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Sustainable agriculture and microbes a concomitant: A review

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Abstract
Microorganisms found in the soil environment are microbes that have recently come to light as a crucial part of sustainable agriculture. Through interactions between host plant roots and microbes in the rhizosphere, these beneficial microorganisms perform a variety of plant growth-promoting activities, such as nitrogen fixation, nutrient mineralization, mineral solubilization, mobilization of plant nutrients, siderophore production, antagonistic substance production, antibiotic production, and release of plant growth-promoting substances, such as auxin, cytokines, and gibberellin hormones. Many plants associate symbiotically with microorganisms to obtain mineral nutrients more efficiently, and their distribution is determined by root exudate abundance, crop species, and cultivars. Important roles for microorganisms in the microbiome can be found in products known as biofertilizers. Important microorganisms are employed in agriculture to promote crop growth, and advances utilizing microbiomes are what sustainable agriculture will look like in the future. A safe environment can be achieved through sustainable agriculture with the help of effective use of microbiomes.

Keywords: Microbes, nitrogen fixation, PGPRs, mineralization, solubilization

Introduction
In order to meet the world's food demand, extensive and intensive cropping as well as the heavy use of fertilizers, pesticides, herbicides, and water resulted in environmental imbalances, land degradation, and the loss of natural resources and soil organic matter. Sustainable agriculture is made possible by food production that has less of an adverse effect on the environment and the food chain from chemical pesticides and fertilizers. Ecological niches found in plants' rhizosphere, rhizoplane, phylloplane, and endosphere are home to a wide variety of microorganisms that interact with plants in ways that can be advantageous, neutral, or destructive. The scientific community has conducted research on the link between plants and their external environment. Although their interaction has been extensively studied, plant-microbe interaction is actually far more complex in real life. Maximizing the soil's potential usage.

Microbes found in soil are seen to be a very practical and long-term answer to food security, pollution in the environment, and sustainable living. In agriculture, biostimulants, biocontrol agents, and biofertilizers live in the microbiome. Since microbes can reproduce themselves in soil and are self-sustaining in the wild, annual inoculation is not necessary. The microclimate, soil organic matter, plant species, and microbial community all affect how well and long-lasting microbial inoculants are at fostering plant development and soil health. Because beneficial microorganisms aid in nitrogen fixation, plant growth, and nutrient uptake through the solubilization of P, K, and Zn, rhizosphere microbiomes are crucial to agriculture (Prasanna *et al.*, 2016) [26].

Beneficial bacteria have the ability to suppress diseases, eliminate pollutants, boost crop yields, and generate new compounds or fixed nitrogen. Plant microbiomes can stimulate growth through a variety of mechanisms, including biological nitrogen fixation, the synthesis of plant growth regulators like gibberellic acids, cytokines, and antibiotics; the biocontrol of phytopathogens by producing agents that are antibacterial, antifungal, or antibiotic-resistant; the production of Fe-chelating compounds; nutrient competition; the induction of acquired host resistance; and the enhancement of mineral bioavailability. All living things that make up the microbiome are referred to as the microbiota. The term "microbiota" refers to the collection of live microorganisms found in a certain habitat. In addition to having a major influence on how many nutrients are present in our diet, soil bacteria also assist in controlling our emotions and immune system. The human gut is the microbiota's hotspot, and food and dietary intake have a significant impact on their makeup. The concentrations of micronutrients in various crops are typically insufficient for human nutrition in diets. Because they provide a significant amount of dietary energy and minerals, eating cereals and cereal products of this kind is a mainstay in the diets of most people in both developed and developing nations. However, eating too much of these foods can lead to micronutrient deficiency and serious health problems. Research on the function and use of soil microbes in the biofortification (defined as "the process of adding essential micronutrients and other health promoting compounds to crops or foods to improve their nutritional value") of crops has increased recently due to an understanding of the intricate interactions between plant roots and microbial communities (plant growth-promoting fungi and rhizobacteria) in the rhizosphere. A lot of focus is being placed on the biofortification strategy to improve the availability of micronutrients in main food crops, particularly in Se, Fe, and Zn. According to Sundaria *et al*. (2019) [36], seeds can be primed before sowing by being exposed to iron oxide nanoparticle bombardment. By using this technique, the wheat plants would absorb more iron, increasing the nutritional content of the grains. Probiotics, or functional foods containing beneficial microorganisms, are another way to use them for human health. Probiotic microorganisms are being utilized more frequently as dietary supplements in functional food products. Examples of these microbes include *Lactobacillus*, *Methanobrevibacter, Saccharomyces,* and *Bifidobacterium*. Microbes with advantageous qualities might be used for human health and sustainable agriculture. These days, there's more interest in the creation of novel functional foods and how to incorporate them into a balanced diet. After ingestion, these products probiotics in particular have a positive impact on the host's gut microbiota and may be effective in preventing a number of disorders. Probiotics are live microbiomes that boost the host's health when given in sufficient quantities. This review highlights the significance of how the microbiome and biotechnology intervention affect soil, human health, and the environment in sustainable agriculture.

