

The Role of Soil Microorganisms as Inoculation in Maintaining Soil Fertility and Crop Productivity
Review

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Abstract
Increasing human population while soil fertility depletion is becoming a serious problem. Fertile soil functions as a complex living system that provides various ecosystem services, such as preserving water quality and crop production, regulating decomposition of soil nutrient recycling, and eliminating atmospheric greenhouse gases. Soil fertility is closely related to sustainable farming; the key components of soil health are diversity and activity attributable to soil microorganisms. The ability of a crop production system to consistently produce food without environmental damage is agricultural sustainability. Arbuscular mycorrhizal fungi, cyanobacteria, and beneficial nematodes increase the efficiency of water use and the supply of nutrients to plants, the development of phytohormones, the cycling of soil nutrients, and plant resistance to environmental stress. Farming practices have shown that, by increasing the abundance, diversity, and operation of microorganisms to preserve soil fertility and increase crop quality, organic farming and tillage improve soil health. Conservation tillage may theoretically improve the profitability of the grower by reducing inputs and labor costs compared to traditional tillage, whereas organic farming can add additional management costs due to high labor demands for weeding and pest control and fertilizer inputs such as Nitrogen-based, which are usually less reliable than synthetic fertilizers in terms of uniformity and stability. This review has shown soil micro-organisms enhance soil fertility and crop productivity.
Keywords: Soil fertility, Soil microorganisms, Inoculation, Crop productivity
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1. Introduction

By 2050, the world population is estimated to reach approximately 9 billion and Africa, especially sub-Saharan Africa, is supposed to boost to the bulk of the increase (Godfray *et al.,* 2010). This increasing population has created competition for all types of resources, such as land, water, energy and food, needed for human survival. Perhaps the food supplies that have become scarce are the most important, and thus its increased production cannot be compromised (Asenso and Jemaneh, 2012). The major challenges facing productivity among smallholder farmers have been low fertility and inefficient management of sub-Saharan African soils. Unfortunately, inorganic fertilizer is unsustainable and induces soil depletion and environmental contamination as the primary control of soil nutrients (Raimi *et al.,* 2017).

The use of fertilizers to increase soil fertility and crop production, including chemical fertilizers and manures, has also adversely affected the complex biogeochemical cycle method (Steinshamn *et al.*, 2004). The use of fertilizers has resulted in nutrient leaching and run-off, especially nitrogen (N) and phosphorus (P), leading to environmental degradation (Gyaneshwar *et al.,* 2002). Low fertilizer efficiency and continuous long-term usage are important explanations for these issues. The total quantity of fertilizers used systems is expected to increase with the increasing world population, despite the negative environmental consequences, due to the need to produce more food through intensive agriculture that needs large amounts of fertilizer (Frink *et al.,* 1999).

Soil organism, any organism inhabiting the soil during part or all of its life. Soil organisms, which range in size from microscopic cells that digest decaying organic material to small mammals that live primarily on other soil organisms, play an important role in maintaining fertility, structure, drainage, and aeration of soil. They also break down plant and animal tissues, releasing stored nutrients and converting them into forms usable by plants (Smith and Smith, 2011). Therefore, using organic fertilizer is an alternative approach to improve soil fertility status and crop production, there is a need for global attention. It is anticipated that the evaluation of soil health indicators would strengthen our understanding of the factors underlying processes leading to sustainable agriculture. This review will discuss research findings on soil health management practices and the role of soil microorganisms in sustainable crop production by maintaining soil fertility. It is intended to provide a better understanding of soil rhizosphere micro-biota and the external factors controlling their abundance and diversity.

1.1. Objective

1.1.1. General Objective

The general objective is to review the contribution of soil organisms in maintaining soil fertility.

1.1.2. Specific objectives

The specific objectives of this review are;

1. To review the role of soil microorganisms on soil fertility
2. To review the contribution of inoculation by bacteria on soil fertility improvement
3. To review role of microorganisms on crop productivity.

2. LITERATURE REVIEW

2.1. Soil health

Doran and Zeiss (2020) described soil health as "the ability of a soil to function as a vital living system within the ecosystem and boundaries of land use to sustain plant and animal production, maintain or improve the quality of water and air, and promote plant and animal health." Soil health is a soil's intrinsic feature. In comparison, the consistency of the soil is an extrinsic feature of the soil and varies with the intended human use of that soil. It can relate to agricultural production and the capacity to sustain wildlife, the conservation of watersheds or the provision of recreational facilities.

The estimated rapid increase in the world population to 8.9 billion by 2050 would result in higher demand for agricultural products (Lichtfouse *et al.,* 2009). Strong food demands and the absence of new agricultural land growth in the future will entail a doubling of crop yields by sustainable means. Two sustainable agricultural management techniques are aimed at increasing soil organic matter and minimizing erosion by enhancing plant diversity and tillage conservation (Doran, 2002).

It is a key challenge to fulfill the expected demand for balanced and sustainable food supply. In reality, one of the important objectives of sustainable agriculture is to increase crop productivity by mitigating climate change and maintaining agro-ecosystems (Timsina, 2018). However, meeting agricultural demand through the heavy use of synthetic fertilizers and pesticides in many agro-ecosystems has resulted in soil depletion and environmental contamination, which has had an adverse impact on humans, animals and aquatic ecosystems (Devarinti, 2016). A multi-year wheat monoculture farming research, for example, resulted in a decrease in soil quality, groundwater purity, and beneficial microorganisms, leaving plants vulnerable to pathogens and parasites (Singh *et al.,* 2011).

Sustainable agriculture using organic matter has been identified as an alternative, integrated solution that could be used in an ecological way to solve basic and applied food production issues (Lal, 2008). In order to implement new practices that are not detrimental to the environment, biological, physical, chemical and environmental values are combined (Lichtfouse *et al.,* 2009).

