International Journal of Bio-resource and Stress Management https://pphouse.org/ijbsm.php

Crossref

IJBSM November 2022, 13(11):1186-1200 Print ISSN 0976-3988 Online ISSN 0976-4038 Article AR3141a

Review Article Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2022.3141a

Soil Health Management in Organic Production System – A Review

Amit Anil Shahane[1] and Yashbir Singh Shivay[2]

[1]Dept. of Agronomy, College of Agriculture, CAU (Imphal), Kyrdemkulai, Ri-Bhoi District, Meghalaya (793 105), India
[2]Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi (110 012), India

Open Access

Corresponding amitiari89@gmail.com

0000-0003-0551-8573

ABSTRACT

At present, the soil is discussed in terms of the extent of degradation, increased pollution (footprint of human activity), and ecosystem services apart from the fertility and productivity point of view. To address these issues, soil needs to be defined in terms of its health. Healthy soil is the first and foremost entity in organic farming. In India, organic farming is spreading in areas subjected to different kinds of land degradation (hilly areas and semi-arid areas). Therefore, the study of soil health is important in organic farming. The article aims to discuss the concept of soil health and different agronomic interventions and management practices with their possible economics for maintaining soil health in an organic production system. The practices such as the use of biodynamic formulations, the use of microbial inoculations, and intercropping with leguminous crops have a positive effect on the nutrient supply besides improving soil health. The availability of a large array of options including input addition and management practices for soil health management provides potential for soil health management. Organic farming can afford the cost on soil health management considering its specification for organic sources, organic farming niche (North East India with high organic matter and semi-arid area with large bovine population), and premium prices of produce; while trade-off between premier prices and low yield in organic farming is well-defined constraint for investing of soil health at commercial scale in organic farming.

KEYWORDS: Agro-industrial waste, conservation tillage, manures, green manuring

Citation* (VANCOUVER)*: Shahane and Shivay, Soil Health Management in Organic Production System – A Review. *International Journal of Bio-resource and Stress Management,* 2022; 13(11), 1186-1200. HTTPS://DOI.ORG/10.23910/1.2022.3141a.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 19th June 2022 RECEIVED in revised form on 18th October 2022 ACCEPTED in final form on 01st November 2022 PUBLISHED on 19th November 2022

1. INTRODUCTION

Soil is the 4-dimensional body on the earth's surface characterized by its physical, chemical, and biological properties, while in the agro-ecosystem, the soil is mainly explained for its productive capacity (Lal, 2016). The productive capacity of soil in the agro-ecosystem is expressed in terms soil fertility and soil productivity. Soil fertility is defined as the capacity of soil to provide the nutrients for crop growth in adequate amounts, in balanced proportion and in available form. This definition mainly deals with soil nutrient availability and conditions influencing it. Another term is soil productivity (though holistic term explaining the capacity of soil to produce crops under a given environment and said management) which mainly considers the soil properties in relation to crop productivity. The ever-growing need for provisional and ecosystem services from agro-ecosystem with soil as a base medium for all agro-ecosystem activities necessitates us to quantify the soil in different parameters other than those directed towards crop or agricultural productivity. This creates scope for defining soil in terms of soil health (Katyal et al., 2016; Tahat et al., 2020; Kibblewhite et al., 2008; Rattan et al., 2009; Katyal et al., 2016; Field, 2017; Haney et al., 2018; Wander et al., 2019) and soil security (Field, 2017). At the same time, faster rate of soil degradation (Bhattacharyya et al., 2015,Anonymous, 2018, Mirzabaev et al., 2019, Wijitkosum, 2020) and extent of area occupied due to one or more kinds of soil degradation due to human interference also signifies the need of defining soil in term of soil health perspectives rather than just defining its crop productive capacity. Human interference is mainly related to input addition and management practices in agricultural land whose contribution to soil degradation and soil health need to be quantified. The evidence of the development on soil health concept and increasing awareness can be seen from the increasing area under conservation agriculture (CA) from 106.5 to 180.4 mha globally (Kassam et al., 2019) as well as the increasing area under organic farming from 11 to 72.3 mha in globally (Willer et al., 2021). The conservation agriculture based on three principles viz., minimum disturbance to soil, retention of crop residue to cover a minimum of 30% soil surface (Bhan and Behera, 2014; Pittelkow et al., 2015; Somasundaram et al., 2020; Tabriz et al., 2021) and crop rotation is gaining momentum. All these principles are having positive effect on soil health (Chivenge et al., 2007; Cheesman et al., 2016; Powlson et al., 2016; Pheap et al., 2019). In case of organic farming, the area is increasing rapidly with 84.8% increase over 1999 in the World (Willer et al., 2021). Though it is a market driven production system, it is having significant impact on natural resources and their impact on soil health (Garcia-Palacios et al., 2017; Krauss et al., 2022; Tian et al., 2018; Dewi et al., 2022; Khatri et al., 2023) can be justified by use of organic sources of nutrition, harvesting positive interaction between plant, animal and microbes and complete or partial restriction on use of agrochemicals. Therefore the potential of both conservation agriculture practices and organic farming need to recognize along with their impact on agricultural productivity. Besides, different governmental schemes such as soil health cards system (Reddy, 2017) which provide the soil nutrient status and also advise the farmers about the need for balanced fertilization to promote soil health. Furthermore, the role of different soil and water conservation practices in soil health maintenance needs to be studied. This will be addressed by studying the extent of soil degradation and by defining and measuring soil health.

2. SOIL DEGRADATION

The increased level of soil degradation is one of the most important reasons for evaluating soil for its health rather than productive capacity alone. This can be judged by the extent of the soil degradation problem (Table 1). The degradation is explained by different terms such as land degradation, soil degradation, soil desertification, and soil pollution (Roy Chowdhury et al., 2018; Williams et al., 2018; Olsson et al., 2019; Sterk and Stoorvogel, 2020). Land degradation as a native trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of biological productivity, ecological integrity, or value to humans(at least one of them).Soil degradation is considered as a subset of land degradation which directly affects soil and is defined as the decline in the soil's productivity through adverse changes in nutrient status, soil organic matter, structural attributes, and concentrations of electrolytes and toxic chemicals (Aulakhand Sidhu, 2015; Reddy, 2017; Sahoo et al., 2019). Another term, soil desertification, is mainly related to physical degradation of soil and is defined as, land degradation in arid, semi-arid and dry sub-humid areas, collectively known as drylands,

Table 1: Land degradation due to different processes

Sl. No.	Causes of land degradation	Area under land degradation (mha)
1.	Water erosion	93.7
2.	Wind erosion	9.5
3.	Water logging	14.3
4.	Salinity/alkalinity	5.9
5.	Soil acidity	16.0
6.	Area with the complex problem	7.4
	Total	146.8

