Soil Health in Cropping Systems: An Overview

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Abstract

Soil health has existed as an integrative property that reveals the capability of soil to react to agricultural interference, so that it persistently supports mutually the agricultural production and the stipulation of other ecosystem services. The key confrontation within sustainable soil management is to safeguard the ecosystem service besides optimizing agricultural yields. It is anticipated that soil health is reliant on the preservation of four foremost functions: carbon alterations, biogeochemistry mediated nutrient cycles, soil structure continuance and the directive of pests and diseases controlled by cropping system. Every one of these functions is marked as a comprehensive of a variety of biological processes provided by a multiplicity of interacting soil organisms under the authority of the abiotic soil upbringing which dictate assessment and management of soil health.

Keywords

Soil health · Agricultural impact · Ecosystem services · Cropping system

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4.1 Introduction

With the increasing growth of population, there is a greater demand for food. Thus, world agriculture has to be intensified. But land availability is still limited or even decreasing at increasing rate of urbanization. The per capita availability of land in India has decreased from 0.48 ha in 1951 to 0.12 ha in 2016 and projected to further reduce to 0.10 ha by 2025. Intensive agriculture needs higher doses of fertilizers for crop nourishment and pesticides for crop protection. Several intensive cereals or vegetables-based cropping systems have been practised by farmers across diversified ecology. Intensive agriculture, that is cultivation of high-yielding cereals and other crops which lead to nutrient depletion from the soil and use of chemical fertilizers and pesticides without any proper dosage, resulted in soil health degradation (John et al. 2001). Further, world agriculture is fully dependent on specific climatic conditions and specific management practices. These agricultural management processes could be substituted for biological functions, which affect the ecosystem's natural balance (Kibblewhite et al. 2008) and lead to deterioration of soil quality. As of now, although organic agriculture is developed to sustain production, it is very costly and labour intensive and can't provide demand-based food quantity. In addition to this all-out drive, soil health has also become major interest in developing areas, where the extensive production system has been intensified (Sinha et al. 2013). There is an increasing interest on the impact of cropping systems on soil quality to assess the physical, chemical and biological properties of soil in relation to crop production. In this review, we will discuss about how different soil groups show different responses in different cropping systems.

4.2 Concept of Soil Health

The term soil health is used as a synonym of soil quality. Soil quality is related to the function of soil (Letey et al. 2003; Karlen et al. 2013), whereas soil health represents a limited dynamic living resource which is non-renewable in nature (Doran and Zeiss 2000). Agricultural and environmental scientists in general prefer the term soil quality, and farmers or producers prefer the term soil health. Furthermore, soil health describes the biological virtue of soil microbial community that includes balanced interaction between organisms within soil and with their environment (Sinha et al. 2013).

Soil quality can be viewed in two ways:

(i) As inherent characteristics of soil which is formed by combined effect of climate, topography, organisms, parent material and time (Jenny 1941). Therefore, soil has an innate capacity to function. Five soil functions as given by Karlen et al. (1997) are
   - Sustaining activity of soil microbes with their diversity and productivity
   - Regulation of water and solute flow

- Buffering, degrading, immobilizing and detoxifying organic and inorganic toxic compounds which includes industrial wastes and by-products
- Acting as storage of nutrients and other elements within Earth's biosphere and continues to recycle it
- Providing foundation archaeological structures and buildings associated with human habitation

(ii) As a dynamic system of soils, influenced by climate and biosphere especially for human use. For example, erosion of surface layer with consequent loss of clay, organic matter and nutrients can't be protected by only cropping system, and thus soil properties are degraded continuously over time. Larson and Pierce (1991) reported that approaches for evaluating soil health were (i) comparative (e.g. land use management) and (ii) dynamic assessment by measuring changes in soil quality attributes over time.

Physical, chemical and biological properties of soil interact in complex way to create a favourable environment in soil to perform. Thus soil quality cannot be measured directly but can be determined by measuring changes in its properties which are known to as indicators. Generally indicators are complex set of attributes which are derived from functional relationships and can be monitored with laboratory or field analysis, remote sensing or combinations of them. Soil indicators should

- React to quick or slow change in management practices
- Coalesce soil physical, chemical and biological properties
- Be measured easily
- Have a limiting or threshold value
- Be stable for some time during analysis to enable measurement
- Be sensitive to change in management practices
- Be resistant to short-term weather pattern

Indicators as described in Table 4.1 which monitor the soil directly are grouped as visual (change in soil colour, gullies, ponding), chemical (soil pH, CEC, organic matter, nutrients), physical (soil structure, surface crust, B.D, hydraulic conductivity) and biological indicators (potentially mineralizable N, enzyme activity, soil microbial biomass/respiration).

