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Contribution of soil health to sustainable agriculture

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Abstract
Soil is intended to produce food for feeding the growing population of the world. A healthy soil acts as a dynamic living system that delivers multiple ecosystems such as sustaining water quality and plant productivity, controlling soil nutrient recycling decomposition and removing greenhouse gases from the atmosphere. Soil health is closely associated with sustainable agriculture. Agricultural sustainability is the ability of crop production system to continuously produce food without environmental degradation. Soil management is important, both directly and indirectly, in terms of crop productivity, environmental sustainability and human health. Hence to evaluate sustainability of agricultural practices assessment of soil health is crucial to overcome the vagaries of climate change on soil functions. Assessment of Soil health by using various indicators of soil quality and soil management practices such as organic farming, site specific nutrient management and tillage improvement practices like conservation tillage can improve the soil health by increasing the abundance, diversity and activity of microorganisms. Conservation tillage can potentially increase Growers profitability by reducing inputs and labour costs as compared to conventional tillage. This paper reviewed about the impact of crop and soil management practices on soil health and their role in sustainable agriculture.

Keywords: Soil health, sustainable agriculture, tillage, conservation tillage and conventional tillage

Introduction

Soil is a heterogeneous natural resource which supports life on terrestrial earth. Soil is intended to produce food to feed the growing population of the world. Soil health is defined as "the capacity of a soil to function as a vital living system within ecosystem and land use boundaries to sustain plant and animal production, maintain or enhance water and air quality and promote plant and animal health." Soil health is an intrinsic characteristic of a soil (Doran and Zeiss, 2000) [8]. Managing soil organic carbon (C) is important in terms of soil organic matter as it influences numerous soil properties relevant to ecosystem functioning and crop growth. Small changes in total soil carbon content can have exceptionally large impacts on soil physical properties. Adaptation of practices for maintenance of soil C is important for ensuring sustainability of all soil functions. The soil health is closely associated with sustainable agriculture, because soil microorganism diversity and activity are the main components of soil health. Soil also act as a filter for nonhazardous and toxic metals through various mechanisms such as clay surface adsorption and precipitation which balances the composition of soil chemical environment. Most of the above functions of the soil benefit the humans and animals (Palm *et al*. 2007) [23]. Soil affects the human life directly and indirectly by the quality of food produced from agriculture. From agriculture point of view, nutrient depletion through erosion, salinization, and alkalinization due to poor soil and water management leads to decline in soil fertility which reduces the crop productivity. The loss of soil organic matter (SOM) affects most of the soil functions which are mediated by soil microorganisms. Agricultural sustainability is the ability of crop production systems to continuously produce food without degradation to the environment (Sharma and Mandal 2009) [29].

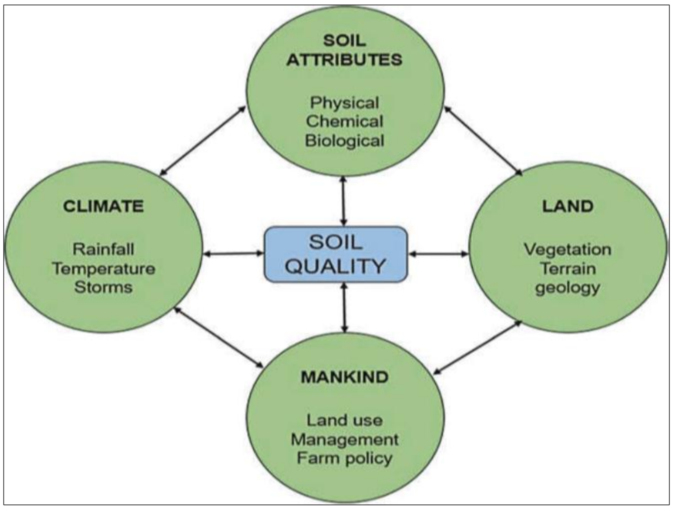
Soil Health Components for sustainable Agriculture

The terms "soil quality" and "soil health" are used similarly for nearly half a century (More 2010; Bünemann *et al*. 2018) [21, 3]. However, they may be differentiated in terms of timescale that the term "soil health" indicates the condition of soil in a short period and "soil quality" over a longer period much analogous to the condition of a human health and quality of life at a particular time and period (Acton and Gregorich 1995) [1].