(Bhattacharyya et al., 2015)

resulting from many factors, including human activities and climatic variations (Mirzabaev et al., 2019). The term soil pollution was defined as the build-up in soils of persistent toxic compounds, chemicals, salts, radioactive materials, or disease-causing agents, which have an adverse effect on plant growth and animal health (Selvi et al., 2019). The area under one or more kinds of the degradation process is 146.8 million ha which is more than the net cultivated area of 139.51 mha and 44.65% of the total geographical area of India(Bhattacharyya et al., 2015; Anonymous, 2020. The major cause of land degradation is water erosion which accounts for 63% of the total area under land degradation and this is mainly due to heavy rainfall and land topography (steep slopy land). The expansion of agriculture in forest areas and improper handling of land (shifting cultivation) again intensify soil erosion. This is more common in a hilly area (mainly in the western and eastern Himalayan zone) and also in part of semi-arid areas where rainfed agriculture is followed with least agro-chemical inputs addition due to resource scarcity. The agriculture in these areas is dominated by organic practices either intentionally or by default. This was mainly due to the fact that agrochemical-based input intensive technologies are not implemented and also due to the richness of the soil in organic matter (Eastern Himalayan region) which serves as a source of crop nutrition. The soil organic carbon/matter has multifarious effects on the soil health and productive capacity of the soil, therefore the study of soil health in organic farming is of paramount importance.

3. SOIL HEALTH AND ITS MEASUREMENT

Soil health is defined as an integrative property that reflects the capacity of soil to respond to agricultural intervention, so that it continues to support both agricultural production and the provision of other ecosystem services(Kibblewhite et al., 2008; Rattan et al., 2009; Katyal et al., 2016; Field, 2017; Haney et al., 2018;Wander et al., 2019; Tahat et al., 2020). With an increased level of understanding about different soil properties and their contribution to tangible and non-tangible services, soil health is also explained in the terms of different soil properties viz. soil physical health, soil chemical health, and soil biological health. The soil with the ability to meet plant and ecosystem requirements for water, aeration, and strength over time and to resist and recover from processes that might diminish the ability is considered physically healthy soil (McKenzie et al., 2011; Are, 2019). The soil biological health is the ability of soil to support large and diverse microbial communities, suppress pathogens, and support healthy crop development; while chemically healthy soil is the soil with the presence of plant nutrients in optimum quantity, available form, and balanced proportions which can be available to plants without the hindrance of soil mineral composition as modified by different biogeochemical processes, other chemical compounds, and properties. The soil chemical health also considers the presence or absence of harmful soil agrochemicalsand pollutants. Among all the above-mentioned three soil health, soil chemical health gets more attention due to its significant and distinctly visible contribution to our major agricultural activity i.e., crop and animal production. This can be judged from the amount of nutrient addition (27.37 mt), the amount of energy involved in nutrient addition out of total energy required in production, and the amount of subsidy given on primary nutrients by the government. Singh et al. (2016) reported that nutrient application in maize-wheat cropping system consumes 36% out of the total energy used in the production process. At the same time, extensive research on the response of crops to different nutrients and the establishment of long-term experiments with major objective to study the soil nutrient balance and crop response to different nutrient addition also indicate the first and foremost place of soil chemical health. The soil's physical health getting attention with the intensification of the soil degradation process (the most important cause of soil degradation is water erosion followed by wind erosion). Along with it, an increased level of soil degradation due to plough-based intensive tillage system is another reason for increasing the recognition of soil physical health. The term biological health is mainly discussed with respect to the application of microbial inoculations for nutrient fixation and acquisition (mobilization and solubilization) and for control of harmful microbial life. At present, biological health getting attention due to the adverse effect of conventional agrochemical-based farming and increased understanding the functional capacity of soil biota in soil sustainability (Khatri et al., 2023). These three soil health are measured in different parameters with their threshold level (Table 2). Considering the involvement of a large number of parameters as well as the involvement of qualitative parameters, the expression of soil health is becoming more complex and case-specific. The soil health is expressed using some indices calculated based on the soil properties having a significant impact on crop production and ecosystem services. Such indices include soil tilth index, soil quality index, and recently artificial intelligence soil quality index. The soil tilth index is a qualitative index given by Singh et al. (1992) used to explain the physical property of soil. It is based on five soil physical properties, viz. bulk density, cone index, aggregate uniformity coefficient, organic matter content, and plasticity index. The soil quality index is a minimum set of parameters that provides numerical data concerning the capacity of soil to carry out one or more functions (Garrigues et al., 2012; Mukhopapdhyay et al., 2014; Mukherjee and Lal, 2014;

Table 2: List of different soil health indicators

Soil physical indicators	Soil chemical indicators	Soil biological indicators
Texture	pH	Earthworm populations
Bulk density	Electrical conductivity	Nematode populations
Penetration resistance	Soil organic carbon	Arthropod populations
Aggregate stability	Total organic carbon	Mycorrhizal fungi
Water holding capacity	Total soil nitrogen	Nitrogen fixation of microorganisms
Infiltration rate	Cation exchange capacity	Soil chlorophyll
Depth of hardpan	Macro and micronutrient content in the soil	Dehydrogenase activity
Depth ofwater table	Presence of residue of agrochemicals	Alkaline phosphatase activity
Porosity	Presence of heavy metals	Urease enzyme
Erosive potential	–	Soil respiration rate (Soil CO_2 efflux)
Soil structure	–	Microbial biomass carbon
Soil crust	–	–

(Cardoso et al., 2013; Ray et al., 2014; Roper et al., 2017; Mukherjee et al., 2018; Bhowmik et al., 2019; Maini et al., 2020; Eze et al., 2021)

Gelaw et al., 2015; Mukhopapdhyay et al., 2016; Vasu et al., 2016). The evaluation of the soil quality index is also important as it is important in determining sustainable land management, environmental risk management, monitoring of environmental changes and soil restoration (Pawlas et al., 2019). The selection of the minimum data set is case specific(subjective) and it is based on expert opinion, or mathematical and statistical (objective).This can be done using multivariate techniques such as principal component analysis, redundancy analysis, discriminant analysis, and multiple regressions.

4. ORGANIC PRODUCTION SYSTEM AND SOIL HEALTH

The organic production system emphasizes complete (or some cases partial) restriction of agrochemicals (including chemical fertilizers), antibiotics, and restriction on the use of genetically modified crops. The International Federation of Organic Agriculture Movement (IFOAM) defines organic farming as a production system that sustains the health of soils, ecosystems, and people; it relies on ecological processes, biodiversity, and cycles adapted to local conditions, rather than the use of inputs with adverse effects; it combines traditions, innovations, and science to benefits the shared environment and promotes fair relationships and good quality of life for all involved. The area under organic farming in India till March 2020 was 3.67 mha out of which 2.299 mha is cultivated area and 1.37 mha is wild harvest (Anonymous, 2021); while organic cultivated area as reported under different government schemes is 2.777 mha (Khurana and Kumar, 2020). The organic farming area in the hill region is dominantly following one or more components of shifting cultivation in which the productive capacity of the land is decreases due to fading of soil organic carbon and direct exposure of soil to raindrop and runoff. Therefore, an attempt for maintaining soil organic carbon is of utmost essential in such areas to sustain production capacity of these areas over a longer time. Out of the total organic farming area in India 17.5% area is occupied by seven eastern and western Himalayan states where shifting cultivation and soil erosion is a major problem. In the case of arid and semi-arid areas, higher temperature leading to a faster rate of organic carbon decomposition, few and high-intensity rainfall events, very low crop residue available for addition in soil and increased prices of organic sources of crop nutrition are the reason for reducing the soil productive capacity and soil health. The states such as Madhya Pradesh, Maharashtra, and Rajasthan having arid and semiarid climatic conditions occupy 50% of the total organic farming area indicating the need of studying soil health in this area.

