, and its role in stabilizing soil aggregates and supporting the soil biota responsible for creating pores through which air and water move cannot be ignored. In addition, SOM plays a major role in the retention of cationic nutrients by dominant soils of these areas, which have clays composed of kaolinite, and low activity iron and aluminium oxides clays with only a weak ability to hold nutrient cations. Furthermore, under acid conditions, some of the organic compounds present in soil form complexes with aluminium, which would otherwise be toxic to plants. In addition to physical and chemical effects, organic matter provides substrate for supporting biological life in the soil.

Under natural vegetation, the amount of SOM tends to be established at a relatively high level but under cultivation, addition is usually much lesser than in the natural vegetation, and consequently the SOM level tends to fall. If good crops are grown and all residues returned to the soil, the level established after cropping may be different from grasslands. A general principle of sustainable SH management systems is to return as much organic material as possible to arable upland soils but it should be free from toxic contaminants, and the costs and problems of collecting and spreading should be socially and economically viable.

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