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Review Article

Review on Soil Protection Implications for Soil Health and Sustainability

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Abstract: Soil health and soil quality are determined by a soil's capacity to function as a dynamic living system within the confines of land use. Soil health and sustainability are significantly impacted by soil protection. To demonstrate its effectiveness as a conservation technology, climate resilient agriculture, and a viable option for sustainable intensification of agro ecosystems for advancing food security and for adaptation to/mitigation of climate change, soil protection needs to use conservation agriculture wisely. The same process that keeps soil biologically productive also keeps the environment and human health in good shape. Additionally, nutrient cycling and storage, improved soil aggregation, microbial diversity, and higher soil water retention and availability are ecosystem services that healthy soils can offer. They can also aid in the management of plant diseases, insect and weed pests, and soil health. The adoption of techniques including conservation tillage systems, residue retention, no residue burning, crop rotation and diversification, balanced and effective nutrient management, organic soil amendments, and integrated nutrient, pest, and weed management helped it to advance. In general soil health is viewed as the key link between agricultural conservation management measures and the accomplishment of the main objectives of sustainable agriculture.

Keyword: Soil Protection, Soil Health, Conservation Agriculture, Sustainability

1. Introduction

On a human life scale, soil is becoming more and more recognized as a non-renewable resource since, once degraded, it regenerates very slowly [1]. It is a valuable asset that must be properly managed in order to remain sustainable. Soil can be referred to be a multicomponent and multifunctional system because it is a very complicated system [2]. The primary physical and chemical characteristics of soils are mostly determined by the parent material, climate, and terrain from which it was formed. Agricultural interventions like drainage, irrigation, the use of lime to change the reactivity of the soil, and the addition of plant nutrients frequently change these features [1].

A sustainable agricultural production depends on healthy soil, which is a crucial natural resource. "Defined as the capacity of soil to function within ecosystem boundaries to sustain biological activity, preserve environmental quality, and promote plant and animal health," soil health (also known as soil quality) is a term used to describe this property of soil [3]. Increased soil water retention and availability, soil aggregation, nitrogen cycling and storage, and microbial diversity and function are just a few of the ecological services that soils perform. According to estimates, our soils directly or indirectly produce 95% of our food [4].

A balanced state of the soil's physical, chemical, and biological activities is referred to as "soil health," and it is favorable to high productivity and good environmental quality. But several man-made and natural processes restrict soils' capacity to carry out these functions. Inorganic fertilizer use, intensive farming, population increase, and deforestation are a few of them. These activities alter the biological, chemical, and physical characteristics of soils, which results in a global deterioration in soil quality [5]. Biological functions such as plant anchoring and nutrient delivery should be supported by healthy soil, which should also be able to maintain ideal water and soil characteristics, support soil food webs, recycle nutrients, maintain microbial diversity, remove pollutants, sequester heavy metals, and aid in disease suppression [6].

In the current era of resource degradation and climate change, conservation agriculture is being practiced on more than 125 million hectares worldwide, and it has been linked to several reports of lower production costs, better water use efficiency, and sustained or increased crop productivity [7, 8]. Through careful planning and consideration of specific procedures that will aid in obtaining effective results in conservation agriculture, the limitations and uncertainties of can be addressed [4].

Because soil serves as a pollutant sink and a yardstick for environmental policy, protecting the soil is an environmental policy issue with overlapping operations. The effectiveness of initiatives in areas like waste management, sewage treatment, and air quality can have an effect on the soil. The environment's main component is the soil. They assist agricultural productivity, water storage and nutrient cycling, support buildings, recreation, organic materials, food and feed, manage water quality and supply, climate, and atmospheric gases, and are a part of our natural heritage [9]. The review's objectives are to examine the influence of soil protection on soil quality and soil health, as well as to evaluate agricultural management for sustainable soil health and quality.

2. Soil Health and Its Quality

Soil health is defined by the USDA-NRCS as the continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans [10]. For the preservation of ecological diversity and upholding environmental equality within land use boundaries, soil health and quality are crucial. The two terms are often used synonymously [10]. The ability of soil to support physiological, chemical, and biological processes, as well as to foster environmental equity and the flourishing of plant and animal life, is referred to as soil health. While soil quality refers to a soil's ability to work within the confines of an ecosystem that has been naturally or artificially managed, sustain plant and animal productivity, improve or maintain the quality of the water and air, and support human health and habitation [11, 12].

