Soil health sustainability and organic farming: A review

IRDM Faculty Centre, RKM Vivekananda University, Ramakrishna Mission Ashrama Narendrapur, Kolkata-700103, West Bengal, India. e-mail: sudarsanbiswas@yahoo.com, nasimali2007@gmail.com, goswamirupak@rediffmail.com, som_pau@yahoo.com

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Abstract
The need of sustainable agriculture is universal and way to achieving it has been defined through intensive empirical research. Several indicators for the sustainability of agricultural systems have also been developed. Use of synthetic fertilizers and their effects on crop production, soil health, environmental quality, biodiversity conservation and self-reliance of farming system have been discussed in the context of agricultural sustainability. Degradation of soil fertility due to use of synthetic agro-inputs is considered as one of the most important factors affecting sustainability of agricultural systems. Presence of soil organic matter and soil microbial population are primarily useful indicators of soil health and productivity of both crops and livestock. A long-term integrated approach will be an appropriate solution for standardizing fertility management in organic farming considering the complex interactions among different components of this system. A comprehensive and systematic review on different qualitative and quantitative changes of soil health parameters for improved nutrient management supports these observations.

Key words: Organic farming, soil fertility, soil health, sustainable agriculture.

Introduction
According to the International Federation of Organic Agriculture Movement 102, the primary objective of organic farming is the sustainable crop production for maintaining long-term soil fertility in harmony with natural systems. Therefore, to sustain the agricultural productivity and environmental quality soil health management should be the primary concern of all stakeholders of agricultural development 87. According to Larson and Pierce 59, apart from nourishing plants, ‘mother earth’ creates a congenial atmosphere for the survival of the soil organisms. Therefore, better soil health is inevitable for better growth and development of crop leading to higher production 29. Soil health is defined as the continued capacity of soil to function as a vital living system. The biological elements are key to ecosystem function within land-use boundaries 23, 50 and are able to sustain not only biological productivity of soil but also maintain the quality of surrounding environment. These ultimately promote plant, animal, and human health. Conversely, Oldeman 71 defined soil degradation as the process, which lowers the current and/or future capacity of soil to provide goods or services. Application of excessive chemical fertilizers, imbalanced nutrient management, and soil pollution are the main causes of soil degradation 42, 107. Noticeably, the United Nations Environment Programme (UNEP) sponsored project, Global Assessment of Soil Degradation estimated – more than two decades ago – 38% of degraded agricultural land globally due to anthropogenic reason 71.

The context is no exception to a country like India, which has a glorious agricultural background since the Vedic era 8, 85. In Vedic era, the cultivation procedure was solely based on local resources, which were completely free from the application of synthetic compounds 8. The uses of animal manure, oil cakes, green manures etc. were emphasized in the Vedic Era to maintain the soil fertility 82. The Indian epic Ramayana described the importance of organic matter in soil management as “all dead things – rotting corpse or stinking garbage – returned to earth are transformed into wholesome things that nourish life. Such is the alchemy of mother earth.” Farmers treated the soil as living entity, which was one of the five elements of life along with air, water, fire, and sky, collectively known as ‘Panchabhuta’ 51. In Vedas, soil was considered as ‘Mother’ and the human beings were treated as her ‘Sons’: “Mata bhumi putro aham prthvya” (Atharva Veda 12.1.12) 86. In the modern context, Doran et al. 24, in similar vein, has described soil as the mother of any agricultural activity.

With the advent of industrial agriculture or so called green revolution technologies agriculture became dependent on external inputs, environment became polluted, natural resources depleted, human health deteriorated, and agriculture itself experienced the challenge of sustainability 104. There are several evidences, which prove that agrochemical based, external input intensive agriculture is not sustainable in long run due to gradual decline in productivity factor and adverse impact on soil health and quality including soil organic carbon 90, 102, 104, 107. Thus, the ‘Europeanization of Indian agriculture’, i.e. the introduction of green revolution has threatened long-term soil health, and at the same time farmers have become frustrated because of declining agricultural productivity and surged cost of cultivation.

Organic farming system is based on the management of soil organic matter, which in turn maintains the physical, chemical, and biological properties of soil 84, 101. It is now a well-established fact that organically managed soil exhibits greater soil organic carbon and total nitrogen, lower nitrate leaching 26 and biological...
soil quality than conventionally managed soil. Long-term studies have shown higher soil microbial biomass carbon under organic than conventional management. From the environmental perspective also, organic practices were claimed to have improved soil ecosystem quality and long-term farm-level sustainability.