4.3 Cropping System in Relation to Soil Fertility and Productivity

Cropping system may be defined as sequence or order in which crops are grown on a piece of land over fixed period of time. Cropping system is an important component of a farming system. The productivity of land is maintained over time through proper soil management practices. Sustainable management is necessary for better germination, growth and yield of crops over the long run. Thus to maintain soil fertility as well as intensive cropping, soil should be cultivated with various crops

Table 4.1 Major soil nutritional, chemical and biological indicators and related soil processes (Lal 1994)

Indicators	Process
pH	Acidification and soil reaction, nutrient availability
Base saturation	Absorption and desorption, solubilization
Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
Soil organic matter	Structural formation, mineralization, biomass carbon, nutrient retention
Earthworm population and soil macrofauna and activity	Nutrient cycling, organic matter decomposition, formation of soil structure
Soil biomass carbon	Microbial transformations and respiration, formation of soil structure and organo-mineral complexes
Total soil organic carbon	Soil nutrient source and sink, biomass carbon, soil respiration and gaseous fluxes

that ameliorates soil as well as sustain minimum productivity. Depending on resource availability, different types of cropping systems are practised in different agroclimatic regions.

There is a growing consensus that comprehensive knowledge about the effect of continuous cropping on soil properties (physical, chemical and biological) is needed for the establishment of extent to which impacts on soil quality is quantized, thereby creating a sustainable cropping system (Aparicio and Costa 2007). Baseline values of soil properties have been assessed and determined in many parts of globe (Richter et al. 2007), including China (Ding et al. 2007; Wu et al. 2004), Canada (Zentner et al. 2001), India (Masto et al. 2008), the USA (Khan et al. 2007; Varvel et al. 2006), Nigeria (Oluwatosin et al. 2008), New Zealand (Lilburne et al. 2002; Murata et al. 1995), Sweden (Gerzabek et al. 2001; Gerzabek et al. 2006; Kirchmann et al. 2004), etc. From the experiments conducted in different agroecology, it has been observed that many suitable cropping sequences under different soils (Table 4.2) ensure and indicate the probable chances of maintaining soil fertility for next cultivation practices to follow.

4.4 Farming System Diversity in Different Agroecological Regions Impacts on Soil Environment

A farming system is a combination of farm enterprise like cropping system, forestry, livestock, poultry and fishery, practised on farm to increase the profit of farmer per unit land. Without disturbing the effect of other components or ecological balance, the enterprises interact with each other in a synergistic manner. As different farming system is adapted in different agroecological regions, more of soil and water resources are being utilized differently according to the need-based practices, for example area under the small farmer community is being practised with crop and livestock production in combinations (McIntire et al. 1992). Now grassland is

Table 4.2 Diversification of crops: viable answers

Dominant soil order	Constraints	Preferred cropping system (region under practice)	Effect on soil health	References
Vertisol	1. Swelling and shrinking behaviour due to addition and losses of moisture 2. Too much of clay content (>30%) 3. Not easy to cultivate (tillage problem) 4. Develops wide and deep cracks during dry seasons	1. Wheat – soybean (FYM+ poultry manure+ N-P-K) (Central India)	(a) Build-up of high amount of organic matter during summer than under normal cereal cultivation (b) Availability of phosphorus to soybean is more (c) Enhanced activity of non-symbiotic bacteria observed	Behera et al. (2007)
		2. Lupin – strawberry (Temporary flooding for 30 days) (Spain)	(a) The increased amount of Fe^{2+} particularly oxalate-extractable Fe (Feo) (b) The SPADc values for lupin and strawberry were larger for the vertisols than for the inceptisols (vertisols contain little carbonate and cause less Fe chlorosis than the inceptisols) (c) Increases in Feo and amount of Fe^{2+} released in the incubation experiment (d) Weak response of the vertisols to flooding was partly a result of their history including flooding episodes in the field, so a steady state had been reached in which the pool of Fe compounds undergoing reductive dissolution and reprecipitating upon oxidation as poorly crystalline Fe	Velazquez et al. (2004)
		3. Dry farming with legumes such as chickpeas (*Cicer arietinum*), broad bean (*Vicia faba*), vetch (*Vicia sativa*), field pea (*Pisum sativum*), (Southern Spain)	(a) Direct drilling (DD) resulted in significantly greater soil organic C (12 gkg^{-1}) in the surface horizon (0–10 cm) of soil 25% greater than conventional tillage (CT) (9.5 g kg^{-1}) (b) After 22 years of cropping, a significantly larger amount of available phosphorus and exchangeable potassium was found in the surface horizon (0–10 cm) under DD compared with CT (c) The extractable calcium content was higher in CT (600 $mgkg^{-1}$) than in DD (500 mg kg^{-1}) (d) Irrespective of the tillage, the CEC had high values, indicating the good fertility level of the soil used in the experiment	Bravo et al. (2007)