Additionally, maintainability can possibly assist with meeting food rural requirements around the world (Singh *et al.,* 2011). The plant rhizosphere is the tight zone of soil closest the root framework that can support crop creation with adjusted or diminished degrees of agrochemical inputs (Berendsen *et al.,* 2012). Soil wellbeing evaluation depends on soil quality factors that ensure manageability of harvest creation in horticultural terrains (Doran and Zeiss, 2020). A few investigations demonstrated that dirt biota parts, for example, microbial local area, wealth, variety, action, and security are significant markers of soil quality (Doran and Zeiss, 2020). Soil biota has an extraordinary job in plant deposits mineralization to frame plant supplements effectively consumed by the plant for development and advancement (Meena *et al.,* 2016). Soil biota likewise quickens the deterioration rate by delivering various catalysts that impact plant supplements energy in the dirt (Dotaniya *et al.,* 2016). Soil microorganisms (generally, microbes and growths) can change N among natural and inorganic structures, which thusly impacts plant minerals take-up, organization, and creation (Van *et al.,* 2008).

Microbial people group add to principal measures that give strength and profitability of agro-ecosystems (Singh, 2015). For instance, it has been demonstrated that populaces of soil microorganisms, for example, arbuscular mycorrhizal organisms (AMF), dynamic microbes, and useful nematode are exceptionally connected with crop yield, natural product quality, soil water stockpiling, and supplement cycling, assuming key parts in improving plant wellbeing and soil richness (Al-Karaki *et al.,* 2007; Doran and Zeiss, 2020).

Past examination demonstrated that natural cultivating and conservational culturing (strip culturing) practices can fundamentally improve soil biota in watermelon (Citrullus lanatus) and globe artichoke (Cynara cardunculus) filled in mud topsoil soils (Leskovar and Othman, 2018). A drawn out investigation (7 years) on vegetables and field crops (tomato, carrot, rice, and French bean) uncovered that dirt microbial biomass carbon in a natural field was higher than a regular field (Das *et al.,* 2017). In a three-year watermelon study, protection culturing (strip culturing) was appeared to improve soil parasites wealth and movement when contrasted with traditional culturing (Leskovar *et al.,* 2016). While culturing rehearses didn't influence mean all out night crawler bounty in customary cultivating frameworks (decreased culturing, 153 worms m^{-2}, mould board furrowing $130m^{-2}$), mean complete worm wealth in natural cultivating was 45% higher in mouldboard furrowing (430 m^{-2}) than in diminished culturing (297 m^{-2}) natural cultivating (Crittenden *et al.,* 2018).

2.2. Soil Biodiversity and there role to crop productivity

Soil biodiversity alludes to all living beings living in the dirt. The Convention on Biological Diversity characterized the dirt biodiversity as "the variety in soil life, from qualities to networks, and the natural edifices of which they are part, that is from soil miniature environments to scenes" (Turbe *et al.,* 2010). Expanding human populaces, worldwide environmental change, soil corruption, and loss of beneficial agrarian terrains have been appeared to press normal assets and undermine measures that keep up worldwide manageability (Gomiero, 2018). Soil microorganisms associate roots with soil, reuse supplements, disintegrate natural issue, and react rapidly to any progressions happening in the dirt biological system, going about as exact markers for explicit capacities in the dirt climate (Jacoby *et al.,* 2018). Microbial people group capacities and their connection with the dirt and plant can build up an economical soil biological climate for supporting harvest development, improvement, and long haul yields. Thusly, a comprehension of microbial networks' capacities, conduct and correspondence measures in soil and plants are basic for anticipation of unforeseen administration rehearses before beginning of non-repairable harm in the agroecosystem. Indeed, understanding microbial exercises will gives predictable diagnostics of maintainable soil wellbeing and yields creation (Sahu *et al.,* 2019).

Soil biota addresses perhaps the biggest supply of biodiversity on earth (Yang et al., 2018). Worldwide dissemination of soil biodiversity and soil capacities are basic for progressing worldwide manageability since it fuses fundamental parts including the living space for over-the-ground and submerged biota, climatic factors, water quality, contamination remediation, and food creation (Bach and Wall, 2018).

Soil biota influences biological system dependability by directing plant variety, over-the-ground net essential creation, and species asynchrony (Yang *et al.,* 2018). Soil biodiversity alludes to all living beings living in the dirt. The Convention on Biological Diversity characterized the dirt biodiversity as "the variety in soil life, from qualities to networks, and the environmental buildings of which they are part, that is from soil miniature natural surroundings to scenes" (Turbe *et al.,* 2010). Expanding human populaces, worldwide environmental change, soil corruption, and loss of beneficial farming grounds have been appeared to press common assets and undermine measures that keep up worldwide supportability (Gomiero, 2018). Soil microorganisms interface roots with soil, reuse supplements, decay natural issue, and react rapidly to any progressions happening in the dirt biological system, going about as precise markers for explicit capacities in the dirt climate (Jacoby *et al.,* 2018).

Microbial people group capacities and their connection with the dirt and plant can set up a manageable soil natural climate for supporting harvest development, improvement, and long haul yields. Consequently, a comprehension of microbial networks' capacities, conduct and correspondence measures in soil and plants are basic for counteraction of surprising administration rehearses before beginning of non-repairable harm in the agroecosystem. Understanding microbial exercises will gives steady diagnostics of manageable soil wellbeing and harvests creation (Sahu *et al.,* 2019). Soil biota addresses probably the biggest repository of biodiversity on earth (Yang *et al.,* 2018).

Worldwide dispersion of soil biodiversity and soil capacities are basic for progressing worldwide supportability since it fuses fundamental parts including the territory for over-the-ground and submerged biota, climatic components, water quality, contamination remediation, and food creation (Bach and Wall, 2018).Soil biota influences environment steadiness by controlling plant variety, over-the-ground net essential creation, and species asynchrony (Yang *et al.,* 2018).

Root-related soil biota advances biological system strength by affecting how plant species reaction to changes in the climate; for instance by improving plant variation to extraordinary burdens (dry season, saltiness, and temperatures) actuated by environment changes (Yang *et al.,* 2018). In any case, late reports proposed that worldwide soil biodiversity is compromised, particularly in regions with high human populaces and concentrated land use rehearses (Bach and Wall, 2018). Soil biodiversity stressors included serious human use, environmental change, and loss of over-the-ground biodiversity, overgrazing, soil natural issue decrease, contamination, soil disintegration, and land debasement (Orgiazzi *et al.,* 2016).Therefore, distinguishing the dangers and intercession to soil biodiversity is basic for worldwide farming maintainability.