The concept of organic farming depends on the four basic principles viz., the principle of health, the principle of ecology, the principle of fairness, and the principle of care. All these principles are aligned with the concept of soil health management. Among the several soil properties, soil organic carbon is important both in organic farming and in soil health management. At the same time, soil organic carbon has a dominant role in soil ecosystem services and the productive capacity of the soil. Therefore, prime attention is needed for maintaining soil health in the organic production systems.

5. AGRONOMIC INTERVENTIONS AND PRACTICES FOR MANAGEMENT OF SOIL HEALTH UNDER ORGANIC FARMING SYSTEM

The soil health improvement practices need to have economic basis towards crop production and income generation. This will enhance the chance of adoption of these practices. As soil health management interventions/ practices has potential to address one or more crop production related problems (Table 3), there is increasing change of their adoption in organic production system. In intensive cereal-based cropping system, residue management in a short time is a problem (Shahane and Shivay, 2016; Prasad and Shivay, 2018), for which residue incorporation, zero tillage sowing, and land configuration are the interventions which along with solving problem also contributes to soil health. The positive effect of residue incorporation or retention on soil physical properties was reported by Reddy et al. (2002) and Shaver (2010); while Prasad et al. (1999), Dhiman et al. (2000) and Jacintheet al. (2002) reported the positive effect on soil chemical properties. The significant and positive impact of residue management through conservation agricultural practices on soil biological properties is reported by Chaudhary et al. (2018). In the case of the use of mineral matter rich in any nutrient, their availability and knowledge of suitable niches for their use are needed at the stakeholder end. The concept of zeolitic farming (Kulasekaran et al., 2015) and the use of rock phosphate as a source of phosphorus either alone

Table 3: Agronomic interventions for the management of soil health under organic production system

Sl. No.	Agronomic interventions/ practices	Significance in crop production	Significance in soil health	Constraints	Suitable niche	References
Input addition						
1.	Green manuring	Crop growth and yield enhancement and improving the quality parameters such as physical and cooking quality in rice; increasing net returns	Correction of soil reaction in saline soil; potential for nematode management; increases biogeochemical cycling of nutrients; improving soil chemical health through increasing the nutrient supply (N, P and K); add the voluminous amount of organic carbon which has multifarious benefits to crop production; enhance the micronutrient supply and their use efficiency	Occupy land for 40–45 days which may lose one season; difficult to be incorporated in rainfed conditions	Irrigated ecosystem; rice and maize-based cropping systems; area with a good amount of pre-monsoon rainfall	Gangaiah and Prasad Babu (2016), Ramesh and Chandrasekaran (2004), Singh and Shivay (2016), Pooniya and Shivay (2015), Singh and Shivay (2013)
2.	Mulching	Strategy for weed management in an organic production system; positive effect on soil moisture conservation efficiency and avoid the terminal stress in late maturing crops/ varieties of rice	Moderation of soil temperature and moisture; improve the soil properties and enhance the population and diversity of desirable microbes in the soil	Awareness about the technology and availability of seeds on time; Use of herbicide to knock down Sesbania which is not allowed in the organic farming system; Uprooting and spreading mulch between crop rows can be possible	Direct-seeded rice; an organic farming area with cereal dominated cropping system in NEH region due to the large availability of forest letter and residue of wild seasonal vegetation.	Yadav et al. (2019)

Table 3: Continue...

Sl. No.	Agronomic interventions/ practices	Significance in crop production	Significance in soil health	Constraints	Suitable niche	References
3.	Use of crop residue	Reduce the cost of purchased nutrient inputs to some extent, a good source of potassium; reduce the environmental pollution due to residue burning	Recycling of nutrients and making a closed system of nutrients cycling	Immobilization of nitrogen; termite infestation in light texture soil; may hibernate the insect-pests population, allelopathic effect; competitive uses of crop residue	Intensive cereal-based cropping system (Rice-wheat cropping system in Indo-Gangetic plains); organic farming area; Sugarcane-based cropping system; irrigated agriculture	Prasad et al. (1999), Dhiman et al. (2000), Jacintheet al. (2002), Shahane and Shivay (2016), Yadav et al. (2016)
4.	Agro-industrial waste	Cost-effective amendment for soil improvement; enhance the microbial activities, supply nutrients in small quantity	Improvement in soil reaction and maintaining or enhancing soil nutrient retention capacity through a positive effect on soil chemical health	More competitive uses (such as sugarcane factory waste), lack of knowledge about nutrient supplying capacity, lack of cost-effectiveness	Peri-urban area; the area around agro-industry; an area with vegetable cultivation; organic farming area	–
5.	Biodynamic formulations	Enhancement of growth and quality of crop produce; used for management of insect-pests and diseases	Enhanced for the soil microbial population and diversity; enrich the soil with microbial enzymes and growth regulating hormones; positive effect on soil inherent microbial biodiversity	Lack of knowhow about technology; lack of awareness about the positive effects on crop production and their marginal effect on crop growth	For all types of crops especially under organic farming; primitive measures to reduce insect infestation mainly in vegetable crops and arable crops	–
6.	Use of microbial inoculation	Acquisition of nutrients from environmental pool; solubilising and mobilization of nutrients such as phosphorus and potassium; secretion of plant growth enhancing hormones; enhance the population and diversity of desirable microorganisms. These all will contribute to the enhanced growth and yield ability of crop; complementary to the use of chemical fertilizers and can reduce the fertilizer addition by 25–30% thereby reducing the cost and enhancing the nutrient use efficiency; increasing the share of soil inherent but a non-available pool to nutrients in crop nutrition	Enhance soil microbial population diversity; may have antagonistic effect with soil disease causing pathogen and therefore reduce their infestation; enhancement in the soil biological health through improving different soil biological properties	The performance is affected by weather variations, the enhancement in growth of crop is not visible as that of chemical fertilizers and hence less adoption by the farmers; non-availability of quality material (with required colony forming units and free from admixture)	All types of crops and cropping practices (both organic and inorganic); cost-effective options hence suitable for resource poor farmers	Prasanna et al. (2009, 2012), Beraet al. (2018), Chaudhary et al. (2018), Shahane et al. (2015, 2019, 2020)

Table 3: Continue...