2.1. Soil Quality

Singer and Ewing [13] stated that the concept of soil quality includes soil fertility, potential productivity, resources sustainability, and environmental quality. Soil quality can be considered as the ability of a soil to fulfil its functions in the ecosystem, which are determined by the integrated actions of different soil properties. With respect to agriculture, soil quality would be the soil's fitness to support crop growth without becoming degraded or otherwise harming the environment [14, 15]. Soil has both inherent and dynamic qualities [16]. Inherent qualities are fixed and difficult to modify, and they are used to compare a soil's capabilities to those of another soil and to assess a soil's worth or suitability for a particular use [15]. Dynamic soil quality refers to how soil changes as a result of management practices. The capacity of the soil to hold water and nutrients as well as the amount of organic matter it contains are all impacted by management decisions. Learning how to manage soil in a way that enhances its functions is one of the objectives of research on soil quality [15].

2.1.1. Steps in Soil Quality Evaluation

Six fundamental steps were stated by Thien [17] for a soil quality management program: Critical soil-use functions must be identified, indicators must be chosen to assess them, indicators must be analyzed by soil sample and testing, indicators' status must be evaluated, and indicators must be monitored for changes.

2.1.2. Processes Influencing Soil Quality

The following ecosystem processes are important for environmental quality and agricultural sustainability: (1) soil structure, which includes form, stability, and resilience to stress; (2) nutrient cycling, which includes transformations like mineralization and immobilisation; and (3) biological interactions and relationships within food webs [18]. Due to their ease of manipulation by soil and crop management inputs into agro ecosystems, these processes may have an impact on soil quality. Pest management, fertilisation, and tillage techniques are recognised as practises that can affect soil structure, nutrient cycling, and biological interactions [19].

2.2. Soil Health

According to Doran et al. [20], soil health is the ability of soil to continue functioning as an essential living system within ecosystem and land-use boundaries, to preserve biological productivity, to advance the quality of air and water environments, and to uphold plant, animal, and human health. Accordingly, the soil is viewed as a living system that addresses all of the fundamental roles that soil plays in the landscape, compares the state of a given soil to its own particular potential within climatic, landscape, and vegetation patterns, and somehow enables meaningful assessments of trends [21, 22]. Wang and Hooks [6] note that soil health can be synthesized into six main characteristics:(1) high biological diversity (2) high community stability that can provide resilience and self-recovery to chemical and biological disturbance (3) ability to maintain the integrity of nutrient cycling and energy flow (4) suppression of multiple pests and pathogens (5) ability to improve plant health (6) maintenance of water and air quality.

Physical, chemical, and biological indicators all contribute to the understanding of soil health [23]. Soil health depends on both inherent and dynamic soil quality. The former depends on a variety of factors, some of which may be natural soil characteristics like texture as a result of soil formation, while the latter is impacted by changes in land use patterns and management practises and is generally correlated with soil biological function Table 1. Farmers are especially interested in the dynamic component, as well, because it enables sustainable soil productivity through appropriate management [15]. Although there is interaction between the inherent and dynamic components of soil quality, some soil types are far more vulnerable to degradation and bad management than others [24].

Table 1. *Various factors affecting dynamic and inherent soil quality.*

Dynamic soil quality	Inherent soil quality
Land management decision	Environmental/ natural factors
Tillage	Soil biology
Drainage	Parent material
Soil fertilizer usage	Climatic condition
Mulching and cover crops	Topography

Source: Havugimana *et al*. [24].