(continued)

Table 4.2 (continued)

Dominant soil order	Constraints	Preferred cropping system (region under practice)	Effect on soil health	References
		4. Sorghum + pigeon pea (Jhansi, Uttar Pradesh, India)	(a) Sorghum releases HCN which helps to control the soil-borne pathogens (b) The use of straw mulch after sorghum harvesting reduces soil moisture loss and enhances more beneficial microbial colony growth (c) As in initial stage sorghum is used for fodder crop, more pigeon pea recovers faster and provides N to sorghum (d) Intercropping pigeon pea with sorghum reduces the soil-borne wilt disease in pigeon pea (Natarajan et al. 1985) (e) Willey et al. (1981) reported that on deep vertisols of peninsular India, sorghum and pigeon pea intercropping were highly productive both in maintaining the soil health and farmer's return	Ali (1985)
		5. Soybean–wheat (with combination of cattle dung manure, poultry manure and vermin compost) (Central India)	(a) At the end of 3-year cycle, application of organic manure produces good soil structure (b) Elevated soil organic carbon was noted down (c) Increased availability soil nutrients like N, P and K (d) Significant increase in dehydrogenase and alkaline phosphatase is also recorded (e) This cropping cycle increases high microbial biomass c in upper 0–15 cm soil	Pedaprolu et al. (2009)
Mollisol	Generally has no limitation in agriculture point of view, but excessive water saturation during rainy season causes reductive soil layer (marshy soil).	1. Cotton–grain sorghum–winter rye (with haygrazer [a sorghum–sudan grass hybrid} and winter rye cover, i.e. maximum biomass returned {three times more} to soil) (sandy soils of Texas High Plains, US)	(a) Due to incorporation of three times, more residue annually by including haygrazer, sorghum and winter rye crops into cropping system microbial biomass C and N was increased (10–26%) at 0–5 cm soil depth (b) More fungal and bacterial population was observed (c) More of enzyme activities have been recorded such as β-glucosidase, α-galactosidase, arylsulfatase, β-glucosaminidase, phosphodiesterase, alkaline phosphatase, etc. (d) But after adding more cotton crops in next cycle, the phosphodiester activity was reduced (e) Moreover, this practice induces more microbial diversity in sandy soils compared to cotton monoculture	Acosta-Martínez et al. (2011) and Acosta-Martínez and Cotton (2017)

		2. Soybean–soybean/maize–maize For 10 years (Northeast China)	(a) Decline in soil organic C when rotation changed from soybean to maize monocropping (b) More of N fixed during soybean cultivation is used for nutrition of maize (c) Hydrogenase activity was more in soybean system (d) When maize biomass after harvesting is returned to soil as mulch, it also provides soil organic C pool and more bacterial population	Tong et al. (2017)
Entisol	1. Generally no soil profile development has been seen 2. Soils are deficient in organic carbon and nitrogen content but rich in available potassium content 3. As its development is influenced by local conditions, some soils show stony, infertile and poorly drained conditions, and some exhibits sand dunes or floodplains.	1. *Prosopis cineraria*-based agroforestry system (Jaipur, Rajasthan, India)	(a) Increased activity of dehydrogenase and alkaline phosphatase activity (b) Long canopy diameter of tree gives protection against wind and splash water erosion (c) Deep taproot system holds soil particles tightly (d) Canopy provides shade to the soil surface Hence soil moisture is conserved to some extent, and soil microbial community becomes more active (e) Fluxes of C, N and P through microbial biomass are higher	Yadav et al. (2011)
		2. Paired row-planted maize + black gram (West Bengal, India)	(a) This system increases more C and N into soil (b) Conserve more soil water (c) Dehydrogenase activity is higher (d) Porosity and aggregate stability are more (e) In lowland, utilization of water is more (f) Microbial activity tends to increase	Sarkar et al. (1998)
		3. Rice–cabbage (*Brassica oleracea*)–green gram (West Bengal, India)	(a) Rice cultivation provides more soil moisture for the next cabbage. Thus water requirements are reduced in cabbage (b) Urease activity was higher (c) Fungal pathogenic incidences were lowered down (d) Green gram compensates N economy in soil, previously depleted by continuous submergence in rice field (e) Soil porosity and aggregate stability are improved during green gram cultivation (f) Soil organic C is restored in green gram cropping	Acharya and Mondal (2010)