Sustainable agriculture for soil health

Countries use intensive farming methods to increase productivity in order to fulfil the demand from a growing global population, however these methods have negative effects on the environment, animals, and human health as well as the soil. Ray and associates, 2020. Internal nutrient cycling in soil is hampered by the heavy reliance on modern agricultural practices, the use of mineral fertilizers, and the application of agrochemicals. Adoption of different mineral fertilizers and agrochemicals pollutes water systems, creates contaminated runoff, damages beneficial insects, the soil microbiota, and plants. It also causes climate change by altering rainfall and temperature (Kughur *et al*., 2015) [13]. Rainfall was not distributed evenly, which resulted in significant soil erosion and degradation that had a negative impact on soil productivity and structure. For sustainable agriculture, soil fertility and plant growth development are significantly influenced by the soil microbiome. Through the breakdown of organic matter and ecosystem functioning (nutrient recycling and tolerance to biotic and abiotic stress), the soil microbiome contributes to the cycle of nutrients. Diverse microbiome groups are employed in sustainable agriculture for plant protection via the use of biopesticides and biofungicides, as well as for nutrient absorption through rhizospheric, endophytic, or phyllosphere interaction in symbiotic/free living processes. As the primary sources of mineral nutrients, soil and water are natural resources that must be preserved and used responsibly for crop productivity, human health, and a safe environment. Natural resource conservation is achieved through sustainable agricultural methods. It is possible to reduce the use of off-farm resources like agrochemicals. For instance, crop rotation that rotates a variety of crops, such as cereals, oilseeds, and pulses (rice, soybeans, and green grams), depending on the climate and water source is beneficial to farmers, lowers production risk and uncertainty, and improves the ecological sustainability of the soil. Agroforestry, intercropping, crop rotation, green manuring, conservation tillage, cover crops, and the use of biofertilizers are examples of sustainable agriculture methods (White *et al*., 2012) [41].

Crop Rotation

A key component of sustainable cropping systems is crop rotation, which has several advantages for crop production, healthy soil development, effective insect management, and other benefits like nutrient cycling and organic residue decomposition. They can aid in the preservation, upkeep, or replenishment of soil resources, such as its physical and chemical characteristics, organic matter content, nitrogen, and other nutrient inputs. Crop rotation is the practice of varying the crop cultivated on a specific plot of land from one year to the next. It significantly affects the microbiological characteristics of the material. Machado, 2009 [20]. An inadequate land management strategy can result in a decline in soil fertility as well as a drop in the variety and quantity of soil microorganisms (Hauggaard *et al*., 2006) [42]. If nitrogen cycling in the agricultural system is to be maximized and losses are to be kept to a minimum both in the short and long term, then the selection of crops within the rotation and their order are essential. The traits of each crop species vary slightly, such as whether they require nitrogen or nitrogen dioxide, whether they have shallow or deep roots, and the quantity and quality of crop residue that is returned. By aggregating both organic and mineral components through the synthesis of extracellular molecules with adhesive qualities, soil microorganisms alter the structure of the soil. According to (Veneklaas *et al*., 2003) [39], a number of legume crops, including white lupine and chickpea, can mobilize soil and fertilizer P by exuding organic acid anions from their roots, such as citrate and malate, among other compounds. After organic-anion-emitting legumes, Hocking and Randall saw an improvement in the growth and P nutrition of less P-efficient crops. showed that, in comparison to not applying manure, the application of organic manure to crops grown in a three-year rotation under poor soil fertility enhances soil organic matter and increases accessible soil N, P, and K. Crop rotations have the potential to further raise soil productivity by gradually raising the total soil carbon (C) and nitrogen (N) contents. It was discovered that when dry season rice was substituted with maize in the rice-rice rotation, the estimated amount of mineralized C and N during the dry season increased by 33–41%, resulting in a decrease in soil C and N. Consequently, compared to the maize–rice rotation, there was 11–12% more C sequestration and 5-12% more N accumulation in soils continuously cultivated with rice, with the higher levels sequestered in N-fertilized treatments (Kelley *et al*., 2003) [10].