Sl. No.	Agronomic interventions/ practices	Significance in crop production	Significance in soil health	Constraints	Suitable niche	References
7.	Use of concentrated organic manures (oil-cake and animals slaughterhouse products such as bonemeal, blood meal, meat meal, etc.)	Quick acting and suitable for in-season nutrient management in an organic production system; efficiently used in high-value crops, flowering plants, nurseries (preparation of potting mixture), and greenhouse/ poly-house cultivation; enhance the efficiency of nitrogenous fertilizers if applied combined with neem cake	Cakes of neem and Pongamia have capacity to reduce the population of soil-born pathogen and nematodes	These sources are costly to be used in arable crops; the availability of these sources may sometimes become constraints	Production of high-value crops and also in the organic farming areas; protected cultivation of flowers and vegetables, short-duration fruit crops	-
8.	Use of enriched manures (such as vermicompost, phosphorus enriched compost, gypsum or single super phosphate added compost, super digested compost, etc.)	Enhance the nutritional status of normal manure and also reduce the losses of nutrients such as nitrogen due to volatilization and through other ways; effective use of low-cost mineral reserve or mineral mining waste for the valuable crop produce	Positive effect on soil physical, chemical, and biological health; reduce the pollution through the reduction in the wastage of nutrients such as volatilization of nitrogen.	Lack of awareness about the technological knowhow and significance of using such materials; lack of availability of material for nutrient enrichment	Organic farming of arable crops, combined application with chemical fertilizers in the conventional farming areas to reduce the cost and enhance the soil fertility through residual effects	–
9.	Use of minerals and waste from mineral treatment plants	Cost-effective soil amendment in problem soil area; improve the soil nutrient supplying capacity	Reduce the piling of mineral waste generated from mining activity thereby reducing the pollution	Heavy metals if present in minerals waste, then are harmful to human and animal health; logistics of voluminous raw minerals over longer distances may not be cost-effective; awareness about the processes and conditions needed to make these materials suitable for crop growth is lacking	All types of crops and cropping practices (both organic and inorganic); restrict the use in vegetable crops if heavy metals are higher (as vegetable crops are consumed without much processing some vegetables such as spinach are prone to accumulation of heavy metals)	Shivay et al. (2010), Kulasekaran et al. (2015)

Table 3: Continue...

Sl. No.	Agronomic interventions/ practices	Significance in crop production	Significance in soil health	Constraints	Suitable niche	References
Management practices						
10.	Split application of concentrated organic manures	Increase the use efficiency of manure; synchronize timing between nutrient availability and crop requirement;	Extent the duration of the residual effect of manure application on soil health;	Higher cost of concentrated manure and its availability due to other competitive uses	In all crops in the organic farming system; especially suitable for vegetable crops and long-duration arable and plantation crops	Shahane and Shivay (2021)
11.	Intercropping of legumes and use of fallow land for legumes	Nutrient enrichment of soil through biological nitrogen fixation; bringing nutrient from the bottom layer to the top layer; enhance the nutrient availability due to the faster decomposition of crop residue	Enhancing the soil's physical, chemical, and biological health; enhancing the nutrient cycling and reducing the nutrient mining in the production system	–	Suitable in all types of cropping systems; useful in low rainfall and resource-poor farmers due to cost-effectiveness; Risk-reducing strategy	Kumar et al. (2018)
12.	Inclusion of forage crops in rotation	Act as a break crop in intensive cereal-based cropping system thereby reducing crop-associated biotic stresses (insect-pests, pathogens and weeds); Meet the forage requirement	Addition of a large quantity of organic matter through their roots and enhance the soil microbial population; positive effect on soil and water conservation	Not suitable for the commercial farm as the return on growing forage crops are lower than commercial crops; Restricted only with those farmers with the animal component in their farming system; loss of the productive season in case of rainfed area	Especially for cereal-based intensive cropping systems; All production systems (both organic and chemical-based conventional); Most of Northeast hilly area with the animal component in agriculture	–
13.	Agro-forestry	Effective utilization of marginal land which is not suitable for cultivation of arable crops; generation of large wood biomass which has multifarious uses; production of leafy biomass which can act as fodder during the lean period	Ecosystem services (carbon sequestration potential); stabilization of marginal land and reduce their degradation; improvement in soil health of marginal land	Lack of management of plants during early growth and harsh environmental condition reduces the survival rate of plants; land holding rights(as such land are owned by either government or by the community);Lack of recognition about the productive potential for marginal land	Marginal and degraded land with land capability class V and above; fragile hilly area affected by water erosion	–

Table 3: Continue...

Sl. No.	Agronomic interventions/ practices	Significance in crop production	Significance in soil health	Constraints	Suitable niche	References
14.	Cover crops	Suitable on soil subjected to continuous erosion; can be grown on bunds thereby helping to reduce the breaching of bunds due to intense rain; generate green matter with least rainfall and resources poor environment	Stabilization of highly eroded areas and gullies formed due to intense erosion; effective measure for reducing soil erosion and water conservation	Less productive potential than arable crops and loss of the season in rainfed area	The area which kept fallow with the availability of pre-monsoon or post-monsoon rainfall; in permanent agriculture such as orchard and plantation crops; all sortsof organic production system	–
15.	Tillage system (conservation tillage)	Potential to reduce the problem of crop residue management in an intensive cereal-based production system; timely sowing; enhanced soil nutrient status (for potassium and nitrogen and micronutrients)	Improvement in soil health due to addition of organic matter, minimum disturbance to soil, and crop rotation; reduce environmental pollution	Lack of availability of suitable machinery for sowing and harvesting on marginal farm	Suitable intensive cereals-based cropping system; soil subjected to soil erosion; organic farming area	Kassam et al. (2019)
16.	Harvesting methods (Adopting harvesting methods that maintain the 5–7 cm height of stem on soil surface or methods which maintains the soil surface covered with part of crop residue)	–	Enhance the nutrient cycling in crop production; positive effect on soil physical and biological properties; on the plant growth and act as a resource use efficiency	Competitive uses of crop residue, hence less residue available to retain on the soil surface; lack of machinery (combine harvester for marginal farm); chances of hibernating the insect-pests and diseases on stubbles	Cereal-based production system; legumes crop harvested by picking of pods such as greengram, garden pea, French bean etc.	–
17.	Land configurations	Increase the opportunity time for infiltration of rainfall thereby increasing the water availability; enhance the crop productivity due to increased moisture availability and safe disposal of excess water; methods such as permanent bed may be used for growing 3–4 crops once prepared (zero tillage) thereby reducing the cost of land preparation	Reduce erosion losses of soil; reduction in silting of reservoirs thereby maintaining the water storage capacity of reservoirs; enhance the microbial activity of soil due to moisture availability over an extended period	An additional cost is involved in land configuration	Zero tillage; organic farming in hilly areas; the sloppy area with bench terraces	Gangwar et al. (2009)

Table 3: Continue...