Conceptualization of the Impact of Organic Farming on Soil Quality

Soil quality is often argued as an ecosystem concept that integrates diverse soil functions, including nutrient supply, which leads to crop productivity (instead of seeing it as the continued ability of soil to supply nutrients to crops). This understanding suites well to organic farming, since there are complex relationships between different system components and the system sustainability depends heavily on functioning of the whole system. It is then crucial to conceptualize the relationship of organic farming with soil quality for a sound appreciation of organic farming’s impact on soil fertility. The integration of different components of organic practices enhancing soil properties to sustain soil health is shown in Fig. 1.

Review Methodology

Although case study or single source of information on a given issue may generate rich insight, inferring relationships or developing theory on the issue require information from a wider universe. Literature survey is no exception to this, since it is also laden with the biasness of social surveys and questions may well be raised on the validity of making conclusions based on a single review. Thorne et al. propose synthesis-based methodologies to address this limitation and calls for building new knowledge from rigorous analysis of existing research findings, which is clearly distinguishable from single reviews in terms of collection and treatment of data and detection of literature omissions. Although systematic reviews have widely been quantitative in nature, recently, qualitative systematic reviews have been used as useful methodology. Following Plummer et al., a four-step approach for the systematic review and analysis of literature was undertaken for the present paper. First, the objectives of the review were set to study the impact of organic farming on soil health in terms of physical, chemical and biological properties of soil, and to compare the outcomes of organic and conventional soil health management. Second, we established a search protocol including selection of key words, bibliographic databases, establishing selection criteria for search engine ‘hit’ etc. We used a combination of key words involving “organic farming”/“organic agriculture” and all the soil quality parameters conceptualized in Fig. 1. ScineceDirect, Google Scholar and DOAJ were used as the bibliographic database and the first 50 ‘hits’ were considered for screening literature. Third, we screened the results as per the screening criteria, i.e. publication in the last 20 years, article published in English, key word match etc. Fourth, analysis of the literature was performed through the principle of qualitative analysis of literature. This employed iterative coding of themes related to soil quality parameters and their relationship with organic agricultural practices.

Impact of Organic Farming on Soil Health

Impact on physical properties of soil: The physical properties of soil denote structure, texture, bulk density, porosity, water-holding capacity etc. and positive effects of organic farming on soil physical properties viz. soil structure, water holding capacity, soil aeration and soil temperature are well-reported. Papadopoulos et al. notice that organic management can improve soil structure, organic matter content, and porosity in soil. Crop rotation is an important component under organic farming which directly and indirectly influences the physical structure of soil. Accumulation of organic matter in soil during the lean phase has a direct influence in the modification of soil structure. The architectural form of different root systems of several crops included in the crop rotation also helps to modify the soil structure. Mulching of soil surface with organic materials renders the soil soft, pulverized, and humid that ultimately creates a congenial environment for beneficial microbes to maintain bulk density and porosity in the soil. Organic farming adds more organic matter to the soil, which is the basic requirement for improving soil health. Presence of this organic matter in soil

**Figure 1.** Integration of different of organic practices for sustainability of soil health.
increases its moisture retention capacity. A combination of crop residue mulching and no-tillage increases soil fertility, crop production, and control soil erosion. Further, residue decomposition adds organic matter to the soil, which contributes to reduce the soil hydrological response, increase soil water repellency that reduces infiltration rates. Application of organic fertilizer not only provides nutrient to the standing crop but also to the succeeding crop. The improvement of soil physical properties due to organic farming has spatio-temporal dimension also. Lotter et al. reported that organic farming is better in areas having extreme rainfall because of the higher absorption and less run-off of water in the field.

**Impact on chemical properties of soil:** Unlike conventional agriculture, organic agriculture follows the natural cycle to add essential nutrients for quality improvement. Organic farming has potential to maintain soil fertility and increase organic carbon in soil. Application of different organic inputs like FYM, vermicompost, green manuring etc. ensures both the sustainability of soil organic carbon and supply of nutrients to the plants. Application of good quality FYM improves the total nitrogen and organic matter in the soil, which is “an important substrate of cationic exchange and the warehouse of most of the available nitrogen, phosphorus, and sulphur; the main energy source for microorganisms; and is a key determinant of soil structure.” Significant differences and higher values of soil organic carbon, carbon stocks, and carbon sequestration rate were observed in organically managed plots compared to non-organic plots. It is undoubtedly an important controlling factor for C:N ratio, total and available N, N mineralization, soil moisture, microbial activity, and soil texture. Strikingly, several studies have reported that organically amended soil holds more available N than the soil receiving inorganic fertilization, mainly due to relatively slower and constant mineralization rates, ultimately decreasing nitrogen leaching. Organic acids and humus fraction of decomposing matter are more efficient in releasing phosphorus and reducing its fixation in soil. Nutrient supply through organic sources also ensures micronutrient availability to the plant.