2.2.1. Principles of Soil Health Management

The soil health foundation consists of five principles: (1) soil armor (2) minimizing soil disturbance (3) plant diversity (4) continual live plant/foot (5) livestock integration. The impact of soil building will be maximized by using these ideas in a systems approach. In order to control plant diseases, insects, and weeds, recycle essential plant nutrients, form beneficial symbiotic relationships with plant roots, and improve soil structure with favorable effects on soil, water, and nutrient holding capacity, healthy soils must maintain a diverse community of soil organisms [25]. The wide diversity of its biota and the high concentration of inorganic soil materials are two essential traits of a healthy soil. It is reasonable to infer that a soil is healthy if the organic matter is added or maintained at an acceptable level for the growth of productive crops. Pest outbreaks are less likely to spread in healthy soil. For instance, in healthy soils, the parasitic weed Striga is much less of an issue [26]. In fertile soils, even damage from pests that are not present in the soil, like maize stem borers, is diminished [27].

2.2.2. Soil Health Protection

Farming practices including extensive cultivation, irrigation, excessive and improper fertilizer usage, fewer crop rotations, a lack of organic matter amendment, etc. are the main causes of soil health disturbance. Compaction and decreased crop production are the results of soil physical deterioration, which takes the form of erosion and aggregate instability. These factors moreover cause chemical and biological property loss [28].

Environmental policies concerning air and water quality were already well developed before environmental soil problems gained political attention. Prior to 1970, most people believed that soil was a naturally self-purifying environment. This mistake may have occurred in part because the effects of poor air and water quality are obvious, whereas the effects of soil contamination may not become apparent until the soil and groundwater are examined. Given the wide variety of soil issues, it is now widely believed that an integrated environmental policy for soils is necessary. The need for soil protection has been put in an international perspective already in 1972 by the Council of Europe [29]. In their European Soil Charter the general principles of soil protection were laid down. Proposals for international action are presently discussed and are based on the following principles: (1) recognition that soil is a common heritage and non-renewable resource (2) integration of soil protection into other environmental policies (3) rational use of soil and careful management of soil (4) respect for multi functionality through harmonization of surface land use (5) the reversibility rule (impact on soil quality by man should be reversible) [29].

It will be obvious in soil protection policy based on the sustainability principle that human activities that have irreversible effects on the structure and composition of the soil deserve special attention, especially if they endanger any future use of the soil by humans, plants, or animals. A number of nations are currently developing general policies for soil protection and restoration [30]. The primary objectives of soil protection are to maintain the following soil functions: filtering, buffering, and natural material breakdown and decomposition [29].

2.2.3. Management and Protection of Soil for Sustainable Development

The concept of soil quality can be thought of as the sustainability concept applied to soil [31]. The quality of the soil has declined as a result of increased modern crop variety and intensified agricultural land use [32]. It is more crucial than ever to use a comprehensive and system-based approach to soil management as the catalyst for boosting productivity by boosting effectiveness and making agriculture ecologically friendly [15].

Improved soil management practices for economic, social and environmental sustainability require better management of soil crop nutrient: (i) soil management and conservation for sustainable agriculture and environment. This includes combating desertification, soil erosion assessment, soil fertility enhancement, and fertilizer recommendation and soil conservation measures; (ii) technologies and practices for sustainable use and management of water in agriculture. This includes optimizing irrigation systems and enhancing crop water productivity and water use efficiency under rain fed and irrigated agro-ecosystems; and (iii) integrated soil-plant management packages to increase crop productivity in harsh environments [33].

2.3. Soil Threats

Consideration of soil threats is crucial for assessing the quality of the soil system. These are the major threats faced by soils: (i) soil erosion (ii) soil contamination (iii) soil compaction (v) salinization (vi) floods and landslides, and (vii) soil sealing. Controlling soil erosion is a requirement for a healthy soil since in many locations it is the most severe effect of soil degradation on efforts to restore soil quality. However, the majority of soil degradation processes are connected, and these connections are frequently caused by the same causal variables. Use of indicators, such as trends in yields on soils under irrigation to monitor risk of salinity, can be used to track the likelihood of various soil problems. The various challenges must be addressed jointly in order to safeguard soil quality [15].

3. Soils Health and Sustainable Agriculture

Soil salinization, acidification, compaction, crusting, nutrient shortage, reduction in soil biomass and biota, water imbalance, and disruption of elemental cycling are unsuitable agricultural practices that have a negative impact on soil quality. According to research, healthy soil inhibits pathogens, supports biological processes, breaks down organic matter, inactivates harmful substances, and recycles nutrients, energy, and water [34]. Normal functions of soil biota include the control of pathogenic organisms, nutrient cycling, detoxification of toxins, improvement of water storage, and quick response to soil management techniques [35]. A crucial tactic for ensuring the sustainability of agriculture is the contribution of soil biota to the biological processes that increase soil fertility and productivity [36, 37].