Soil Quality

Concept of Soil quality

Warkentin and Fletcher (1977) [34] introduced the concept of soil quality for appropriate input allocation to increase the production of food and fiber. Karlen *et al*. (1997) [15] defined soil quality as "the capacity of specific kind of soil to function, within natural or managed ecosystem to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health."



Soil Quality

Soil quality assessment

The basic need for soil quality assessment is the deleterious hanges in soil functions caused by inappropriate management and other natural factors. Soil quality assessment is an exercise in measuring the changes in soil properties due to management, change in land use, deforestation, etc.

Soil quality indicators

The soil quality indicators are generally classified into four categories (More 2010) [21]:

1. Visual indicators
2. Physical indicators
3. Chemical indicators
4. Biological indicators

Visual indicators

The visual indicators are field observations of mostly qualitative soil properties, *viz*., soil depth, colour, erosion, gully formation, salt deposition, drainage, surface ponding, soil structure, consistence, mottles, rooting depth, root development, earthworm population, rodent activity, etc. The main advantage of visual SQ indicators is that they are immediately interpreted without time-consuming laboratory analysis (Bünemann *et al*. 2018) [3]. Among the many visual soil quality indicators, soil structure is given importance in the recent literature (Emmet-Booth *et al*. 2016) [11]. The Natural Resources Conservation Service (NRCS) proposed a set of indicators and their ranking for SQ evaluation (Table 1).

Table 1: Qualitative visual soil quality indicators and their ranking

Soil quality indicators	Low	Moderate	High	Method of assessment
Earthworms	Few worms (1–4) per shovel, no casts or holes	More worms (5–8) per shovel, some casts and holes	Many worms (>8) per shovel, many casts and holes	Use of quadrant and counting the number of earthworms or casts (five quadrant throws per site)
Organic matter	No visible roots or residues	Some plant residues and roots	Lots of roots/ residues in many stages of decomposition	Presence and abundance of visible residues or roots, colour
Subsurface compaction	Hard layers, tight soil, restrict root penetration, obvious hardpan, roots turned awkwardly	moderate shovel resistance, penetration beyond tillage layer	Loose soil, unrestricted wire penetration, no hardpan, mostly vertical root plant growth	Degree of resistance to a stick (100 cm × 1 cm in diameter) when inserted into the soil
Erosion	Obvious soil deposition, large gullies joined, obvious soil drifting	Some deposition, few gullies, some colored runoff, some evidence of soil drifting	No visible soil movement, no gullies, clear or no runoff, no obvious soil drifting	Presence of gullies, rills, or any evidence of runoff
Water holding capacity	Plant stress immediately following rain or irrigation, soil has limited capacity to hold water, soil requires frequent irrigation	Crops did not easily suffer from dry spell in the area, soil requires moderate irrigation	Soil holds water Well for long time, thick topsoil for water storage, crops do well in dry spells, soil requires little irrigation	Rate at which water runs out after a good rain, with or without puddling
Drainage	Excessive wet spots on the field, ponding, root disease	Some wet spots on the field and profile, some root diseases	Water is evenly drained through field and soil profile, no evidence of root disease	Degree of wetness or dryness, ponding, or runoff
Crop condition	Stunted growth, uneven stand, discoloration, low yield	Some uneven or stunted growth, slight discoloration, signs of stress	Healthy, vigorous, and uniform stand	Leaf color and rate of crop growth throughout season