**Impact of organic inputs on biological properties of soil:** Although many researchers confine the concept of soil quality to physical and chemical properties, others value biological parameter as an important aspect, which should be incorporated in soil quality assessment process. These biological properties are very important while assessing soil quality since soil quality is strongly influenced by the flora and fauna present in the soil. Soil micro-organisms are the living part of soil organic matter present in the soil. The microbial biomass and microbial activities in soil are crucial to sustain the productivity of soil. For ensuring consistent release of nutrients to the plants, there is a need to have balanced ratio of microbial biomass and activity in soil. Organic farming is reported to have enhanced both microbial biomass and microbial activity by 20-30% and 30-100%, respectively. The soil having high organic matter content ensures greater microbial activity and greater soil N supplying power than the soil having less organic matter (which is managed inorganically). In addition to this, soil organic matter has a capacity to sink the atmospheric CO₂ and thereby increasing the carbon content in the soil, which further enhances the microbial biomass and respiration. It has also been well documented that the organically managed soil enriched with several beneficial microorganisms like arbuscular mycorrizal fungi for ensuring improved crop nutrition and decreasing soilborne diseases. Arbuscular mycorrizal fungi is a special fungal group, which makes symbiotic association with the plant’s root system enhancing plant nutrient uptake and water absorption. This mutualistic relationship primarily helps plant to take more P from the soil and also protects plants from several diseases. As organic farming increases the microbial activity, leads to increased competition, parasitism and predation in the rhizosphere, it collectively reduces the chances of plant disease infestation. Application of quality organic inputs enhances the microbial population in the soil. Organic fertilizer application improved nodule dry weight, photosynthetic rates, N₂ fixation, and N accumulation as well as N concentration in several crops. However, it was also found that organic agroecosystem management strongly influences the soil nutrients and enzyme activity while it has lesser influence on soil microbial communities. Several composts like vermin-compost, farmyard manure etc. are generally used for nutrient management in organic farming, which ultimately promote the beneficial macro and micro flora in the soil. Application of organic inputs like human urine, sewage sludge, municipal waste, deep litter, cattle slurry, cattle manure etc. ensures higher soil microbial biomass. Hence, household waste and sewage sludge help to maintain the highest number of colony forming heterotrophic bacteria in the soil.

**Organic farming and biodiversity:** Biodiversity in soil refers to a variety of taxonomic groups including bacteria, fungi, protozoa, nematodes, earthworms, and arthropods present in the soil. Intensification and expansion of modern agriculture have created a threat to biodiversity worldwide. Several studies have shown that it has been reducing the abundance and diversity of a host of plant and invertebrate taxa over the past four decades. On the contrary, organic farming helps to maintain biodiversity. It has also been well documented that organic farming resulted in higher biodiversity and enhanced soil fertility than conventional farming. However, recent studies found no effect of landscape heterogeneity, and differences in any of the measured soil and microbial variables between conventional and organic farms; but N mineralization was higher in organic farms.

**Outcome of Soil Management through Organic and Inorganic Means**

At the end of 40-47 years of dairy farm management in Denmark, organically managed soil had greater fragment size, aggregate stability in water, and microbial biomass carbon than conventionally managed soil. Moreover, at the end of 21 years of long-term crop rotation management in Switzerland, soil organic carbon and total N were greater under biodynamic than conventional management, but organic management and integrated management (combination of manures, inorganic fertilizers, and herbicides) were moderate. Soil microbial biomass carbon and dehydrogenase activity were greater under organic than that of conventional management, but basal soil respiration did not vary between systems. In North Dakota and Nebraska,
total and microbial C and N, and mineralizable C and N were greater under organic than that of conventional management. In Washington State, a comparative study of organic, conventional and integrated apple production systems from 1994 to 1999 indicated that the organic and integrated systems had higher soil quality and potentially lower negative environmental impact than the conventional system. Limited studies of intensive organic farming systems in Australia have generally shown an increase in soil health compared to conventional practice. Lamkin reported that nitrate leaching may be less under organic than conventional systems.