Sustainable intensification aims to produce more food from the same piece of land with less environmental impact. Innovation and new technologies will help to overcome these obstacles and advance the goal. Sustainable agriculture is an effective method for producing high-quality food and fibre that preserves and regenerates the environment, strengthens regional economies, and improves the quality of life for farmers and farm workers [38]. By utilizing ecological processes (such as biological nitrogen fixation and natural predators), reducing environmental risks, utilizing integrated modern and traditional strategies, utilizing ecological processes (such as soil and water quality maintenance), and acknowledging local environmental and cultural conditions, sustainable intensification increases productivity (Figure 1) [38]. Also emphasized the definition's five criteria for sustainability—productivity, security, protection, viability, and acceptability—and proposed that these standards be applied to determining soil quality [39].

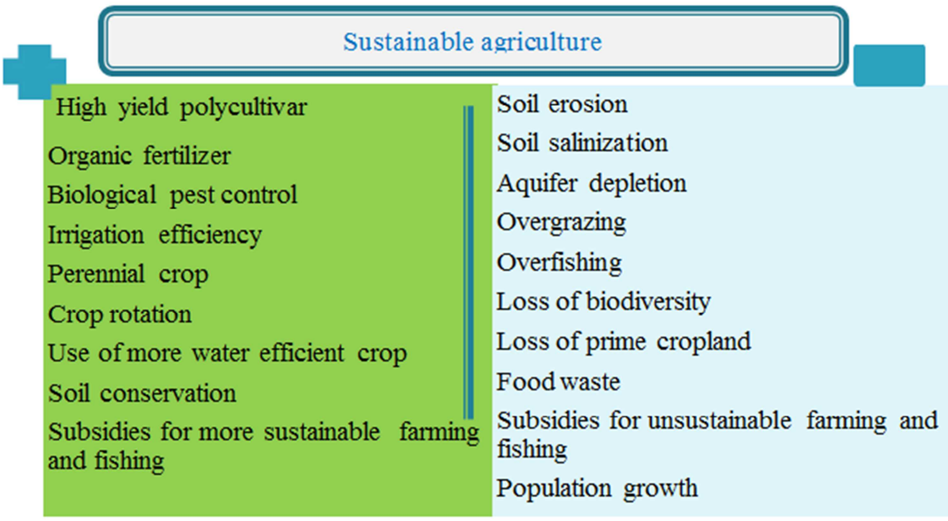

Figure 1. *Sustainable agriculture and soil health principles. Source: Pretty et al. [38].*

4. Agricultural Management for Soil Health Sustainability

Agricultural soil management techniques must be chosen to ensure: (i) Liberal use of crop residues, animal dung and other biosolids (ii) Minimal disturbance of soil surface to provide a continuous cover of a plant canopy or residue mulch (iii) Judicious use of sub-soil fertigation techniques to maintain adequate level of nutrient and water supply required for optimal growth (iv) Adequate level of microbial activity in the rhizosphere for organic matter turnover and elemental cycling (v) Use of complex cropping/farming systems which strengthen nutrient cycling and enhance use efficiency of input [40].

The requirement to take into account human usefulness, resource efficiency, and the ability to maintain a balance with the environment that is beneficial to most other species as well as humans makes it difficult to develop sustainable land management systems [41]. The requirement to take into account human usefulness, resource efficiency, and the ability to maintain a balance with the environment that is beneficial to most other species as well as humans makes it difficult to develop sustainable land management systems [41]. It could be concluded that, a sustainable agriculture is to sustain the people and preserves the land [41]. Soil health is conceptualized as the major linkage between the strategies for agricultural conservation management practices and achievement of the major goals of sustainable agriculture. In short, the assessment of soil health, and direction of change with time, is the primary indicator of sustainable land management [42]. Strategies for healthy soil sustainable management are shown in Table 2.