Intercropping

Intercropping, which is most common in areas with somewhat degraded soils, is the simultaneous cultivation of two or more crops in a field. As farmers work to preserve soil health and become more sustainable, intercropping is becoming more and more popular around the world as an agricultural technique (Nawaz *et al*., 2016) [23]. In areas where water shortage is anticipated, this intercropping system provides an affordable management approach while lowering the demand for both land and water. Intercropping is crucial to sustainable agriculture because it keeps crop yield stability and helps farmers maintain a primary economic yield balance. Compared to pure cropping, intercropping techniques have a complementing influence on plants' resource utilization, making efficient use of water, sunlight, and nutrient components (Koul 2012) [12]. Thus, the preservation of soil moisture and efficient use of natural resources are benefits of intercropping; microorganism activity and nitrogen fixation further aid in these processes (Awaad, 2018) [3]. Consequently, intercropping has the potential to enhance the rhizosphere of plants by improving its physiological and biochemical properties, which raises output. Intercropping has been shown to have favorable benefits on the ultimate products of the intercropping unit area under sustainable agriculture. It can also reduce disease and insect harm, promote the growth of natural enemies, and prevent weed growth. Applying various intercropping techniques can boost crop productivity by improving soil conditions and the growing environment for the plants. This has a number of advantages.

Conservation Tillage

Conventional tillage practices involve the use of a plow and the maintenance of 30% crop residue on the soil's surface following harvest (CT). Conservation tillage techniques have been extensively employed in sustainable agricultural production systems to mitigate the adverse impacts of traditional farmland management techniques. Crop residue retention and the no-tillage (NT) or reduced-tillage (RT) techniques Pittelkow *et al*., 2014 [25] are examples of common conservation tillage techniques. The spatial distribution of soil microbial communities and soil organic matter in the soil profile is changed by conservation tillage techniques. Li and associates, 2018. No-tillage methods raise the water content and C and N concentrations in the surface soil, which boosts microbial resource utilization and enzyme activity levels to prevent soil and water degradation, reduces pollution to the environment, and preserves soil health and biodiversity. The definition of sustainable agriculture is the integration of plant and animal products, such as crop residue and farmyard manure (FYM), to meet the demand for food and fiber from humans while maximizing the use of non-renewable resources and on-farm resources to improve economic viability and the quality of the environment and the farmer's life. According to Somenahally *et al*. (2018) [33], sustainability can be attained by employing animal manure and good waste management on the farm to increase efficiency over conventional tillage (CT) techniques. Additionally, conservation tillage can change the pH of the soil, which can affect the diversity of soil microbes and the soil's appropriateness for crop growth. It can also encourage the construction of fungal hyphal networks and increase the numbers of soil fungus populations. Moreover, crop residue retention and tillage alone, as well as their combined impacts, can have an impact on the size and diversity of the microbial population in agricultural soils Wang *et al*., 2017 [40]. The benefits of conservation tillage methods, such as improvements in soil physical qualities, increases in soil microbial biomass, increases in soil enzyme activity levels, and declines in crop production, have been assessed by recent meta-analyses Wang *et al*., 2017 [40]. Numerous conservation tillage techniques can gradually raise soil quality, lower the risk of soil erosion, enhance soil attributes, and lower tillage expenses. By keeping a higher percentage of crop residue close to the soil surface, conservation tillage has the potential to increase the amount of organic matter at the soil's surface when compared to conventional tillage. Because the soil surface absorbs a large amount of fertilizer and organic amendments, rainfall, and acts as an interface for gaseous exchange, this stratification with the depth of soil organic matter has significant effects on soil quality and the environment.