It is reported that the bulk density of organic soil is less than the soil which was managed chemically, indicating better soil aggregations and soil physical conditions owing to increased soil organic matter. There is a 29.7% increase in organic carbon aggregations and soil physical conditions owing to increased the soil which was managed chemically, indicating better soil

The multidimensional effects of organic soil management approaches on soil health are summarized in Table 1.

### Table 1. Effects of selected organic farming practices on soil health properties.

<table>
<thead>
<tr>
<th>Organic Components / Management</th>
<th>Soil Properties</th>
<th>Effects on Soil Properties</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td></td>
<td>Improve soil structure, porosity, moisture retention capacity etc. in the soil.</td>
<td>Alteri and Nicholls, Papadopoulos et al., and Jannourea et al.</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td>Supply several macro and micro nutrients to the plants.</td>
<td>Bharadwaj and Guar, Parthasarathy et al.</td>
</tr>
<tr>
<td>FYM, Vermi-compost, Green Manuring, Household waste and sewage sludge and Soil Organic Matter</td>
<td>Biological</td>
<td>Soil Organic Matter is the main energy source for microorganisms and it increases the microbial population in the soil.</td>
<td>Ewel, Smith and Paul, Lal et al., Dalal, Chowdhury et al., Friedel et al., Peacock et al., Poulsen et al. and Mattana et al.</td>
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<td></td>
<td></td>
<td>Soil micro-organisms are the living part of the soil organic matter.</td>
<td></td>
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<td></td>
<td></td>
<td>Soil organic matter has a capacity to sink the atmospheric CO₂ and thereby increase in the carbon content in the soil which further enhance the microbial biomass and elevate respiration.</td>
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<td></td>
<td></td>
<td>In general, organic fertilizer application improved nodule dry weight (DW), photosynthetic rates, N₂ fixation, and N accumulation as well as N concentration in several crops.</td>
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<tr>
<td></td>
<td></td>
<td>House hold waste and sewage sludge helps to have the highest number of colony forming heterotrophic bacteria in the soil.</td>
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<tr>
<td>Crop Rotation</td>
<td>Physical</td>
<td>Architectural form of different root systems of several crops included in crop rotation and which influences the physical structure of soil.</td>
<td>Clement and Williams, Chan and Heenan, and Grace et al.</td>
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<tr>
<td></td>
<td>Chemical</td>
<td>Crop rotations significantly increased soil pH, available phosphate, exchangeable K and Ca in soil.</td>
<td>FAO.</td>
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<tr>
<td></td>
<td>Biological</td>
<td>Crop rotation decreases the incidence of soil-born pathogen by increasing soil chemical properties and soil microbial biomass.</td>
<td>Dick, and FAO.</td>
</tr>
<tr>
<td>Mulching</td>
<td>Physical</td>
<td>It makes the soil softer, pulverized and humid that ultimately helps to maintain bulk density and porosity in the soil.</td>
<td>Lamkin, Pinamonti, Naeini and Cook, Lotter et al., Garcia-Morenoa et al., Inyang and Gbadel.</td>
</tr>
<tr>
<td></td>
<td>Chemical</td>
<td>It increases soil fertility, crop production and control soil erosion; residues become decomposed and add organic matter to the soil.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biological</td>
<td>Mulch materials improve soil physicochemical properties, suppress soil temperature, reduce evaporation and increase the soil moisture.</td>
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<tr>
<td></td>
<td></td>
<td>The mulching materials become decomposed and add organic matter and other nutrients to the soil.</td>
<td>Agbede et al.</td>
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<td></td>
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<td>Mulching helps to increase the population, species diversity and activity of macro fauna in the soil.</td>
<td>Lal, Ojeniyi and Adetoro, Awodun and Ojeniyi.</td>
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</table>

### Conclusions

To achieve sustainable crop and livestock production, the primary requirement is the maintenance of soil fertility and soil health. Organic farming systems being highly complex and integrated biological systems could be the potential technology option to maintain good soil health. Organic practice has both direct and indirect effect to soil properties as it affects more than one component of the system simultaneously. The previous studies on the impact of organic practices on different aspects of crop production, soil health and environment envisage the potentiality of the organic farming in maintaining the soil health and soil fertility.

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References