(continued)

Table 4.2 (continued)

Dominant soil order	Constraints	Preferred cropping system (region under practice)	Effect on soil health	References
Alfisol	Soils are rich in exchangeable bases (>35%) Generally these soils are fertile and do not have much constraints But soils have very low organic matter content (<1%) and become very dry	1. Long-term alley cropping with *1. Gliricidia sepium* 2. *Leucaena leucocephala* *3. Alchornea cordifolia* 4. *Dactyladenia barteri* (southwestern Nigeria)	(a) Surface soil properties declined with time with continuous cultivation (b) Alley cropping with woody species maintained higher soil organic carbon, phosphorus and potassium levels (c) Plots alley cropped with *Gliricidia* and *Leucaena* showed lower pH and extractable calcium level (d) *Leucaena* alley cropped plot also showed lower magnesium level (e) The decline in soil pH and extractable cations may be due to increased cation leaching with application of high rates of *Gliricidia* and *Leucaena* pruning	Kang et al. (1999)
		2. Pearl millet + cowpea (Africa)	(a) In intercrop millet, sole cowpea and intercrop cowpea, the NUEs were 15.20, 45.33 and 46.00%, respectively, indicating that the use of nitrogen fertilizer significantly decreased in intercrop only for millet (b) No significant difference was observed between sole and intercrop cowpea relative to the nitrogen derived from N_2 fixation	Sarr et al. 2008
		3. Maize–soybean (Pennsylvania, USA)	(a) Most of the surplus nitrogen received by the MNR (manure as N source) increases in soil nitrogen, whereas in the CNV (conventional system) system, soil nitrogen levels have decreased (b) Maximum nitrogen input from the green manure over 15 years to be 840 kg N/ha (c) Nitrogen fixation was lower in conventional-system soybeans and greater in LEG-system (N directly from (d) Legumes) soybeans (e) LEG system reduces average CO_2 emissions to 7% (f) More of legume-derived N than fertilizer-derived N immobilized in microbial biomass Thus NO_3^- leaching has been reduced during summer and rainy seasons (g) These practices in the growing areas of the USA would increase soil carbon sequestration by 0:13–0:30 × 10^{14} g/year which is equal to 1–2% of the estimated annual carbon released into the atmosphere in the USA from fossil fuel combustion	Drinkwater et al. (1998)

		4. Groundnut–fingermillet in rainfed alfisol for 13 years (Bengaluru, India)	(a) Higher EC, CEC, soil organic C in respect of control and only NPK treated acidic plots (b) N availability is greater than P and K (c) Loss of N is less if groundnut is planted first compared to finger millet. Therefore, application of nitrogenous fertilizer is reduced (d) There were negative balances for K, secondary and micronutrients in all treatments (e) Positive balance was found in the case of P and N	Srinivasarao et al. (2014)
		5. Sabai grass (*Eulaliopsis binata*)+black gram (Acid lateritic soils of India)	(a) Sabai grass holds the soil particles with their roots and prevents soil erosion (b) Black gram provides substantial amount of N for good canopy growth of grass (c) Black gram reduces the N losses from the soil (d) At tender stage, leaves are used for fodder purpose (e) Cellulosic material (32%) of the leaves makes sabai grass an excellent raw material in the paper industries, second to bamboo	Mahapatra (2010)
		6. (i) Cucumber + garlic in first season (ii) Cucumber monocropping in second and third seasons (China)	(a) Increase in soil urease and catalase activity (b) Soil polyphenol oxidase activity under intercropping system has also increased in the first two growing seasons (c) Soil bacterial community was relatively stable under intercropping system than monocropping system. (d) This system has more beneficial effect on soil fungal community structure	Zhou et al. (2011)
		7. Brinjal (*Solanum melongena*)–Watermelon (*Citrullus lanatus*) (with reduced tillage and winter cover crops residue as mulch) (Tamil Nadu, India)	(a) Reduced tillage conserves soil moisture and maintains good soil physical conditions during winter (b) Reduced tillage helps in maintaining soil microbial biomass in a sustaining condition (c) Cover crops provide good canopy development and thereby reduce the weed infestation as well as accumulate organic matter on soil (d) Particulate organic matter carbon (POM-C) and particulate organic matter nitrogen (POM-N) were highest compared to bare field cropping (e) This system has no effect on harmful plant-pathogenic nematode populations in soil	Butler et al. (2016)