Understanding the job of soil biota in interceding soil measures is significant in supporting harvest development and efficiency. Soil capacities incorporate aggregate trademark and cycles, for example, disintegration, supplement cycling, and the guideline of populaces (Ritz *et al.,* 2009).The environmental cycles in the dirt are supplement cycling (particularly, N) and decay (Handa *et al.,* 2014). The two cycles are by and large determined by soil biota (Orgiazzi *et al.,* 2016). Nitrogen cycling potential is profoundly connected with soil species biodiversity instead of species lavishness. For instance, soil decomposer biodiversity misfortunes came about in more slow rates in litter disintegration across biomes and thusly lower nitrogen cycling (Handa *et al.,* 2014). A fundamental agronomical practice to advance soil biota-interceded deterioration and mineralization is the choice of legitimate natural residue(s) with the inalienable powerlessness of buildup to actual breakdown and enzymatic hydrolysis (Whalen, 2014).Overall, utilitarian capacities of microbial networks to supplement obtaining, preparation, obsession, reusing, decay, debasement, and remediation in the dirt associate microbial abilities with soil wellbeing and agrarian supportability (Sahu *et al.,* 2019).

2.3. Soil Health and Crop productivity

Soil wellbeing and soil quality are terms utilized conversely inside the logical writing and some accept that they are interchangeable practically. Notwithstanding, the term soil quality is liked by the researchers while ranchers incline toward soil wellbeing (*Karlen et al.,* 2003). Ritz *et al.* (2009) distinguished and screened 183 natural pointers for checking soils. The most widely recognized natural marker applicants were: (1) soil microbial taxa and local area structure utilizing terminal limitation piece length polymorphism methods, (2) soil microbial local area construction and biomass utilizing removed lipids, specifically phospholipid unsaturated fats, as signature lipid biomarkers, (3) soil breath and C cycling from numerous substrate-actuated breath, (4) biochemical cycles from multi-chemical profiling, (5) nematodes, including development record (the conveyance of nematodes across practical groups),taxa number, and plenitude of individual useful gatherings, (6) microarthropod, (7) visual on-site recording of soil fauna and flora, (8) ground-dwelling and soil invertebrate pitfall traps, and (9) microbial biomass, the total amount of life below ground. They concluded, however, that further studies are needed to decide how these biological indicators are susceptible to management variations and how they are related to soil functions and can be used to elucidate particular ecological processes. Overall, the identification of soil health components is important for the effective use of national and global agricultural monitoring systems (Ground Truth Data) and, therefore, for the sustainable development of our agricultural systems (*Ritz et al.,* 2009).

It has been shown that healthy soil suppresses bacteria, sustains biological activities, decomposes organic matter, inactivates toxic materials and recycles nutrients, energy and water (Ritz et al., 2009). Karlen *et al.* (1997) defined soil quality as "the ability of a particular type of soil to function, within natural or managed ecosystem boundaries, to maintain, maintain or manage plant and animal productivity." "Improve the quality of water and air and promote human health and housing." In addition, Bouma *et al.* (2017) presented a broader defining view of soil quality as "the intrinsic capacity of a soil to contribute to ecosystem services, including the production of biomass." The concept of soil quality enables practical applications with regard to targeted ecosystem services (Toth, 2008).

Soil quality is an increasingly common term concerning soil biological features and functions that are closely related to chemical and physical properties (Chaussod, 2002). Soil quality is reduced by unsuitable agricultural practices such as soil salinization, acidification, compaction, crusting, nutrient deficiency, soil biota biodiversity and biomass depletion, water imbalance, and elemental cycling interruption (Lal, 2015). Soil microorganisms is typically related to the suppression of pathogenic species, nutrient cycling and water storage detoxification and reacts quickly to soil management practices (Doran and Zeiss, 2020). The relationship between soil biota, soil fertility, and plant health is solid (Altieri and Nicholls, 2003). The role of soil biota has been recognized as a key strategy for agricultural sustainability in improving land productivity and soil fertility through biological processes (Giller *et al.,* 2005).

2.4. Geographical distribution of soil microorganisms

In deciding the total number of microorganisms, soil aggregates provide the physical environment for microorganisms and play key roles (Drazkiewicz, 1994). The number of bacteria, actinomycetes, and fungi located in 1-3 mm aggregates was higher in humic rendzina (heavy loam calcareous soil) soil than in aggregates of 5-7 mm (Drazkiewicz, 1994). In addition, the population density of soil microbes may be influenced by climate, vegetation, total organic carbon, and pH (Tsiknia *et al.,* 2014). The evaluation of environmental and management factors on the diversity and abundance of rhizosphere microbes showed that soil type was a significant variable affecting the microbial population (Qin *et al.,* 2019).

While the clay soil indirectly increased the bacterial population through changes in the root length and chemical composition of the soil (pH, P and K), fungal biomass was correlated with increased yields of overground plants (Qin *et al.,* 2019). The rhizosphere surrounds the root zone of the plant and consists of three zones: the soil, the rhizoplane (root surface) and the root itself, which is inhabited by endophytic microorganisms (Bowen and Rovira, 1999). The rhizosphere covers at least 2mm of the rhizosplane, but its influence extends to 10 mm (Hartmann *et al.,* 2009) and, in some cases, to 10 mm (Hartmann *et al.,* 2009)

The rhizosphere is a dynamic hot spot of fungi, bacteria, nematodes, protozoa, algae, archaea, viruses and arthropods (Raaijmakers *et al.,* 2009) microorganisms (Bonkowski *et al.,* 2009). The diversity of microorganisms near the rhizoplane is greater, but at distant rhizoplane zones it decreases. This was clarified by the concentration of carbon, which is directly associated with the rhizoplane wavelength (Hartmann *et al.,* 2009). In addition, the release of root exudates and organic material, a term called "rhizosphere effect", is necessary for active microbiome growth (Mendes *et al.,* 2013).