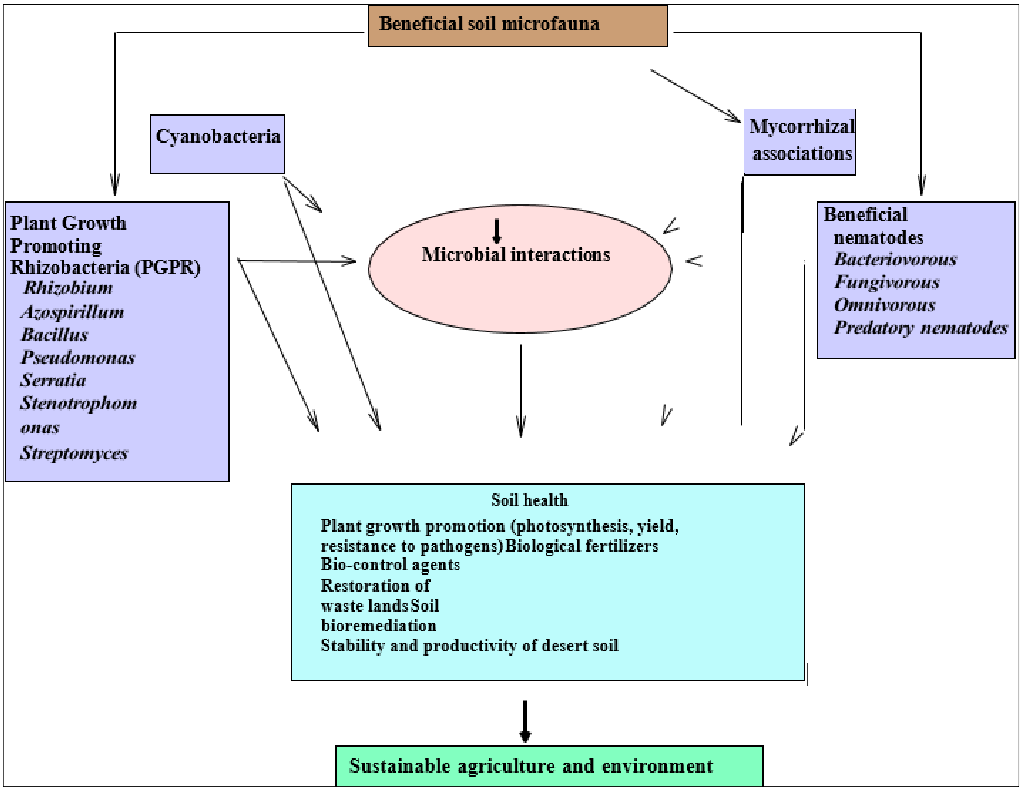


Fig 1: The role of beneficial soil microbes and their interactions for the development of sustainable agriculture and environment (Singh *et al.* 2011 and Monther *et al.* 2020) [32].

Physical Indicators

Physical properties such as texture, structure, hydraulic conductivity, infiltration, porosity, bulk density, and aggregate stability are used as physical SQ indicators (Table 2). They are used to evaluate physical SQ and linked with seedling emergence, root growth, water movement, water holding capacity, penetration resistance, etc. Physical properties play a vital role in determining the soil erodibility and soil plant- water-atmosphere relationships (More 2010) [21].

Table 2: Some of the commonly used soil quality indicators to measure soil functions

Category	Soil properties
Physical indicators	Bulk density, Soil texture, Aggregate stability, Water storage, Soil compaction, Soil depth, Penetration depth, Porosity, Hydraulic conductivity, Infiltration and Penetration resistance
Chemical indicators	pH, EC, CEC, Organic matter, Labile C and N total and available N, available K, available P Sodicity and salinity and Heavy metals
Biological indicators	Soil respiration, Enzyme activities, Microbial biomass, Earthworms, Micro-arthropods and N-mineralization

Chemical Indicators

Important soil chemical processes are ionic diffusion, leaching, acidification, alkalinization, salinization, mineralization, etc. Maintaining a favorable nutrient content is critical to soil chemical quality. The chemical indicators of SQ are pH, EC, salinity, sodicity, organic carbon, nitrogen fractions, phosphorus concentration, cation exchange capacity (CEC), and heavy metal concentrations. Soil pH and available P are the most used chemical indicators in SQ assessment as they indicate most of the nutrient-related transformations in soil.

Biological Indicators

The microorganisms play an important role in organic matter decomposition and recycling of nutrients. Population of microorganisms, earthworms, nematodes, termites, and their actions are important indicators of soil quality. The microbial biomass is an important part of the active ingredient in soil responsible for nutrient circulation and degradation of organic pollutants (Stenberg *et al.* 1998) [33]. Enzymes such as dehydrogenase, urease, phosphatases, and glucosidase are used to measure nutrient mineralization in soil, and they can provide an early warning to the potential threats to soil quality (Comino *et al.* 2018) [7]. Earthworm population is the best indicator of the structural, microclimatic, nutritive, and toxic status of soil. Earthworms play an important role in conserving and improving soil structure, recycling soil nutrients, promoting the gradual mixing of the soil layers and creating a better aeration and drainage system in the soil. The earthworms are indicators of both water and nutrient cycling.