Table 2. *Strategies for sustainable agricultural and indicators of crop performance.*

Sustainability strategy	Indicators for producers
Conserve soil organic matter through Reducing tillage to keep soil C and N levels constant Recycling plant and animal manures	Direction/change in organic matter levels with time (visual or remote sensing by color or chemical analysis) Specific OM potential for climate, soil, vegetation and Soil water storage
Minimize soil erosion through Conservation tillage Increased cover for protection (residue, stable aggregates, cover crops, green fallow)	The visual (gullies, rills, dust, etc.) Topsoil depth, organic matter content/texture, water infiltration, runoff, and ponding cover percentages
Balance production and environment through Conservation and systems of integrated management (optimizing tillage, residue, water, and chemical use) Synchronizing available N and P levels with crop needs during year	Crop characteristics (visual or remote sensing of yield, color, nutrient status, plant vigor, and rooting characteristics) Soil physical condition/compaction Soil and water nitrate levels Amount and toxicity of pesticides used
Better use of renewable resources through Reducing reliance on petrochemicals and fossil fuels More on renewable resources and biodiversity (crop rotations, legumes, manures, IPM)	Input/output ratios of costs, energy, and renewable/non-renewable resources Leaching losses/soil acidification Crop characteristics (as listed above) Soil and water nitrate levels

Source: Lakaria et al. [21], Doran and Zeiss [43].

The basic principles on sustainable agricultural practices focus on the positive effects on the soil quality: Increased organic matter, Decreased erosion, Better water infiltration, more water-holding capacity, less subsoil compaction, and less leaching of agro-chemicals to groundwater [41]. To achieve these objectives, the following sustainable soil use and management strategies will be developed: Arable land identification, Crop diversification, Biomass restoration, appropriate tillage intensity and Soil input rationalization [41, 15].

4.1. Conservation Agriculture for Sustainable Soil Health Management

Conservation agriculture is a farming strategy that uses no-till, cover crops, integrated nutrient management (INM), and crop residue mulch to effectively conserve soil and water, sequester carbon, increase sustainability, and adapt to and mitigate climate change [1, 44]. Conservation agriculture (CA) is an approach that aims to sustainably improve farm productivity, profits, and food security by combining three principles which are: minimum mechanical soil disturbance, permanent soil cover, and crop rotation [45].

Conservation agriculture practices is proved to improve soil health [46], soil biological activities [47], soil organic matter [48, 49], soil hydraulic properties [50, 51], nutrient availability [52], root water uptake [52-54], and conserve soil moisture [48]. Conservation agriculture makes necessary modifications in different soil hydro-physical properties, viz. increased soil water infiltration [51], reduction in water runoff and soil loss, and reduction in evaporation loss, thus improves soil health. Balanced application of inorganic fertilizers and organic amendments greatly influences the accumulation of soil organic matter and also influences the soil physical environment [55].

4.2. Different Conservation Agriculture Practices for Soil Health and Sustainability

According to SSSA (2013) Soil health can be improved by adopting practices such as conservation tillage systems, residue retention, no residue burning, cropping rotation and diversification, annual cropping, balanced integrated nutrient, pest, and weed management, effective nutrient management, organic soil additions, lowering acidity, etc. FAO defines conservation agriculture as [56] a system based on minimal soil disturbance (no-till, minimum tillage) and permanent soil cover (mulch, crop residue) combined with diversified rotations with legumes [57]. conservation agriculture is the generic title for a set of farming practices designed to enhance the sustainability of food and agriculture production by conserving and protecting the available soil, water, and biological resources such that the need for external inputs can be kept minimal [58].

4.2.1. Tillage Practice

One of the key land management techniques essential to agricultural production is tillage. In order to promote soil aeration and infiltration rate, prepare the seedbed, conserve soil and moisture, expose soil-borne diseases and insects to light, and suppress weeds, tillage is typically done. Tillage has a detrimental impact on a number of soil parameters, including subsurface compaction, erosion, increased mineralization, and soil organic matter decomposition, among others [59]. Modern tillage concepts including no tillage (NT), minimum tillage (MT), and stubble-mulch tillage (SMT) practices are introduced to reduce the detrimental impacts of tillage on soil quality [60].