Interestingly, the complex interactions in the rhizosphere showed that it was possible to control or engineer all components (roots, soil and microbes) to support plant growth and development (Dessaux *et al.,* 2016). For instance, a better understanding of the interactions of the rhizosphere root-soil microbe and its relationships will help reduce our dependency on chemical fertilizers by using beneficial microbes (Zhang *et al.,* 2015). Studies on habitat-specific functional microbial communities as prominent indicators raise hope for developing regional or agro-climatic, zone-specific microbial inoculants for successful implications in agriculture and environment (Sahu *et al.,* 2019).

The production and efficiency of commercial microbial inoculants such as AMF, biofertilizers and decomposers based on microbes give farmers the ability to minimize synthetic farm inputs (fertilizers and pesticides) and to stimulate integrated nutrient and pest management practices for sustainable agriculture (Sahu *et al.,* 2019). However, it is important to evaluate the cost-benefit and explore the possible decrease in fertilizer inputs when introducing exogenous beneficial bacteria into agricultural soils. Present studies concerning Bacillus spp. A sweet onion processing system in Texas is underway in the clay soils (Leskovar *et al.,* 2018).

Because of their vulnerability and reaction to minor changes in abiotic stresses, soil and micro-hizosphere organisms are considered bio-indicators of soil quality (Mendes et al., 2013). And its impact on the structure, composition, and productivity of plants (Schnitzer *et al.,*2011). It has currently been postulated that plant productivity is associated with below-ground diversity under various environmental conditions (Wagg *et al.,* 2011).

By using a range of mechanisms, such as improving plant nutrient use quality, production, selective uptake of Fe and P, the rhizosphere microorganisms can promote plant growth and protection from pathogen attack (Al-*Karaki et al.,* 2007), acting as a frontline defense for plant roots against soil-borne pathogens (Cook et al.,1995), Via antibiosis (Raaijmakers and Mazzola, 2012, or the induction of systemic resistance and parasitism on soil farms (Schenk *et al.,* 2012).

The most commonly studied rhizosphere species are beneficial rhizosphere microorganisms such as nitrogen-fixing bacteria, mycorrhizal fungi, plant growth stimulating rhizobacteria (PGPR), biocontrol microorganisms, mycoparasitic fungi, and protozoa for their beneficial effects on plants (Mendes *et al.,* 2013). In plant health, each community plays a vital role in (Kent and Triplett, 2002). However, depending on the plant and environmental factors, their contact with plants may be neutral or negative (Bais *et al.,*2006). Beneficial microorganisms can improve plant nutrition and directly and indirectly stimulate plant development (Mihajlovic *et al.,* 2017). Figure 1 illustrates the role of beneficial soil microbes and their interactions for the development of sustainable agriculture and environment as modified from Singh *et al.* (2011).

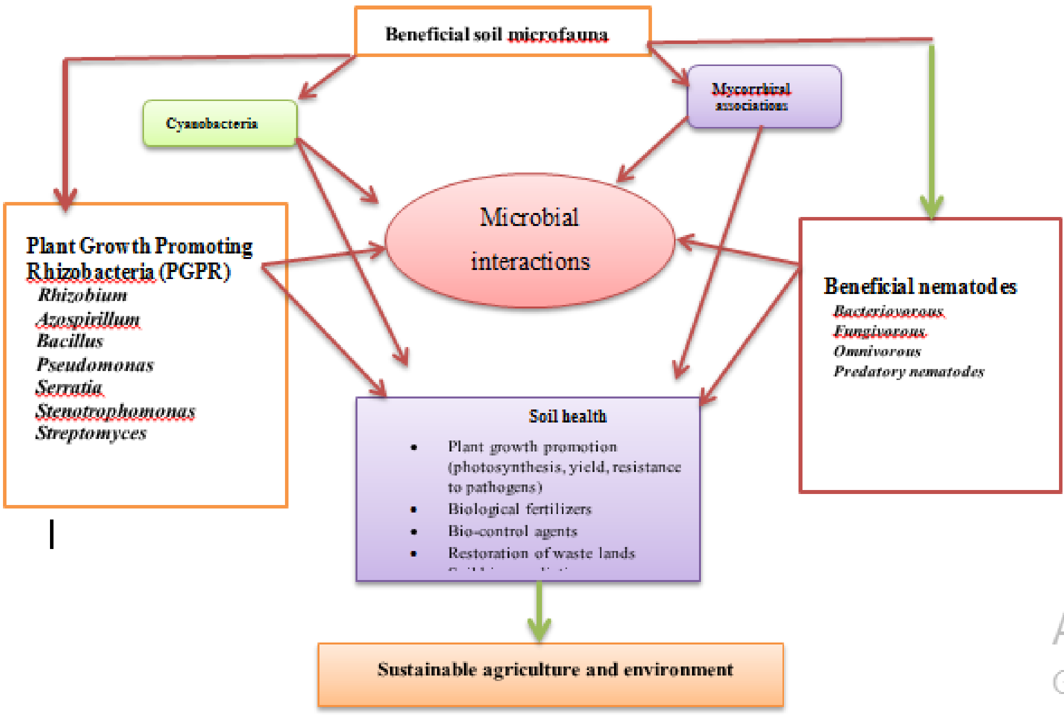

Figure1.Role of beneficial soil microbes and their interactions

Diverse bacterial taxa reflect plant growth that promotes rhizobacteria (Lucy *et al.,* 2004). Azospirillum, Bacillus, Pseudomonas, Rhizobium, Serratia, Stenotrophomonas, and Streptomyces (among them, the most commonly active used plant growth promoting rhizobacteria PGPR on plant inoculations) (Wagg *et al.,* 2011).

Pseudomonas and Bacillus are the most investigated and rhizosphere-dominant PGPR genera (Morgan *et al.,* 2005). Some fungi, such as Ampelomyces, Coniothyrium, and Trichoderma, have also been reported to be beneficial to plants (Harman *et al.,* 2004). Complex processes, including biofertilization, phytostimulation and biocontrol, are involved in plant growth promotion, production and defense through PGPR (Mihajlovic *et al.,* 2017).