Soil Quality in Intensive Agriculture

Apart from SQ, crop yield is influenced by many external factors such as solar radiation, temperature, evapotranspiration and precipitation. Continuous intensive cultivation improves soil fertility however, in the recent decades; inappropriate management practices caused adverse consequences for the overall environment. Application of high amount of chemical fertilizers, especially P, and reduction in the use of organic manures leads to eutrophication at the surrounding water bodies. Excessive application of nitrogen decreases C fixation capacity due to C release from the soil. The intensively cultivated lands are susceptible to degradation due to various reasons including inappropriate crop and soil management. In intensive cultivation, crop rotation influences soil quality through inputs related to the crop species included in the rotation.

Farming Practices to Improve Soil health components

Crop management practices like tillage, water and fertilizer management, cropping systems, and land-use conversion are some of the management practices which have pronounced impact on soil quality.

Effect of tillage

Tillage is one of the main land management practices to create favorable soil environment, i.e., increase soil aeration and infiltration rate, seedbed preparation, soil and moisture conservation, expose the soil-borne pathogens and insects to light, and weed control. To minimize the negative effects of tillage on soil quality, modern tillage concepts such as no tillage (NT), minimum tillage (MT), stubble-mulch tillage (SMT) and conservation tillage (CT) practices are introduced. They considerably improve many soil properties which in turn sustains the soil quality and crop productivity (Table 3). Zero tillage or CT systems combined with crop residue incorporation increases the possibility of sustaining crop production especially under rainfed conditions in semiarid regions (Sharma *et al.* 2005) [28]. Conservation tillage practices increased soil available P in the topsoil (0-20 cm) by 3.8%, K by 13.6% and soil organic matter by 0.17% compared to conventional (Shao *et al*., 2016) [30]. Maintaining crop residues on the top soil surface layer (full cover, no till; partial cover, strip tillage) can also reduce soil erosion and increases soil moisture content (Celik *et al*., 2013 and Mullins *et al*., 1998) [4, 22]. Legumes as cover crops and rotations with cereals increase SOC stocks in the soil (Fortuna *et al*. 2008) [12].

Table 3: Influence of different tillage methods on some soil quality indicators

Soil quality indicator	No tillage/ conservation tillage	Conventional tillage	Deep ploughing	References
Organic carbon	Increase in surface soil	Reduced	Reduced	Motta *et al*. (2002) [20], Shukla *et al*. (2006) [31], Mendoza *et al*. (2008) [19], Fortuna *et al*. (2008) [12] and Schmidt *et al*. (2018) [25]
Bulk density	Decrease	No effect	No effect/ increase	Shukla *et al*. (2006) [31] and Idowu and Kircher (2016) [14]
Soil compaction	Reduce	Increase	Increase	Idowu and Kircher (2016) [14] and Schmidt *et al*. (2018) [25]
pH	No effect	Slight decrease	Slight decrease	Motta *et al*. (2002) [20]
Total N	Increase	decrease	Decrease	Fortuna *et al*. (2008) [12]
Aggregate stability	High	Low	Low	Shukla *et al*. (2006) [31], Mendoza *et al*. (2008) [19] and Idowu and Kircher (2016) [14]

Effect of cropping systems

In general, agroforestry systems and tree plantations sustain soil quality than annual crop-based systems. The cereal cropping systems with pulses improve the soil quality than cereals without pulses (Wienhold *et al*. 2006) [36]. In rice-based cropping systems, ploughing (puddling) leads to the breakdown of capillary pores, reduced void ratio, poor soil aggregates, dispersed fine clay particles and low soil strength, surface crust formation, and cracks after drying which ultimately degrades the physical quality of the soil (Masto *et al*. 2008) [17]. Pulse crop-based cropping systems and cover crops protect the soil from erosion and nutrient loss (Weerasekara *et al*. 2017) [35]. The added advantages of growing cover crops in crop rotation are suppression of weeds, carbon sequestration, soil moisture conservation, and reduced nonpoint source pollution. Legume cover crops increase soil N by fixing atmospheric nitrogen and thus reduce the quantity of external N fertilizer requirement.