Sl. No.	Agronomic interventions/ practices	Significance in crop production	Significance in soil health	Constraints	Suitable niche	References
Reduction of soil pollution						
18.	Treatment of sewage and sludge	Rich source of nutrients and add to the fertility of the soil	Reduction in the pollution of soil in the area around the periphery of cities	The cost involved in treatment; lack of separation of grey and black water; heavy metal contamination; restriction for use in organic farming	Used in non-food crops or recycled for use in industry	Saha et al. (2018)
19.	Phyto-remediation	Reduction in contaminants in polluted water and can be used for irrigating non-food crops	Reduce the pollution of soil and make such area/ soil suitable for cultivation of food crops	Lack of technological know-how and availability of plants with phytoremediation capacity	Peri-urban area with the use of sewage water for agriculture; Industrial effluents are directly discharged into rivers/streams/ canals and used for irrigation	Yan et al. (2020)
20.	Efficient waste disposal and reducing the footprint of agricultural activities	Enhance the sustainability of the production system	Reduction in level of degradation thereby improving soil health	Lack of awareness and aspiration for reducing footprint; decreasing diversity and increasing commercialization of few crops leading to need for repetitive use of agrochemicals; unhealthy competition for increasing trading and use of agrochemicals	–	–
21.	Bio-drainage	Reduce the soil degradation due to waterlogging and make the area available for cultivation	Reduce the admixture of polluted water to groundwater	–	Dump yards and landfill around the cities, the low laying area	Ram et al. (2008)

or in combination with microbial inoculation (Sharma and Prasad, 2003) are the best example of the use of mineral matter in soil health management. At present, several biodynamic formulations are referred for their capacity to enhance plant growth and produce quality as well as their capacity to manage biotic and abiotic stresses. Imparting knowledge of such technology to farmers may enhance the rate of adoption which ultimately has a positive effect on soil ecosystem services. The detailed agronomic interventions and practices along with their agronomic benefits and benefits to soil health are given in Table 3.

6. CONCLUSION

The organic production system in India is mainly acquiring land in the northwest Himalayan region (17.5%) and arid and semi-arid region (50%) where soil degradation taking place at faster rate. The inputs such as manures, microbial inoculants, biodynamic formulations, and minerals as well as management practices such as crop rotation, tillage systems, cover crops, agroforestry, and crop harvesting methodologies are entitled for the positive effect on the economics of crop production and soil health management in an organic production system.

7. REFERENCES

Anonymous, 2018. Economics of desertification, land degradation and drought in India (Volume I: Microeconomic Assessment of the Cost of Land Degradation in India). The Energy and Resource Institute, New Delhi, India, 149. Available at www.teriin.org. Accessed on 26th December 2020.

Anonymous, 2020. Agricultural Statistics At A Glance 2020. Directorate of Economics and Statistic, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India; Available online at: www.agricoop.nic.in; Accessed on 5th February, 2022.

Anonymous, 2021. The world of organic agriculture, statistics and emerging trends. Research Institute of Organic Agriculture FiBL, Frick and IFOAM-Organic Internationals, Bonn, 336. Available online on https://www.fibl.org/fileadmin/documents/shop/1150-organic-world-2021.pdf. Accessed on 5th March, 2022.

Are, K.S., 2019. Biochar and soil physical health. In: Abrol, V., Sharma P. (Eds.), Biochar-an imperative amendment for soil and environment. ISBN 978-1-83881-989-7 (eBook). DOI 10.5772/intechopen.83706.

Aulakh, M.S., Sidhu, G.S., 2015. Soil degradation in India: Causes, major threats, and management options. In: MARCO Symposium 2015 – Next challenges of agro-environmental research in monsoon Asia. National Institute for Agro-Environmental Sciences (NIAES), Tsukuba, Japan, 151–156.

Bera, T., Sharma, S., Thind, H.S., Singh, Y., Sidhu, H.S., Jat, M.L., 2018. Soil biochemical changes at different wheat growth stages in response to conservation agriculture practices in a rice-wheat system of north-western India. Soil Research 56(1), 91–104.

Bhan, S., Behera, U.K., 2014. Conservation agriculture in India–Problems, prospects and policy issues. International Soil and Water Conservation Research 2(4), 1–12.

Bhattacharyya, R., Ghosh, B.N., Mishra, P.K., Mandal, B., Rao, C.S., Sarkar, D., Das, K., Anil, K.S., Lalitha, M., Hati, K.M., Franzluebbers, A.J., 2015. Soil degradation in India: Challenges and potential solutions. Sustainability 7, 3528–3570. DOI 10.3390/su7043528.

Bhowmik, A., Kukal, S.S., Saha, D., Sharma, H., Kalia, A., Sharma, S., 2019. Potential indicators of soil health degradation in different land use-based ecosystems in the Shiwaliks of North-western India. Sustainability 11, 3908. DOI 10.3390/su11143908.

Cardoso, E.J.B.N., Vasconcellos, R.L.F., Bini, D., Miyauchi, M.Y.H., Santos, C.A., Alves, P.R.L., De Paula, A.M., Nakatani, A.S., Pereira, J.M., Nogueira, M.A., 2013. Soil health: Looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Scientia Agricola 70(4), 274–289.

Chaudhary, M., Datta, A., Jat, H.S., Yadav, A.K., Gathala, M.K., Sapkot, T.B., Das, A.K., Sharma, P.C., Jat, M.L., Singh, R., Ladha, J.K., 2018. Changes in soil biology under conservation agriculture based sustainable intensification of cereal systems in Indo-Gangetic Plains. Geoderma 313,193–204.

Cheesman, S., Thierfelder, C., Eash, N.S., Kassie, G.T., Frossard, E., 2016. Soil carbon stocks in conservation agriculture systems of Southern Africa. Soil and Tillage Research 156, 99–109.

Chivenge, P.P., Murvira, H.K., Giller, K.E., Mapfuma, P., Six, J., 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. Soil and Tillage Research 92(2), 328–337

Dewi, R.K., Fukuda, M., Takashima, N., Yagioka, A., Komatsuzaki, M., 2022. Soil carbon sequestration and soil quality change between no-tillage and conventional tillage soil management after 3 and 11 years of organic farming. Soil Science and Plant Nutrition 68(1), 133–148.

Dhiman, S.D., Nandal, D.P., Om, H., 2000. Productivity of rice-wheat cropping system as affected by its residue management and fertility levels. Indian Journal of Agronomy 45(1), 1–5.

Eze, S., Dougill, A.J., Banwart, S.A., Sallu, S.M., Smith, H.E., Tripathi, H.G., Mgohele, R.N., Senkoro, C.J., 2021. Farmers indicators of soil health in African Highlands. Catena 203, 105336. DOI https://doi.org/10.1016/j.catena.2021.105336.

Field, D.J., 2017. Soil security: dimensions. In: Field, D.J., Morgan, C.L.S., McBratney, A.B. (Eds.), Global Soil Security. Springer, Cham, 15–23. DOI 10.1007/978-3-319-43394-3.