Biofertilization enhances the acquisition of plant nutrients by directly supplying plant nutrients, encouraging root growth and maintaining beneficial symbiotic relationships (Mihajlovic *et al.,* 2017). Different microbial taxa are capable of accessing (P and N) nutrients from organic fertilizers and soil residues or of fixing atmospheric N. Diverse bacterial taxa reflect plant growth that promotes rhizobacteria (Lucy *et al.,* 2004). Among them, Azospirillum, Bacillus, Pseudomonas, Rhizobium, Serratia, Stenotrophomonas and Streptomyces are the most commonly used plant growth promoters of rhizobacteria PGPR on plant inoculations (Long, 2001;). Pseudomonas and Bacillus are the most investigated and rhizosphere-dominant PGPR genera (Morgan *et al.,* 2005). Some fungi, such as Ampelomyces, Coniothyrium, and Trichoderma, have also been reported to be beneficial to plants (Harman *et al.,* 2004).

Complex processes, including biofertilization, phytostimulation and biocontrol, are involved in PGPR's promotion, production and defense of plant growth (Mihajlovic *et al.,* 2017). Biofertilization enhances the acquisition of plant nutrients by directly supplying plant nutrients, stimulating root growth and maintaining beneficial symbiotic relationships (Vessey, 2003). Different microbial taxa are capable of obtaining (P and N) nutrients from organic fertilizers and soil residues or of fixing atmospheric N, enhancing water absorption and acting as biocontrol agents (Schutz *et al.,* 2018). Azotobacter, blue green algae, Rhizobium, and Azospirillum are the most well-known environmentally friendly biofertilizers for sustainable agriculture (Sahu *et al.,* 2012). During the phytostimulation process, microorganisms, such as the free-living nitrogen-fixing bacterium (Azospirillum), are associated with direct growth enhancement by endogenous plant phytohormones (indole-3-acetic acid (IAA), auxins, cytokinins, and gibberellins) (Steenhoudt *et al.,*2000). Biocontrol, however, occurs by three strategies: (1) antagonism in which plant pathogens are specifically inhibited (Shodo, 2000), (2) competition for nutrients, oxygen and trace elements (Alabouvette *et al.,* 2006), and (3) mediated resistance by activating plant protection mechanisms (Van ,2007).

2.4.1. Mycorrhizal Associations

Associations of mycorrhizals have a symbiotic relationship with plant roots (Smith and Read, 2008). AMF, which is present in 80% of vascular plants, is the most common mycorrhizal association (Paul,2015). During evolution, plants formed nutrient and water uptake mycorrhizal associations (*Basu et al.,* 2018). Carbon compounds can also be released from hyphae through mycorrhizal interactions to create a niche around the soil, called the mycorhizosphere (Linderman, 1999). In plant nutrition, arbuscular mycorrhizal fungi (AMF) play a major role, allowing water, P, Cu, Zn, and N (N) to be absorbed (Basu *et al.,* 2018). AMF also stimulates the development of phytohormones, such as abscisic acid (Tahat *et al.,* 2010).

In reality, mycorrhizal associations have been shown to play a functional role in mitigating plant biotic and abiotic stresses (Basu *et al.,* 2018) and promoting the growth and stability of the soil structure (Marschner and Dell, 1994). It is therefore important to consider the soil-root-AMF interaction as well as the effect of the physical and chemical factors of the surrounding soil on the contributions of mycorrhizal associations when assessing sustainable agricultural systems. It can be concluded that traditional farming practices can reduce the density of AMFs, whereas the organic low-input method can increase the operation of AMFs and contribute to sustainable agricultural growth (Basu *et al.,* 2018). Overall, through improvements in soil rhizospher activity, AMF can contribute to sustainable agriculture, leading to positive effects on soil properties and agronomic characteristics of plants, including plant height, grain number, and total yield (Heidari and Karami,2014).

2.4.2. Cyanobacteria

Cyanobacteria are gram-negative photoautotrophic prokaryotic bacteria, abundant in many soils, playing significant roles in the construction and maintenance of soil fertility (Sahu *et al.,*2012). They have a major positive impact on soil health and plant tolerance, such as plant diseases, to abiotic and biotic stresses (Prasanna *et al.,*2009). Cyanobacteria are highly adapted to a broad range of severe environmental conditions, including temperature (0-7Co), salinity (~20 dS m^{-1}), pH (including high and low pHs), drought, and heavy metals (Cd, Zn, Mn, Cu, Pb, and Co) (Perez *et al.,*2016). The presence of modified vegetative cells (spores and akinetes) in cyanobacteria tissues can be due to enhanced plant tolerance to desiccation and drought stress (Perez *et al.,*2016). Cyanobacteria are a sustainable biomass source of soluble organic matter (non-ribosomal peptides, isoprenoids, ribosomal peptides, alkaloids and polyketides) mineralized by soil microorganisms that, in turn, promote the productivity of agricultural crops (Kultschar and Llewellyn, 2018). In addition, organic matters for other living organisms may serve as growth promoters and/or inhibitors (Zulpa *et al.,* 2003). The use of indigenous strains of cyanobacteria as a bio-fertilizer has been shown to significantly improve the physical, chemical and biological characteristics of the soil, resulting in higher yields, especially in saline, dry and polluted soils (heavy metals, Ni, Pb, Cr and Cd) (Nisha *et al.,* 2007).

By improving the bio-availability of plant nutrients, such as P, C, and N, cyanobacteria also play a role in chemical soil transformation (Singh, 2014). The use of cyanobacteria in poor semi-arid soils will increase N levels and the population of microorganisms (Acea *et al.,* 2003). Cyanobacteria act as bio-control agents against plant pathogens, which is interesting (Zulpa *et al.,* 2003). Extracellular products from the cyanobacteria strain Nostco muscorum, for example, have been shown to have antifungal efficacy against soybean (Glycine max) Rhizoctonia solani (DeCaire *et al.,*1997) and white lettuce mold (Lactuca sativa) caused by Sclerotinia sclerotiorum (Tassara *et al.,*2008).