(continued)

Table 4.2 (continued)

Dominant soil order	Constraints	Preferred cropping system (region under practice)	Effect on soil health	References
		8. Tomato (*Lycopersicon esculentum*) with hairy vetch (*Vicia villosa*), crimson clover (*Trifolium incarnatum*) and rye (*Secale cereale*) as winter annual cover crops (United States)	(a) Annual cover crops were used to fix N (b) Cover crops prevent soil loss throughout the winter and spring (c) Half of fertilizer N is saved (d) As cover crops were used as mulch after harvesting, it conserves soil moisture, and after incorporating it in soil, it recycles the leftover nutrients (e) 5. Rye can provide an alternative in tomato production for those producers who do not want to use polythene mulch	Abdul-Baki et al. (1996) and Kornecki and Arriaga (2011)
Inceptisol	1. Generally have little profile distinction 2. Coarser in texture 3. Deficient in organic matter, nitrogen and sulphur content 4. Sometimes it poses location specific problems like alkali problem and water stagnation But these soils are good source of plant nutrients as they are fluvial in nature	1. Dhaincha (*Sesbania aculeata*) as green manure in rice field for 2 consecutive years (Gangetic alluvial soils of West Bengal, India)	(a) Microbial population in soil has improved (b) Bio-organic amendment increased soil available N in rice field compared to fertilizers alone (c) Green manured supplemented with $ZnSO_4$, *Azotobacter*, PSB reduce the fertilizer N and P_2O_5 requirement by 25% (Roy et al. 2017) (d) Positive influence of Zn and biofertilizers on microbial population dynamics was recorded (Roy et al. 2017) (e) Organic manures and biofertilizers help in increasing the P concentration in solution through organic P mineralization and solubilization of native soil P compounds by producing organic acids (f) Soil organic C has also been increased	Roy et al. (2017)

		2. Winter wheat–sugar beet–spring barley–potato for 4-year rotation (calcareous marine silt loam, Noordoostpolder, Netherlands)	(a) Bacteria constituted more than 90%, fungi approximately 5% and protozoa less than 2% of the total biomass (b) Carbon flow through the protozoa was higher, corresponding to bacterial production in both conventional and integrated farming (c) Nitrogen mineralization by the protozoa was estimated to be higher in conventional and integrated farming (Brussaard et al. 1990)	Brussaard et al. (1990)
		3. Long-term cultivation of lowland rice (Maruteru, Andhra Pradesh)	(a) Acid and alkaline phosphatase, dehydrogenase activity (threefold), β-glucosidase activity (threefold to sixfold was increased) (b) Increased microbial biomass carbon (c) More of C is sequestered under more C availability of aromatic functional C gr	Srinivas et al. (2015)
		4. Wheat-green gram (Delhi, India)	(a) Persistent source of mineral N in soil (b) Greater amount of Olsen P in flowering and maturity stage of wheat is recorded (c) K content of soil is increased during flowering to pod formation stage (d) Dehydrogenase and phosphatase activity are increased by 40–46%	Moharana et al. (2014)
		5. Summer groundnut-toria + gobhi sarson – fallow (Ludhiana, Punjab, India)	(a) Fixation of nitrogen and solubilization of phosphorus (b) Reduces the root-knot nematode population in soil	Sinha et al. (2013)
		6. Aman rice – chickpea (Rajshahi and Nawabganj Dist. of Bangladesh)	(a) The residual soil moisture is utilized efficiently (b) The N reserve of soil increased (c) More soil rhizosphere activity	Musa et al. (2001)
		7. Groundnut–rice–black gram (Tamil Nadu, India)	(a) High soil N reserve (b) Loss of N (in form of NO_3^-) through leaching is reduced as most of the soil N is in organic form (c) Increased soil organic C, available N, P, K and S content of the soil	Porpavai et al. (2011)
		8. Rice–rice–green gram (Tamil Nadu, India)	(a) Incorporation of more soil N (b) Improvement of soil structure (c) More organic carbon content in soil due to accumulation and decomposition of root residues and shedding of leaves by the leguminous crops on the soil	Porpavai et al. (2011)