The NT or CT methods have now become popular across the dry land ecosystems of the world and implemented in various crop production systems. They significantly enhance a number of soil characteristics, which maintains the soil's quality and crop yield. Table 3. The NT system specifically has greater positive effects in soils with low organic matter, poor structure, and impaired soil physical properties, such as protecting soil from erosion, conserving soil water by reducing evaporation, and increasing organic matter by reducing mineralization. The NT method raises soil organic carbon by decreasing soil surface temperature [61]. Useful tillage techniques are necessary to preserve soil quality and crop yield. Raising soil temperature, root density, cation exchange capacity, and crop production can be accomplished via no-tillage, reduced-tillage, and strip-tillage approaches [62].

Table 3. *Influence o different tillage methods on some soil quality indicators.*

Soil quality indicator	No tillage	Conservation tillage	Deep ploughing	References
Organic Carbon	Increase in surface soil	Reduced	Reduced	[63]
Bulk density	Decrease	No effect	No effect/ increase	[63]
Soil compaction	Reduce	Increase	Increase	[63]
pH	No effect	Slight decrease	Slight decrease	[64]
Total N	Increase	Decrease	Decrease	[65]
Aggregate stability	High	Low	Low	[66]

4.2.2. Balanced Fertilization

Continuous cropping causes soil quality to decline and renders crop production systems unsustainable if sufficient nutrients are not applied in a balanced manner or if organic matter is not added. Manna et al. long-term (30 years) fertilizer experiments demonstrated that applying only nitrogen or nitrogen + phosphorous resulted in a decline in soil respiration, microbial biomass C and N, which was however markedly improved upon addition of NPK or NPK+ organics. In the context of chemical fertilisation, it is important to note that while building up carbon in sand size fractions like POM is important for improving biological soil quality functions like transformation of added organics and nutrients, which are very crucial for sustenance, adding animal manures and sequestering carbon in passive fractions like humus with very low C: N ratio is crucial for sustaining the environmental soil quality functions like filtering and buffering. [37].

4.2.3. Crop Rotations

Crop rotation enhances soil PH, increases soil organic matter content, and boosts soil microbial biomass. It also improves soil structure and reduces bulk density. Crop output and food security benefited indirectly from the advantages of crop rotation [68]. According to several researchers, crop rotation using legume crops significantly enhanced most soil parameters when compared to monocropping [68, 69]. According to [70], the rotation system that produced the highest potato tuber yield was clover. Similar findings were made by Malihe et al. [71], who discovered that potatoes planted in plots after faba bean and common vetch yielded 12.7% and 15.0% more tubers, respectively, than potatoes cultivated after winter wheat.

4.2.4. Organic Farming

Organic farming is regarded as the most sustainable agricultural system in the world since it improves yield in addition to physical, biological, and environmental resources such soil nutrient mineralization, microbial activity, abundance and variety, and groundwater quality [72]. Growing tomato, snap bean, and lettuce plants under organic and conventional conditions for three years found that, as shown in Figure 2, organic farming with compost boosted soil CO2 respiration and microbial biomass carbon compared to conventional mineral fertilizer (NPK). According to another study, organic farming in clay soil enhanced soil water content (15%) and retention capacity (10%) while lowering soil bulk density (8%) in the top 20 cm of soil [73]. In addition, organic farming is a good source of macro-nutrients (Table 4).