2.4.3. Nematodes

There is growing evidence that the immense diversity of soil biota contributes significantly to the shaping of above-ground biodiversity, the functioning of terrestrial habitats and their ecological responses to current and future environmental change (Bardgett and Van,2014). Recent studies have shown that the diversity of biota communities in the underground soil can affect components of the aboveground plant community (diversity, production, abundance, and adaptation to stress factors) and thus influence the stability and resilience of the ecosystem (Yang *et al.,* 2018).Nematode biodiversity in the agroecosystems is associated with the soil ecological condition.

Nematodes have been used as biological measures of soil quality in sustainability studies (Moura and Franzener, 2017). The structural type and function of soil nematode populations can provide an overview of soil processes since most nematodes are active throughout the year and can calculate the biotic and functional state of soils (Ritz and Trudgill, 1999). Nematodes have been recommended for soil quality assessment as biological indicators because they provide biodiversity with a habitat and are active in the process of nutrient recycling (Stone *et al.,* 2016). However, comparative studies between climate zones at very broad or trans-national levels should be carried out with caution since nematode populations vary between bio-geographical zones and land uses within each bio-geographical zone (Stone *et al.,* 2016).

Worldwide, the approximate parasitic nematode yield loss is around 12.3 percent (Singh, 2015). Due to their secret existence, plant diseases caused by nematodes are difficult to monitor. Nematodes with microorganisms can form disease complexes and increase crop loss (Singh, 2015). In comparison, useful nematodes help plants feed on bacteria and fungi and release minerals into the soil (Lambert and Bekal, 2002). These beneficial nematodes are capable of reacting rapidly to chemical, physical and biological changes in the soil because they are omnipresent, have multiple feeding habits and a variety of life strategies (Mekonen *et al.,* 2017). Furthermore, free-living beneficial nematodes (Discolaimus, Tripyla and Prionchulus) increase the growth of plants by releasing N compounds formed as a by-product of soil microbes feeding (Neher, 2010).

For soil health, nematodes that feed on nematodes (bacterivores) as well as algivores and fungivores are useful bio-indicators (Sanchez *et al.,* 2009). Mononchida, Dorylaimida, and Diplogasterida are predatory nematodes that feed on soil microorganisms and plant parasitic nematodes and release minerals into the soil (Khan and Kim,2007). Omnivorus nematodes such as Pristionchus are capable of predatory feeding on other nematodes as well as microbial feeding.

The sufficient biological diversity and nutrient cycling of a good soil (Quist *et al.,* 2017). Cycling and availability of nutrients depends on different soil trophic microorganisms (bacteriovorous, fungivorous, omnivorous, and predatory nematodes) that play an important role in the mineralization (release) of organic matter nutrients. Studies have shown that predatory nematodes increase the mineralization of nutrients and thus the productivity of plants in both grass (Bouteloua gracilis) and perennial ryegrass (Lolium perenne) (Nehe, 2010). Overall, there is a broad and wide variety of free-living nematodes (in particular beneficial nematodes) in a stable, well-structured, fertile soil with a good balance between fungal and bacterial feeders and predatory and omnivorous nematodes (Neher, 2001)

2.5. Soil Borne Pathogens

Worldwide, soil-borne pathogens cause severe crop damage. A healthy soil population has a diverse food web that holds diseases by predation, competition, and parasitism within the control levels (Susilo *et al.,* 2004). Rhizoctonia spp., Verticillium spp., Phytophthora spp., Pythium spp., and Fusarium spp. are soil-borne pathogens. They have detrimental effects on the growth of plants, causing root rot, Damping of seedlings, branch death, wilting, and diseases of blight (Koike *et al.*, 2003). In the absence of their target host plant, soil pathogens may live for several years by developing persistent structures, such as sclerotia, microsclerotia, chlamydospores, or Oosporesa (Mihajlovic *et al.,*2017). As a result, it is difficult to identify and control them (Astrom and Gerhardson, 1998).

Crop production needs healthy soils for crop production to help suppress soil pathogens (Table 1) and manage soil-borne inhibitors and pathogens effectively. Thus, it is possible to follow effective cultural practices (crop rotation, management of crop residues and resistance cultivars), soil disinfection and solarization biological and chemical control strategies by knowing what pathogens are present (identification of causal agents) and spatial distribution (Table 1). Soil-borne pathogens are important biological components of soil biodiversity, and these microorganisms can be controlled in sustainable agriculture to enhance soil quality and plant health (Table1) (Stirling *et al.,* 2017). Understanding the role of various soil management practices (Table 1) is crucial to improving agricultural soil health and contributing to long-term crop productivity (Stirling *et al.,* 2017). Table 1 shows some crop culture practices that are intended to manage soil biodiversity in the agroecosystem by suppressing soil-borne diseases and improving diversity (*Ellouze et al.,*2014).

2.6. Farming Practices to Improve Crop production

2.6.1. Organic Farming

In addition to improving physical, biological and environmental resources such as soil nutrient mineralization, microbial activity, abundance and diversity, and groundwater quality (lower nitrate (NO_3^-) concentrations), the interest of organic farming as the most sustainable agricultural method is rapidly increasing worldwide, but also yield and product quality as evidenced in wheat, potato, watermelon, and strawberry (Schrama *et al.,*2018). "The United States Department of Agriculture defines organic farming as "a production method that is managed to respond to site-specific conditions in compliance with the laws and regulations in this section by incorporating cultural, biological, and mechanical practices that promote resource cycling, promote ecological balance, and preserve biodiversity (Organic Production,2020). Sustainable agriculture has been identified as an alternative, integrated solution that could be used in an ecological way to solve basic and applied food production issues (Lal, 2008). In order to implement new practices that are not detrimental to the environment, biological, physical, chemical and environmental values are combined (Lichtfouse *et al.,* 2009 A long-term (12 year) analysis of rice (Oryza sativa) and maize (Zea mays) crops found that, compared to conventional systems, organic systems using compost and peat sources had a higher microbial population and enzyme activity (Chang *et al.,* 2014). Diversity and dominant population of soil bacteria in organic and traditional bananas (Musa acuminatatat) (proteobacteria, acidbacteria and proteobacteria) in organic systems, it was substantially greater (*Chou et al.,* 2017).