(continued)

Table 4.2 (continued)

Dominant soil order	Constraints	Preferred cropping system (region under practice)	Effect on soil health	References
		9. Pigeon pea + green gram (Ludhiana, Punjab, India)	(a) Soil physical properties become more stable and porous (b) More soil N is available for succeeding crop cultivation (c) Lower losses of N by leaching (d) Nutrient uptake increased both spatially and temporally	Ali (1985)
		10. Sugarcane–ratoon–wheat (residue incorporation + *Trichoderma viride* application) (Lucknow, India)	(a) The bulk density of soil is lowered down (b) Increased porosity (>48%) was observed in this system (c) Soil organic carbon was recorded higher (20%) at 0–15 cm soil depth. (d) Higher total carbon sequestered (@ 1.3 Mg/ha) in 0–15 cm soil depth (e) Residue incorporation along with application of *Trichoderma* sustained soil C level as well as N level for longer period	Shukla et al. (2017)
		11. Sugarcane + soybean (China)	(a) Increased nitrogenase activity (by 55%), urease activity (78%) (b) Increase in N and P contents of rhizospheric soil (c) More number of bacteria and actinomycetes were increased	Li et al. (2013)
Andisol	1. When dry, they are susceptible to wind erosion 2. They have high P fixation capacity; thus crops grown show little response to P application	Ryegrass (*Lolium perenne cv. Nui*) and tall fescue (*Festuca arundinacea cv. Exella*) (Piedras Negras series)	(a) Fertilization with the highest NH_4-N dose strongly decreased soil pH and shoot P content, as well as it increased root phosphatase activity (b) The highest NH_4-N dose strongly decreased soil pH	Paredes et al. (2011)

Aridisol	1. Soils remain dry for most part of the year 2. More evapotranspiration than rainfall, received in these soils 3. Soils have high groundwater table with brackish groundwater 4. Soil is very coarse in texture with low contents of soil organic matter, N, S and micronutrients (except Mo and B) 5. Diurnal and seasonal fluctuations of soil temperature are rapid 6. Water-holding capacity is very low in these soils 7. Development of calcic, gypsic, salic horizons causes poor crop stand	1. Groundnut – wheat (Rajasthan, India)	(a) N and S deficit is found (b) Legumes drive 56–68% of their N requirement through biological N fixation (BNF) (c) Loss of N through volatilization is lowered down (d) Maximum value of phosphorus was recorded in this cropping system partly because of solubilizing effect of decomposing organic residue for native soil phosphorus and less removal compared to quantity applied	Sharma and Jain (2014)
		2. Pearl millet + clusterbean (*Cyamopsis tetragonoloba)* (Jobner, Rajasthan, India)	(a) N dose can be reduced up to 25% in the case of pearl millet (b) More soil organic C helps to increase soil microbial activity (c) Infestation by soil-borne pathogen is reduced (d) Phosphatase activity is higher	Sharma and Gupta (2001)
		3. Cluster bean (*Cyamopsis tetragonoloba*)–wheat (Rajasthan, India)	(a) Maximum positive potassium balance was observed (b) Improvement of soil structure for wheat cultivation was recorded (c) Reduced soil erosion from wind as well as from rain (d) Solubilizing effects of soil phosphorus is recorded	Sharma and Jain (2014)

(continued)

Table 4.2 (continued)