Gangaiah, B., Prasad Babu, M.B.B., 2016. Brown manuring as a tool of weed management and contributor to nitrogen nutrition of direct wet seeded rice. Oryza 53(4), 415–421.

Gangwar, K.S., Chaudhary, V.P., Gangwar, B., Pandey, D.K., 2009. Effect of crop establishment method and tillage practices in rice (*Oryza sativa* L.)-based cropping system. Indian Journal of Agricultural Sciences 79(5), 334–339.

Garcia-Palacios, P., Gattinger, A., Bracht-Jorgensen, H., Brussaard, L., Carvalho, F., Castro, H., Clement, J.C., Deyn, G.D., D'Hertefeldt, T., Foulquier, A., Hedlund, K., Lavorel, S., Legay, N., Lori, M., Mader, P., Martinez-Garcia, L.B., Silva, P.M.D., Muller, A., Nascimento, E., Reis, F., Symanczik, S., Sousa, J.P., Milla, R., 2018. Crop traits drive soil carbon sequestration under organic farming. Journal of Applied Ecology 55, 2496–2505.

Garrigues, E., Corson, M.S., Angers, D.A., Van Der Werf, H.M.G., Walter, C., 2012. Soil quality in life cycle assessment: towards development of an indicator. Ecological Indicators 18, 434–442. DOI https://doi.org/10.1016/j.ecolind.2011.12.014.

Gelaw, A.M., Singh, R.B., Lal, R., 2015. Soil quality indices for evaluating smallholder agricultural land uses in Northern Ethiopia. Sustainability 7, 2322–2337. DOI 10.3390/su7032322.

Haney, R.L., Haney, E.B., Smith, D.R., Harmel, D., White, M.J., 2018. The soil health toll- A theory and initial broad scale application. Applied Soil Ecology 125, 162–168.

Jacinthe, P.A., Lal, R., Kimble, J.M., 2002. Effects of wheat residue fertilization on accumulation and biochemical attributes of organic carbon in a central Ohio Luvisol. Soil Science 167, 750–758.

Kassam, A., Friedrich, T., Derpsch, R., 2019. Global spread of conservation agriculture. International Journal of Environmental Studies 76(1), 29–51. DOI https://doi.org/10.1080/00207233.2018.1494927.

Katyal, J.C., Datta, S.P., Golui, D., 2016. Global review on state of soil health. In: Katyal, J.C., Chaudhari, S.K., Dwivedi, B.S., Biswas, D.R., Rattan, R.K., Majumdar, K. (Eds.), Soil Health: Concept, Status and Monitoring. Indian Society of Soil Science, New Delhi, 1–33.

Khatri, S., Dubey, S., Shivay, Y.S., Jelsbak, L., Sharma, S., 2023. Organic farming induces changes in bacterial community and disease suppressiveness against fungal phytopathogens. Applied Soil Ecology 181, 104658. https://doi.org/10.1016/j.apsoil.2022.104658.

Khurana, A., Kumar, V., 2020. State of organic and natural farming: challenges and possibilities. Centre for Science and Environment, New Delhi, 70. Available at www.cseindia.org. Accessed on 24th February, 2021

Kibblewhite, M.G., Ritz, K., Swift, M.J., 2008. Soil health in agricultural system. Philosophical Transactions of Royal Society B363, 685–701. DOI 10.1098/rstb.2007.2178.

Krauss, M., Wiesmeier, M., Don, A., Cuperus, F., Gattinger, A., Gruber, S., Haagsma, W.K., Peigne, J., Palazooli, M.C., Schulz, F., Van Der Heijden, M.G.A., Vincent-Caboud, L., Wittwer, R.A., Zikeli, S., Steffens, M., 2022. Reduced tillage in organic farming affects soil organic carbon stocks in temperate Europe. Soil and Tillage Research 216, 105262. DOI https://doi.org/10.1016/j.still.2021.105262.

Kulasekaran, R., Biswas, A.K., Patra, A.K., 2015. Zeolitic farming. Indian Journal of Agronomy 60(2), 185–191.

Kumar, S., Meena, R.S., Lal, R., Yadav, G.S., Mitran, T., Meena, B.L., Dotaniya, M.L., Ayman, E.S., 2018. Role of legumes in soil carbon sequestration. In: Meena, R., Das, A., Yadav, G., Lal, R. (Eds.), Legumes for Soil Health and Sustainable Management. Springer, Singapore, 109–138. DOI http://doi.org/10.1007/978-981-13-0253-4_4.

Lal, R., 2016. Soil health and carbon management. Food and Energy Security 5(4), 212–222.

Maini, A., Sharma, V., Sharma, S., 2020. Assessment of soil carbon and biochemical indicators of soil quality under rainfed land use systems in North Eastern region of Punjab, India. Carbon Management 11(2), 169–182.

McKenzie, B.M., Tisdall, J.M., Vance, W.H., 2011. Soil physical quality. In: Glinski J., Horabik J., Lipiec J. (Eds.),Encyclopedia of Agrophysics (Encyclopedia of Earth Sciences Series). Springer, Dordrecht, 770–777. DOI https://doi.org/10.1007/978-90-481-3585-1-153.

Mirzabaev, A., Wu, J., Evans, J., Garcia-Oliva, F., Hussein, I.A.G., Iqbal, M.H., Kimutai, J., Knowles,T., Meza, F., Nedjraoui, D., Tena, F., Türkezs, M., Vázquez, R.J., Weltz, M., 2019. Desertification. In: Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., and Malley, J. (Eds.), Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. 249–343. Available at https://www.ipcc.ch/srccl/chapter/chapter-3/.

Mukherjee, A., Lal, R., 2014. Comparison of soil quality index using three methods. PLoS ONE 9(8), e105981. DOI https://doi.org/10.1371/journal.pone.0105981.

Mukherjee, J., Mridha, N., Mondal, S., Chakraborty, D., Kumar, A., 2018. Identifying suitable soil health indicators under variable climate scenarios: A ready reckoner for soil management. In: Bal, S., Mukherjee, J., Choudhury, B., Dhawan, A. (Eds.), Advances in crop environment interaction. Springer, Singapore, 205–227. DOI https://doi.org/10.1007/978-981-13-1861-0_8.

Mukhopadhyay, S., Maiti, S.K., Masto, R.E., 2014. Development of mine soil quality index (MSQI) for evaluation of reclamation success: A chronosequence study. Ecological Engineering 71, 10–20.

Mukhopadhyay, S., Masto, R.E., Yadav, A., George, J., Ram, L.C., Shukla, S.P., 2016. Soil quality index for evaluation of reclaimed coal mine spoil. The Science of the Total Environment 542(Part A), 540–550.

Olsson, L., Barbosa, H., Bhadwal, S., Cowie, A., Delusca, K., Flores-Renteria, D., Hermans, K., Jobbagy, E., Kurz, W., Li, D., Sonwa, D.J., Stringer, L., 2019. Land degradation. In: Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., Malley, J. (Eds.), Climate change and land: an IPCCspecial report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Available at https://www.ipcc.ch/srccl/chapter/chapter-4/.