Growing vegetable crops such as tomatoes (Solanum lycopersicum), snap beans (Phaseolus vulgaris) and lettuce (Lactuca sativa) under organic and conventional cultivation for three years revealed that organic compost farming increased soil CO2 respiration (soil health indicator) and enzyme activity (fluorescein diacetate hydrolysis, phosphatase and arylsulphatase activity) compared to soil to conventional mineral fertilizer (NPK) (Iovien *et al.,*2009).

In comparison to traditional culture systems, organic culture has also been shown to kill soil pathogens, such as Fusarium wilt in cucumber (Cucumis sativus) (Atandi *et al.,* 2017) and plant parasitic nematodes Pratylenchus and Meloidogyne in maize and beans (Atandi *et al.,* 2017).

The yield gap is characterized as the difference between potential yield and actual yield in the same environment (Fischer, 2015). Whether organic farming can meet global food demands economically is the main point in the debate on the crop yield gap between organic and conventional agriculture and the contribution of organic farming to global agriculture. A meta-dataset of 362 research studies from 43 countries worldwide (85% of data from Europe and North America) found that individual crops' current organic farming yields are 80% of conventional yields on average (standard deviation 21 percent). Relative yields varied between soybean, rice, and corn crops scoring above 80% and wheat, barley, and potato crops scoring below 80%.

With the exception of countries with very intensive agricultural systems (e.g. the Netherlands, where the traditional yield difference was considerably greater), relative yields were very similar to the national average for the majority of the regions studied (De *et al.,* 2012). The physical and chemical properties of the soil can be enhanced by organic agriculture.In the top 20 cm soil layer, for example, organic systems in a clay soil increased soil water content (~15 percent) and retention capacity (10 percent) and decreased soil bulk density (8 percent) compared to conventional systems in the top 20 cm soil layer (Bassouny and Chen, 2016).

Organic cultivation, in addition, is a strong source of macro-nutrients. In a long-term study (18 years) using chemical and organic fertilization regimes, for example, in the 20 cm topsoil, N storage of organic manure treated soil was significantly higher (50 percent) than conventional chemical fertilizers in the 20 cm topsoil (Gong *et al.,* 2011).

Nutrient production (N, P, K) in organic soil was 34 to 51 percent lower than in conventional soil in another long-term analysis (21 years) of organic and conventional agriculture, whereas Ca^{2+} and Mg^{2+} were (30-50 percent) higher (Mader *et al.,* 2002).

Compared to organic farming, short-term, traditional farming typically has a greater potential to increase yield (Leskovar and Othman, 2018). Moreover, organic farming is more expensive for farmers due to the high labor demand for weed and pest control and the lack of uniformity and stability of organic fertilizers (Gaskell and Smith, 2007).

In organic farming, the key challenge is to synchronize nutrient release, specifically N, with seasonal crop growth demand (Gaskell and Smith, 2007). Organic materials do not release sufficient N to successive crops after 6 to 8 weeks after incorporation (Gaskell and Smith, 2007). (Gaskell and Smith, 2007). During crop growth phases, low N supply contributes to a decrease in leaf chlorophyll content, inefficient use of water, and consequently lower growth and yield (Mikkelsen and Hartz, 2008; Zhao *et al.,* 2015). Plants grown after conventional farming had higher growth and yields than those from organic farming in a recent analysis in the world of artichoke (Leskovar and Othman, 2018).

The study also showed that soil modification using organic farming decreased NO_3^-, P, K, Mg^{2+} soils and increased Ca^{2+} compared to conventional ones, thus significantly increasing CO_2 (soil health indicator) soil respiration by 20 times compared to conventional ones. In addition, relative to conventio, the organic system improved head consistency components, specifically chlorogenic acid by 31 percent and cynarin by 12 percent. Similarly, organic soil modifications (organic as opposed to traditional fertilizers) have increased the marketable yield of ascorbic acid and phenolic compounds in kale (Brassica oleracea) and kale (Brassica oleracea) (Antonious *et al.,* 2014).

Meta-data analyses of traditional and organic farming systems have shown that organic products (fruits, vegetables and grains) have lower levels of NO_3 and residues of pesticides and higher levels of nutrients (Fe^{3+}, Mg^{2+}, P) and vitamin C (Worthington, 2001). Though organic farming is less efficient than conventional farming, organic yield can achieve the same productivity after 10-13 years of cultivation (Schrama *et al.,* 2018). Overall, organic farming is the best method for improving the quality of soil and fruit, but it may not be the best (short-term) choice for farmers when yield is the primary goal (Leskovar and Othman, 2018). The productivity difference between organic and conventional systems can therefore be a matter of time, and long-term organic farming can lead to higher soil microbial populations and soil processes becoming more stable (Schrama *et al.,* 2018).

Table 1. Mean values of aggregated soil data from organic and conventional farms at the end of the experimental period.