Dominant soil order	Constraints	Preferred cropping system (region under practice)	Effect on soil health	References
		4. Multistoreyed cropping of coconut (*Cocos nucifera*) with pepper (*Piper nigrum*), cacao (*Theobroma cacao*) and pineapple (*Ananas comosus*) (India)	(a) There was more fungi population and fewer bacterial populations in the rhizosphere zone (b) More P is solubilized in root zones (c) The organic C, total N and K were higher in the root regions of multistoreyed cropping, but C and N mineralization decreased with soil depth (d) Incidence of *Azospirillum* sp. was determined in high-density multistoreyed cropping (e) Higher nitrogenase activity was recorded in this system (f) Application of vermiwash in this multistoreyed system greatly controls the populations of root-knot nematode (*Meloidogyne incognita*), spiral nematode (*Helicotylenchus multicinctus*) followed by burrowing nematode (*Radopholus similis*) and root lesion nematode (*Pratylenchus coffeae*) (Banu and Iyer 2006)	Bopaiah and Shetty (1991) and Ghai and Thomas (1989)
Histosol	1. Generally not used for cultivation in Indian soils 2. Permanent water saturated environment is prevailed as because it formed in low-lying areas 3. Rate of decomposition is lower than rate of organic matter accumulation 4. Local conditions sometimes give rise to unfavourable alkaline pH condition with poor aeration	Six rows of sugarcane (*Saccharum officinarum* L.) Sugarcane cultivar CP 89-2143 was planted for 2 years (Everglades Agricultural Area (EAA), north of the Water Conservation Areas in South Florida)	(a) Enhanced labile P availability >100% compared with untreated soils (b) Higher phosphatase and glucosidase activities (c) Microbial biomass P was higher	Ye et al. (2011)

practised in all farming system as it adds more litters, high in C:N ratio and lignin:N ratio (Rasse et al. 2005); residence of C in grassland is much longer than others (Lemaire et al. 2014). Moderate grazing by cattle improves soil quality and increases soil C and N for longer periods of time (Franzluebbers and Stuedemann 2010). Hence multiple components of a farming system have multiple effects on modification of soil environment in different ecosystems. Some typical example of farming systems mediated changes in soil physical, chemical and biological properties have been provided in Tables 4.1 and 4.3.

4.5 Lessons Learnt and Rephrasing Traditional Approach with Flexible Mode

Yield increment in last few decades is stagnated because of practices such as widespread cultivation intensification, development of high-yielding exhaustive varieties and increasing use of chemicals such as chemical fertilizers, pesticides, wastewater irrigation and farm-mechanization. According to researchers, intensive cropping areas should include legume-based cropping systems. Improved yield of crops followed by legume addition has been widely observed by farmers and recorded by researchers. As legumes with low C/N ratio, high rate of mineralization of organic N can fix atmospheric N_2, breaks diseases and pest cycles in soil, improves soil microbial community and physical and chemical attributes and increases activity of soil macrofauna such as earthworms (Peoples and Craswell 1992; Kundu and Ladha 1995; Wani et al. 1995). Rotational benefits of annual legumes can be achieved by improving the N economy of soils assessed by reserves of organic N which is readily mineralizable in soil and microbial biomass C and N (Dalai et al. 1994; Rupela et al. 1995; Wani et al. 1995). The application of manure with balanced fertilization of N, P and K leads to lowering loss of nutrient and maintains soil organic carbon pool and soil microorganisms for long time. This in turn helps in transformation of nutrients. Again it has been time and again demonstrated that in areas having eroded soil where fertility is major constraints, conservation agriculture should be practised instead of conventional agriculture to sustain soil health and crop productivity for the long term (Govaerts et al. 2009; Hobbs et al. 2008). For eroded soil with flat plains, cost-effective stubble mulch or crop residue mulch gives conservation of moisture under field conditions as well as addition of organic matter with low soil temperature fluctuations. It protects soil from wind erosion. In dry semiarid areas and even in laterites, where soil lacks moisture content, ‘alley cropping’ should be followed. For example, black gram, turmeric, ginger, etc. crops are grown in passages formed by rows of eucalyptus, subabool, etc. to hasten soil fertility restoration by providing more organic litters, conserve moisture by providing shades and reduce soil erosion. Again continuous seashore winds or winds in nearby desert areas bury the croplands with sand when vegetation stabilizing the sand dunes is seriously damaged. Therefore stabilization or mitigation of sand dunes can be achieved by growing vegetation like ephemeral grasses, shrubs and trees with good rooting depth that traps sand because it is less expensive, stable over long period and