Pawlas, A.K., Jaruga, A.U., Smreczak, B., 2019. Soil quality index for agricultural areas under different levels of anthropopressure. International Agrophysics 33, 455–462. DOI 10.31545/intagr/113349.

Pheap, S., Lefevre, C., Thoumazeau, A., Leng, V., Boulakia, S., Koy, R., Hok, L., Lienhard, P., Brauman, A., Tivet, F., 2019. Multi-functional assessment of soil health under conservation agriculture in Cambodia. Soil and Tillage Research 194, 104349. DOI https://doi.org/10.1016/j.still.2019.104349.

Pittelkow, C., Liang, X., Linquist, B., 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature 517, 365–368. DOI https://doi.org/10.1038/nature13809.

Pooniya, V., Shivay, Y.S., 2015. Influence of green manuring and zinc fertilization on quality parameters of *basmati* rice. Communications in Soil Science and Plant Analysis 46(3), 382–392. DOI 10.1080/00103624.2014.981275

Powlson, D.S., Stirling, C.M., Thierfelder, C., White, R.P., Jat, M.L., 2016. Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? Agriculture, Ecosystems and Environment 220, 164–174.

Prasad, R., Ganagiah, B., Aipe, K.C., 1999. Effect of crop residue management in rice-wheat cropping system on growth and yield of crops and on soil fertility. Experimental Agriculture 35, 427–435.

Prasad, R.,Shivay, Y.S., 2018. Management options to alleviate the menace of rice straw burning – An overview. Indian Journal of Agricultural Sciences88(11), 1,651–1,660.

Prasanna, R., Jaiswal, P., Nayak, S., Sood, A., Kaushik, B.D., 2009. Cyanobacterial diversity in the rhizosphere of rice and its ecological significance. Indian Journal of Microbiology 49, 89–97.

Prasanna, R., Joshi, M., Rana, A., Shivay, Y.S., Nain, L., 2012. Influence of co-inoculation of bacteria-cyanobacteria on crop yield and C–N sequestration in soil under rice crop. World Journal of Microbiology and Biotechnology 28(3), 1223–1235.

Ram, J., Dagar, J.C., Singh, G., Lal, K., Tanwar, V.S., Shoeran, S.S., Kaledhonkar, M.J., Dar, S.R., Kumar, M., 2008. Biodrainage: Eco-friendly technique for combating waterlogging and salinity. Technical Bulletin: CSSRI / Karnal / 9 / 2008, Central Soil Salinity Research Institute, Karnal, India, 24.

Ramesh, K., Chandrasekaran, B., 2004. Soil organic carbon build up and dynamics in rice-rice cropping system. Journal of Agronomy and Crop Science 190(1), 21–27. DOI http://doi.org/10.1046/j.0931-2250.2003.00069.x.

Rattan, R.K., Kumar, M., Narwal, R.P., Singh, A.P., 2009. Soil health and nutritional security-micronutrients. In: Proceedings of Platinum Jubilee Symposium of Indian Society of Soil Science, 249–265.

Ray, S.K., Bhattacharyya, T., Reddy, K.R., Pal, D.K., Chandran, P., Tiwary, P., Mandal, D.K., Mandal, C., Prasad, J., Sarkar, D., Venugopalan, M.V., Velmourougane, K., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Srivastava, R., Sen, T.K., Chatterji, S., Patil, NG., Obireddy, G.P., Mahapatra, S.K., Anil Kumar, K.S., Das, K., Raza, R.K., Dutta, D., Srinivas, S., Karthikeyan, K., Srivastava, A., Raychaudhuri, M., Kundu, D.K., Dongare, V.T., Balbuddhe, D., Bansod, N.G., Wadhai, K., Lokhande, M., Kolhe, A., Kuchankar, H., Durge, S.L., Kamble, G.K., Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Sahu, V.T., Sheikh, S., Dasgupta, D., Telpande, B.A., Nimje, A.M., Likhar, C., Thakre, S., Mandal, K.G., Kar, G., Gaikwad, K.M., Bhondwe, H., Dohtre, S.S., Gharemi, S., Khapekar, S.G., Koyal, A., Sujatha, Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N., Halder, A.S., Basu, R., Singh, R., Singh, B., Jat, B.L., Oad, D.L., Ola, N.R., Hukare, A., Khuspure, J., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Sahu, A., Mahapatra, S., Puspamitra, S., Kuar, A., Gautam, N., 2014. Soil and land quality indicators of the Indo-Gangetic Plains of India. Current Science

107(9), 1470–1486. Available at http://www.jstor.org/stable/24107210.

Reddy, A.A., 2017. Impact study of soil health card scheme. National Institute of Agricultural Extension Management (MANAGE), Hyderabad, 210.

Reddy, G.R., Malewar, G.U., Karle, B.G., 2002. Effect of crop residue incorporation and tillage operations on soil properties of Vertisol under rain-fed agriculture. Indian Journal of Dryland Agricultural Research and Development 17(1), 55–58.

Roper, W.R., Osmond, D.L., Heitman, J.L., Wagger, M.G., Reberg-Horton, S.C., 2017. Soil health indicators do not differentiate among agronomic management systems in North Carolina soils. Soil Science Society of America Journal 81, 828–843.

Roy Chowdhury, S., Nayak, A.K., Brahmanand, P.S., Mohanty, R.K., Chakraborty, S., Kumar, A., Ambast, S.K., 2018. Delineation of waterlogged areas using spatial techniques for suitable crop management in Eastern India. Bulletin No. 79. ICAR Indian Institute of Water Management, Bhubaneswar, Odisha, India, 44.

Saha, S., Saha, B.N., Hazra, G.C., Pati, S., Pal, B., Kundu, D., Bag, A.G., Chatterjee, N., Batabyal, K., 2018. Assessing the suitability of sewage-sludge produced in Kolkata, India for their agricultural use. In: Proceedings of Indian National Science Academy 84(3), 781–792.

Sahoo, U.K., Singh, S.L., Gogoi, A., Kenye, A., Sahoo, S.S., 2019. Active and passive soil organic carbon pools as affected by different land use types in Mizoram, Northeast India. PLoS ONE 14(7), e0219969. DOI http://doi.org/10.1371/journal.pone.0219969.

Selvi, A., Rajasekar, A., Theerthagiri, J., Ananthaselvam, A., Sathishkumar, K., Madhavan, J., Rahman, P.K.S.M., 2019. Integrated remediation processes toward heavy metal removal/recovery from various environments- A review. Frontiers in Environmental Science 7, 66. DOI 10.3389/fenvs.2019.00066.

Shahane, A.A., Shivay, Y.S., 2016. Cereal residue – Not a waste until we waste it: A review. International Journal of Bio-resources and Stress Management in Agriculture 7(1), 162–173.