Nutrient Management

The INM provides balanced nutrition to crops and minimizes the antagonistic effects resulting from hidden deficiencies and nutrient imbalance (Mandal *et al*. 2007) [16]. Long-term INM practices sustained the yield of maize-wheat system and sub-stantially improved the soil aggregation stability and physical quality (Dutta *et al*. 2015) [10]. The application of recommended dose of N, P, and K with farmyard manure increased dehydrogenase activity and microbial biomass carbon and improved the soil quality under rice-wheat-jute system in the IGP region of India (Table 4) (Chaudhury *et al*. 2005) [6]. The effect of INM is more pronounced in the rainfed production conditions than irrigated conditions. Longterm INM practice increased the aggregation stability, labile carbon, and dehydrogenase activity in the Inceptisols under pearl millet crop ping system in tropical soil of India (Sharma *et al*. 2014) [27]. Application of organic manures such as cattle dung manure, vermicompost, and poultry manure along with mineral fertilizers based on N equivalents and nutrient requirements of crops improved the SOC content, available nutrients, MBC and dehydrogenase and alkaline phosphatase in the topsoil under soybean-wheat cropping system in vertisols (Ramesh *et al*. 2009) [24]. Farm compost application increases SOC content, earthworm population, and MBC and reduces BD in soil with light texture, thus creating favor able environment for crop growth and increasing the yield of maize-based cropping system (D' Hose *et al*. 2012) [9].

Table 4: Average yield (t ha−1) and sustainable yield index (SYI) of jute, rice, and wheat from a 30-year long-term fertilizer experiment in a sandy loam alluvial soil

Treatment	Jute		Rice		Wheat		Overall
	Yield	SYI	Yield	SYI	Yield	SYI	SYI
100% N	1.627	0.479	3.094	0.379	1.9	0.4	0.419
100% NP	1.721	0.528	3.501	0.433	2.175	0.478	0.480
100% NPK	1.957	0.641	3.797	0.439	2.257	0.529	0.536
100% NPK + FYM	2.063	0.662	3.856	0.538	2.34	0.537	0.579
Control	0.874	0.255	1.564	0.363	0.736	0.312	0.310

Chaudhury *et al*. (2005) [6]

Organic Farming

The interest of organic farming as the most sustainable agricultural system is rapidly growing worldwide because it not only improves the physical, biological and environmental resources such as soil nutrient mineralization, microbial activity, abundance and diversity but also yield and product quality. in organic farming have been known to increase soil organic matter (*Sesbania rostrata* yielded 16.8 ton ha^{-1} dry matter in 13 weeks), N supply capacity and soil N sequestration by about 50% (compared to mineral fertilization) (Gong *et al*., 2011 and Matoh *et al*., 1992) [13, 18]. A long-term (12 year) study with rice (*Oryza sativa*) and corn (*Zea mays*) crops showed that organic systems using compost and peat sources had higher microbial population and enzyme activities compared to conventional systems (Chang *et al*., 2014) [5]. Organic farming can improve soil physical and chemical properties. For example, organic systems in a clay soil increased soil water content (~15%) and retention capacity (10%) and reduced soil bulk density (8%) in the top 20 cm soil layer as compared to conventional systems (Bassouny *et al*., 2016) [2]. Although organic farming is less productive than conventional, organic yield can approach the same productivity after cropping for 10-13 years (Schrama *et al*., 2018) [26]. Overall, organic farming is the best system to improve soil and crop quality.

Conclusion

Soil quality has now become an integral part of sustainable agriculture by means of an effective tool in monitoring both short and long-term changes in soil caused by management practices, intensive crop production systems are identified factors for assessing soil health components in sustainable agricultural systems. The inclusion of practices such as Organic systems, Conservation tillage like no tillage, reduced and strip tillages and plant–based fertilizer will improve the soil health by enhancing the soil nutrient availability, microorganisms abundance and activity, organic matter as well as soil physical properties. Conservation agriculture as zero and minimum tillages reduced the irrigation water requirement (12-25%), increased the water use efficiency (16-24%) and net returns ($49-281) when compared to conventional agriculture.

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