Table 4.3 Farming system impacts on soil health differentially

Agroecological regions	Farming practices	Soil health	References
Tropical ecosystem	1. Crop rotation with rice – groundnut/ mustard/watermelon 2. Horticultural crops: papaya, banana 3. Fishes: Indian major carps and prawns	(a) Papaya and banana utilize soil water during rice cultivation (b) Groundnut provides more of soil N (c) More of hydrogenase and phosphatase activity is prevalent during watermelon cultivation (d) Fish litters provide more of organic matter in the bottom of pond	Srivastava et al. (2004)
Subtropical dry ecosystem	1. Various rice-, wheat- and maize-based cropping system 2. Inclusion of cassava, vegetables and legume crops in upland conditions 3. Perennial tree crops like coconut, oil palm, rubber and fruit trees 4. Cattles like goats, buffaloes and pigs	(a) Crop residue incorporation of cereals can hasten soil organic C dynamics as well as colonization of associative N-fixing organisms (b) Vegetable crops increase more of soil enzymatic activity (c) Perennial trees provide shade to bare lands as well as create a favourable soil structure in the long run (d) Cattle dung provides more of soil organic matter in soil (e) Grazing of cattle hasten soil surface layer more developed	Devendra and Thomas (2002)
Dryland ecosystem	1. Crops like sorghum + cowpea (grain), sorghum + cowpea (fodder) and *Cenchrus* spp. Intercropped with *Emblica officinalis* 2. Goats and dairy cattle	(a) Sorghum provides HCN in soil to control harmful incidence of wilt causing fungi (b) Cowpea both as grain and fodder adds more of biomass into soil. Hence a soil organic matter level of soil is increased (c) Soil erosion is prevented through the binding actions of roots of *Cenchrus* spp. and *Emblica officinalis* (d) Addition of more soil organic matter is achieved through excreta of goats and cattle (e) More of soil surface layer is developed. It also reduces wind erosion	Singh and Sharma (1987)

Semiarid ecosystem	1. Agrosilvopasture with maize in between rows of *Leucaena leucocephala* with grasses like Kentucky bluegrass (*Poa pratensis*), quack grass (*Elymus repens*), etc. with maize straw mulch after crop harvest 2. With grazing of cattle	(a) Readily oxidizable organic matter shows highest CO_2-C stock in upper soil layers of the native area (b) This system provides protection against wind erosion as grasses, and tree sp. holds surface soil more tightly (c) Mulches provide more soil organism diversity Mulching causes less problems for mixed farming (Erenstein 2003) (d) Cattle dung addition provides more of organic C fractions in soil	Maia et al. (2007)
Subtropical humid ecosystem	1. Rice – fish includes common carps in fresh water, fish–fingerlings and rice–fish refuge system 2. Fruits include guava, banana and mango on the side of ponded areas 3. Vegetable cultivation like cucurbits, spinach, chilli, tomato, etc. 4. Agroforestry systems including *Dalbergia sissoo*, *Acacia* spp., *Prosopis cineraria*, etc.	(a) Alkaline phosphatase, urease and FDA activity were observed in rice–fish culture. (b) Hydrogenase and acid phosphatase activity was high in vegetable and fish – fingerlings production system (c) N cycles affected more in this farming system (d) Soil erosion was less compared to only rice monocropping or bare land (e) Agroforestry systems not only provide protection against wind and water erosion, but it helps in adding more of tree litters and thereby increases organic matter content in soil (f) Agroforestry practice provides shades on surface soil and thereby increases more of microbial diversity in surface soil for the long run	Bihari et al. (2015)

self-repairing technique (Woodhouse 1978). In case of waterlogged soils, where anaerobic conditions prevail over the year can be used for cultivation of rice. For utilization of its full potential, reclamation through bio-drainage plants proved to be successful during course of 3–5 years. Bio-drainage plants are crops with higher transpiration rate with good rooting depth and are tolerant to waterlogging, for example *Eucalyptus camaldulensis*, willow (*Salix* spp.), poplar (*Populus* spp.) and alfalfa (*Medicago sativa*). They up take more of water from deeper soil depth and, after using it, transpire rapidly through the stomata of leaves. Continuous transpiration causes higher water levels to go down. Hence, fields become cultivable with more number of crops other than rice.

4.6 Conclusion

Diversification of cropping systems, an innovative movement with farmer-friendly approach, is necessary to get higher yield and return and to maintain soil health, preserve environment and meet daily requirement of human and animals. Thus, not only the number of crops, but type of crops included in the cropping sequence is also important. In this approach, resources are not only utilized efficiently but also ensure on a farm and their interactions with farm resources. Various cropping systems have different residual effects on different soils. Efficient nutrient management is prime concern in the management of optimum soil fertility. Hence, synthetic fertilizers should be applied in soil with optimal dose or little less along with organic manures because the maintenance of soil fertility as well as soil health can only be achieved through building up of soil organic carbon and proliferation of soil microbes. The sensitivity of soil indicators can provide information about dynamic nature of soil properties in field conditions. There is scope for further refinement to assess the soil quality parameters based on crop productivity under different soil types.

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