Shahane, A.A., Shivay, Y.S., 2021. In-season nutrient management in arable crops- A key to increased productivity and nutritional security. Indian Journal of Fertilizers 17(6), 560–577.

Shahane, A.A., Shivay, Y.S., Kumar, D., Prasanna, R., 2019. Crop establishment methods, use of microbial consortia, biofilms and zinc fertilization for enhancing productivity and profitability of rice-wheat cropping system. Agricultural Research 8(1), 44–55.

Shahane, A.A., Shivay, Y.S., Prasanna, R., Kumar, D., 2020. Nutrient removal by rice-wheat cropping system as influenced by crop establishment techniques and fertilization options in conjunction with microbial inoculation. Scientific Reports 10, 21944. DOI http://doi.org/10.1038/s41598-020-78729-w.

Shahane, A.A., Singh, Y.V., Prasanna, R., Chakraborty, D., Kumar, D., 2015. Influence of cyanobacterial inoculants and planting methods of rice (*Oryza sativa*). Indian Journal of Agricultural Sciences 85(5), 738–740.

Sharma, S.N., Prasad, R., 2003. Yield and P uptake by rice and wheat grown in a sequence as influenced by phosphate fertilization with diammonium phosphate and Mussoorie rock phosphate with or without crop residues and phosphate solubilizing bacteria. Journal of Agricultural Science 141, 359–369.

Shaver, T., 2010. Crop residue and soil physical properties. In: Proceedings of 22nd annual central plain irrigation conference, Kearney, US, 24–25 February 2010.

Shivay, Y.S., Krogstad, T., Singh, B.R., 2010. Mineralization of copper, manganese and zinc from rock mineral flour and city waste compost for efficient use in organic farming. Plant and Soil 326(1), 425–435. DOI 10.1007/s11104-009-0023-0.

Singh, A., Shivay, Y.S., 2013. Residual effects of summer green manure crops and zinc applied to rice (*Oryza sativa*) on succeeding durum wheat (*Triticum durum*) under basmati rice–wheat cropping sequence. Indian Journal of Agronomy 58(3), 27–33.

Singh, A., Shivay, Y.S., 2016. Effect of summer green manuring crops and zinc fertilizer sources on productivity, Zn-uptake and economics of basmati rice. Journal of Plant Nutrition 39(2), 204–218. DOI 10.1080/01904167.2015.1009108

Singh, K.K., Colvin, T.S., Erbach, D.C., Mughal, A.Q., 1992. Tilth index: An Approach to quantifying soil tilth. Transactions of American Society of Agricultural Engineers 35(6), 1777–1785.

Singh, R.J., Ghosh, B.N., Sharma, N.K., Patra, S., Dadhwal, K.S., Mishra, P.K., 2016. Energy budgeting and energy synthesis of rainfed maize-wheat rotation system with different soil amendments applications. Ecological Indicators 61, 753–765.

Somasundaram, J., Sinha, N.K., Dalal, R.C., Lal, R., Mohanty, M., Naorem, A.K., Chaudhry, R.S., Biswas, A.K., Patra, A.K., Chaudhari, S.K., 2020. No-till farming and conservation agriculture in South Asia- Issues, challenges, prospects and benefits. Critical Reviews in Plant Science 39(3), 236–279.

Sterk, G., Stoorvogel, J.J., 2020. Desertification: Scientific versus political realities. Land 9, 156. DOI 10.3390/

land9060156.
Tabriz, S.S., Kader, M.A., Rokonuzzaman, M., Hossen M.S., Awal, M.A., 2021. Prospects and challenges of conservation agriculture in Bangladesh for sustainable sugarcane cultivation. Environment, Development and Sustainability 23, 15667–15694. DOI https://doi.org/10.1007/s10668-021-01330-2.
Tahat, M.M., Alananbeh, K.M., Othman, Y.A., Lescovar, D.I., 2020. Soil health and sustainable agriculture. Sustainability 12, 4859. DOI 10.3390/su12124859.
Tian, X.M., Fan, H., Zhang, F.H., Wang, K.Y., Ippolito, J.A., Li, J.H., Jiao, Z.W., Li, Y.B., Li, Y.Y., Su, J.X., Li, W.T., An, M.J., 2018. Soil carbon and nitrogen transformations under soybean as influenced by organic farming. Agronomy Journal 110(5), 1883–1892.
Vasu, D., Singh, S.K., Ray, S.K., Duraisami, V.P., Tiwary, P., Chandran, P., Nimkar A.M., Anantwar, S.G., 2016. Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan plateau, India. Geoderma 282, 70–79.
Wander, M.M., Cihacek, L.J., Coyne, M., Drijber, R.A., Grossman, J.M., Gutknecht, J.L.M., Horwath, W.R., Jagadamma, S., Olk, D.C., Ruark, M., Snapp, S.S., Tiemann, L.K., Weil, R., Turco, R.F., 2019. Developments in agricultural soil quality and health: reflections by the research committee on soil organic matter management. Frontiers in Environmental Science 7, 109. DOI 10.3389/fenvs.2019.00109.
Wijitkosum, S., 2020. Reducing vulnerability to desertification by using the spatial measures in a degraded area in Thailand. Land 9, 49. DOI 10.3390/land9020049.
Willer, Helga, Jan, T., Claudia, M., Bernhard, S., 2021. The world of organic agriculture, statistics and emerging trends 2021. Research institute of organic agriculture FiBL, Frick and IFOAM- Organic Internationals, Bonn, 336. Available at https://www.fibl.org/fileadmin/documents/shop/1150-organic-world-2021.pdf. Accessed on 5th March 2022.
Williams, A.J., Pagliai, M., Stoops, G., 2018. Physical and biological surface crusts and seals. In: Stoops, G., Macrcelino, V., Mees, F. (Eds.), Interpretation of micro-morphological features of soil and regoliths(2nd Edn.). Elsevier publication, 539–574. DOI http://doi.org/10/1016/B978-0-444-63522-8.00019-X.
Yadav, G.S., Das, A., Lal, R., Babu, S., Datta, M., Meena, R.S., Patil, S.B., Singh, R., 2019. Impact of no tillage and mulching on soil carbon sequestration under rice (*Oryza sativa* L.) rapeseed (*Brassica campestris* L. var. rapeseed) cropping system in hilly agro-ecosystem of the Eastern Himalayas, India. Agriculture, Ecosystem and Environment 275(1), 81–92. DOI http://doi.org/10.1016/j.agee.2019.02.001.
Yadav, G.S., Shivay, Y.S., Kumar, D., Babu, S., 2016. Agronomic evaluation of mulching and iron nutrition on productivity, nutrient uptake, iron use efficiency and economics of aerobic rice-wheat cropping system. Journal of Plant Nutrition 39(1), 116–135. DOI 10.1080/01904167.2015.1084323.
Yan, A., Wang, Y., Tan, S.N., Mohd Yusof, M.L., Ghosh, F., Chen, Z., 2020. Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. Frontiers in Plant Science 11, 359. DOI 10.3389/fpls.2020.00359.