Crop	Soil Type	Study Period (Year)	Nutrient	Response	Reference
Citrus (Citrus sinensis)	Clay soil (Oxisols soil, 50% Clay, 20% silt; 30% sand).	6	N	The organic system had 2 ton ha^{-1} more N ($p < 0.05$) stocked at 0–100 cm than in conventional system.	Escanhoela *et al.* (2019)
Wheat (Triticum aestivum) maize (Zea mays) rotation	Sandy loam soil (aquic inceptisol).	18	N	Organic soil had 5-22% more N ($p < 0.05$) than conventional.	Gong *et al.* (2011)
Wheat, potatoes (Solanum tuberosum), and clover (Trifolium sp.)	Clay soil.	21	P, K, Ca^{2+}, Mg^{2+}	Organic farming had higher ($p < 0.05$) Ca^{2+} and Mg^{2} than conventional. Organic (mg kg^{-1}): 16 P, 90 K, 2100 Ca^{2+}, 144 Mg^{2+}. Conventional (mg kg-1): 14 P, 95 K, 1700 Ca^{2+}, 94 Mg^{2+}	Mader *et al.* (2002)
Artichoke (Cynara cardunculus)	Clay soil (hyperthermi c Aridic Calciustolls).	2	NO_3^-, P, K, Ca^{2+},	Organic soil had lower NO_3^-, P, K and Mg+2 and higher Ca^{+2} and Na than conventional. NO_3^-, P, K, Mg^{+2}, Ca^{+2} and Na were significant at $p < 0.05$. Organic (mg kg^{-1}): 5 NO_3^- N, 34 P, 588 K, 11,200 Ca^{2+}, 263 Mg^{2+}, 15.8 S, 64 Na. Conventional (mg kg^{-1}): 22 NO_3^-N, 62 P, 669 K, 10,800 Ca^{2+}, 307 Mg^{+2}, 16.3 S, 28 Na.	Leskovar and Othman (2018)
Cashew (Anacardium occidentale)	Loamyskeletal, mixed isohyperthermic Ustic Haplohumults.	5	N	Available N in organic was higher ($p < 0.05$, 435 kg ha^{-1}) than conventional (402 kg ha□1).	Mangalassery *et al.* (2019)
Cowpea (Vigna unguiculata)	Loamy soil.		N, P, K, Ca^{2+}, Mg^{2+}, Fe, Mn, Zn and Cu	Organic farming increased available P, K, Fe, and reduced total N compared to conventional. N, P, K, Fe were significant at $p < 0.05$. Organic: (73 N, 111 P, 359 K kg ha^{-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 ha^{-1}), (2400 Ca^{2+}, 900 Mg^{2+}, 70 Fe, 15 Mn^{2+}, 4.3 Zn, 1.2 Cu mg kg^{-1}).	Suja *et al.* (2017)
Broccoli (Brassica ole racea), lettuce (Lactuca sativa), potato (Solanun tuberosum), and carrot (Dancus carota)	Loamy soil (Xerofluvent).	5	Fe, Mn2+, Zn and Cu	The available nutrients in organic were Statistically similar to conventional fields.	Maqueda *et al.* (2011) .

2.6.2. Crop rotation

For organic farming systems, crop rotation with legumes typically provides most N. However, it can be difficult to supply sufficient quantities of N to organic crops because the release process of nutrients (specifically N) is very slow compared to mineral fertilizers (Gaskell and Smith, 2007). Therefore, to meet the necessary crop requirements, farmers use organic fertilizers based on plants and animals. However, commercially available organic fertilizers are more expensive than chemical fertilizers (Mikkelsen and Hartz, 2008) because, in order to ensure reliably positive plant responses, they are more difficult to grow and require significant biomass (plant-based fertilizers).

The choice of organic fertilizer dependent on plants or animals is therefore crucial for maintaining crop yield and earning organic farming income. Many plant-based fertilizers (e.g. leguminous crop and maize meals) and animal-based fertilizers (e.g. blood and fish meals, feathers, bones, and composted manure) are commercially available for organic farmers (Fernandez and Strik, 2015). Plant-based fertilizers such as leguminous crops have been commonly used to lift the available N in the soil as green manures (Vyn *et al.,* 2000). Legumes can fix atmospheric N in the soil, decrease the risk of leaching of NO3, improve the physical and chemical properties of the soil and the quality of the fruit (Fageria, 2007).

Organic soil modified with alfalfa meal had higher soil respiration (soil health indicator) and head phytochemicals in artichoke than soil modified with animal fertilizers (fish meal, blood meal and chicken manure) (Othman and Leskovar, 2018). However, the head yield and input costs of artichoke grown in soil modified with animal-based fertilizer (chicken manure) were higher (N: \$US 31 kg^{-1} for blood meal, \$US 28 kg^{-1} for chicken manure, \$US 44 kg^{-1} for fish meal, and \$US 74 kg-1 for alfalfa meal) compared to those modified with alfalfa meal) (Othman and Leskovar, 2018). In order to improve soil health, long-term, plant-based fertilizers (leguminous crops and maize meals) can be an ideal choice, while animal-based fertilizers (blood and fish meals, feathers, bones and composted manure) can be a superior option for organic farmers when yield and cost are the main concerns, especially short-term (Monter *et al.,* 2020).

2.6.3. Tillage Practices

As recorded in watermelon and rice-maize cropping systems, tillage practices affect soil chemical and physical characteristics, as well as fruit quality and crop yield (Sahu *et al.,* 2019); Gathala *et al.,* 2015). A prerequisite for maintaining soil health and crop production is the adoption of useful tillage practice (Jabro *et al.,* 2009). Conservation tillage practices (no-tillage, reduced, and strip) can increase soil microbial activities, soil moisture, organic matter, aggregate stability, capacity for cation exchange and crop yield (Sahu *et al.,* 2019).

Conservation tillage using permanent beds and strip tillage can theoretically increase net income and profit for farmers; cost ratio through increased productivity of plant water usage and decreased use of irrigation water and labor compared to traditional ((Gathala *et al.,*2015). Al-Kaisi *et al.* (2014) also found that soil macro- and micro-aggregate stability was significantly reduced by tillage intensity. Conservation tillage practices increased soil available P by 3.8%, K by 13.6% and soil organic matter by 0.17% in the topsoil (0-20 cm) relative to traditional soil (Shao *et al.,* 2016). Maintaining crop residues on the top soil surface layer can also decrease soil erosion and increase soil moisture content (full cover, no till; partial cover, strip tillage) (Celik *et al.,*2013).

3. Conclusions

I may conclude from this analysis that the implementation of soil fertility management should take into account the soil microorganisms present in the soil in order to sustain soil fertility, maintain soil biota, and increase crop productivity. Soil health considers soil biota components such as the abundance of microorganisms, diversity, activity, and stability of the environment. The diversity and abundance of microorganisms from the soil and rhizosphere affect plant structure, production, and sustainability. Arbuscular mycorrhizal fungi (AMF) enhance water use efficiency and nutrient availability to plants. Adapted to a broad range of harsh environmental conditions, cyanobacteria are a consistent source of soluble organic matter for sustainable biomass, known as secondary metabolites, serving as growth promoters and promoting the productivity of agricultural crops. In order to further develop our understanding of how production strategies and environmental factors affect the physical, biological, and chemical stability and dynamics of the soil-rhizosphere-plant systems and their effect on short-term or long-term sustainability, improved assessment of soil health indicators is important.

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