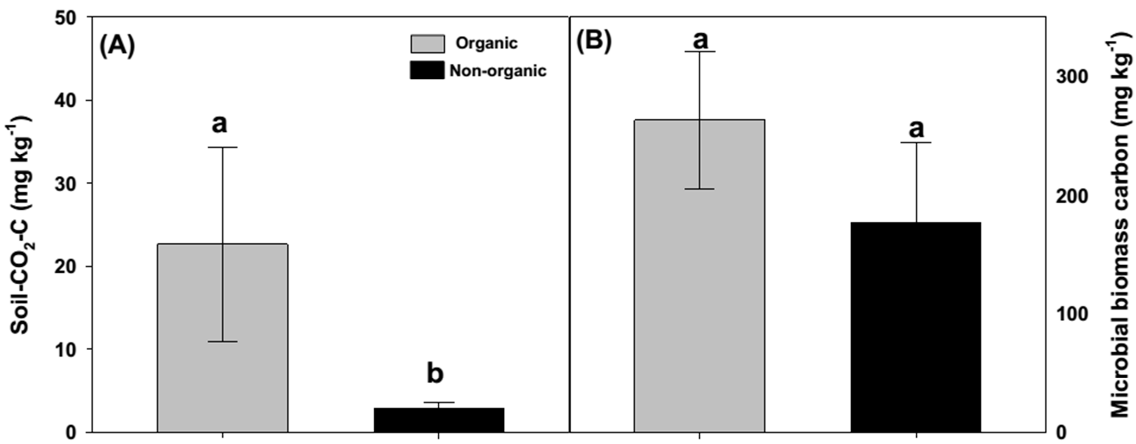

Figure 2. *(A). Soil respiration (CO_2-C) and (B) microbial biomass carbon for organic and conventional soil. Source: Tahat et al. [36].*

Table 4. *Mean values of soil data from organic and conventional farms at the end of the experimental period.*

Crop Study	Soil Type	Period (Year)	Nutrient Response	Reference
Wheat and maize rotation	Sandy loam soil	18	Organic soil had 5-22% more N than conventional. $p < 0.05$)	[74]

Crop Study	Soil Type	Period (Year)	Nutrient Response	Reference
Cowpea	Loamy soil	4	Organic farming increased available P, K, Fe, and reduced total N compared to conventional at $p < 0.05$. Organic: (73 N, 111 P, 359 K kg h^{-1}), (3500 Ca^{2+}, 1200 Mg^{2+}, 80 Fe, 17 Mn^{2+}, 5.5 Zn, 1.3 Cu mg kg^{-1}. Conventional: [(86 N, 96 P, 192 K kg h^{-1}), (2400 Ca^{2+}, 900 Mg^{2+}, 70 Fe, 15 Mn^{2+}, 4.3 Zn, 1.2 Cu mg kg^{-1})].	[75]
Cashew	Loam	5	Organic had more available nitrogen (435 kg /ha) than conventional (402 kg/ ha) (p 0.05).	[76]

4.2.5. Crop Residue and Cover Crops

Crop residue and cover crops play significant roles at several levels for soil conservation and sustainability. By lessening the impact and kinetic energy of raindrops on the soil surface to promote water infiltration and a gradual movement of water in the field, crop residue helps to physically protect the soil from potential erosion during severe rain events. Crop residue and cover crops also protect the soil from the erosive power of wind during times of high wind and dry conditions provide many other ecosystem services [77].

Reducing soil erosion and increasing the time opportunity for water to infiltrate through the soil profile for better water recharge of the subsoil can maintain crop yield during drought events [78]. The value of crop residue in arid and semi-arid climates is in stabilizing and enhancing yield and improving water use efficiency [79].

5. Conclusion

Soils are originated depending on several factors, such as parent material, climate, and topography, which largely determine the dominant physical and chemical properties of these soils. Soil protection needs judicious use of conservation agriculture to prove its potential as a conservation effective technology, climate resilient agriculture, and a viable option for sustainable intensification of agro ecosystems for advancing food security and for adaptation to/ mitigation of climate change. Healthy soils to provide ecosystem services that include increased soil water retention and availability, soil aggregation, nutrient cycling and storage, and microbial diversity, and help to control plant disease, insect and weed pests. It improved by adopting practices such as conservation tillage systems, residue retention, no residue burning, cropping rotation and diversification, balanced and efficient nutrient management, organic soil amendments, and integrated nutrient, pest, and weed management. Crop residue and cover crops play significant roles at several levels for soil conservation and sustainability. In general sustainable agriculture is a profitable way of producing high-quality food and fibre that protects and renews the natural environment, builds local economies, and enhances the quality of life of farmers and farm workers. Our knowledge of how production practices and environmental variables affect the physical, biological, and chemical stability and dynamics of the soil-rhizosphere-plant systems and their effects on short- or long-term sustainability must be further improved through improved assessment of soil health indicators.

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