Green Manuring

Green manuring (GM), crop rotation, and intensive agriculture practices of today provide the technology to efficiently accomplish sustainable production. The process of adding undigested green plants to the soil in order to sustain the availability of nutrients for the crop that follows is known as "green manuring." The practice of adding green plants to the soil that are grown in the same field or another field while they are still green before they flower is referred to as "green manuring." Nair (1993) [22]. Continuous and conventional farming reduces the amount of soil organic matter (SOM), which has a negative impact on the soil's ability to hold nutrients and reduces the sustainability of the soil. Increasing the organic matter content of the soil through the use of green manure crops is one way to preserve agricultural sustainability by improving soil quality and recovering degraded soil. This method is environmentally benign, non-polluting, and safe for the soil, water, and air Kaul *et al*. (2007) [43]. Green manure crops, also known as soil fertility-building crops, are primarily grown for the benefit of the soil. Additionally, by releasing nutrients and energy materials as root exudates, green manure crops promote soil microbial dynamics and growth, ultimately improving soil fertility and health. Furthermore, soil structure is appropriately maintained by microbes because they produce polysaccharide gums, which bind soil particles together to create soil aggregates. By breaking down organic materials found in the soil, soil microorganisms help convert nutrients that aren't readily available for crop growth into forms that are. The distribution and population dynamics of soil microorganisms are greatly impacted by the breakdown of plant remains in the soil. Along with a notable increase in SOM, total N, accessible P, and S in the soil, the GM dhaincha and sunn hemp fed with urea at varying amounts showed an up to 57% increase in sugarcane production. N loss from GM-amended soil is thought to be much lower than that of chemical nitrogenous fertilizers. It has been noted that GM and soil mixing have a major impact on microbial population, growth, and variety. This may be explained by the fact that the soil microbial population was provided with readily available energy and nutrient sources by genetic modification, which encouraged their development and activity. Increased microbial proliferation generates more extracellular enzymes, and when these enzymes are abundant, they significantly change the forms of nutrients that are unavailable to plants into forms that they can use (Ghosh *et al*., 2007) [7].

Biofertilizers

A major problem is meeting the expected demand for food production that is both sustainable and healthful. One of the main objectives of sustainable agriculture is to raise crop output while reducing the impact of climate change and maintaining agroecosystems. A different integrated strategy known as "sustainable agriculture" has been proposed as a means of resolving basic and practical ecological problems pertaining to food production. It combines biological, physical, chemical, and ecological concepts to create novel, environmentally friendly activities. A successful use of microorganisms contributes to the protection of biodiversity as well as soil health, improved water holding capacity, carbon storage, root growth, availability and cycling of vital nutrients, and pollution filtering. Salas-Marina *et al*., 2011 [30]. Common agricultural activities can reduce the number of microbes in the soil and the health of the soil overall; however, this can be avoided in a number of ways by enhancing soil quality. One of the most successful techniques in contemporary agriculture is integrated pest management (IPM), which considers every plant protection strategy accessible. According to Romeh (2018) [29], Integrated Pest Management (IPM) aims to control pest populations while safeguarding non-target species, the environment, and human health. By preventing the growth of pest populations and ensuring the use of plant protection products and other forms of intervention at levels that are both ecologically and economically justified, integrated pest management (IPM) minimizes risks to human health and the environment. Many plant compounds derived from tobacco, pyrethrum, custard apple, neem, etc. have been utilized as safer pesticides in the management of insect pests. Compounds used worldwide to control fleas, aphids, mites, ants, roaches, ticks, beetles, caterpillars, harlequin bugs, thrips, etc. include limonene, pyrethrum/pyrethrins, rotenone, sabadilla, and ryania (Sanchez, 1987) [31].

Agroforestry

Multiple land-use systems, such as agroforestry, involve growing crops and woody perennials on the same land management unit. Globally used, agroforestry systems play a significant role in mitigating the effects of climate change. These days, both rich and developing nations are concerned about climate change, so they are coming together to discover a way to lessen its effects on food security, biodiversity, and agriculture. Because of its benefits to the environment, economy, and society, agroforestry is becoming more and more popular as a sustainable land management strategy worldwide. Through carbon sequestration, agroforestry a sustainable land use that is both biologically and environmentally sound holds out considerable potential for reducing the increasing amounts of CO_2 in the atmosphere. Actions aimed at mitigating and adapting to climate change are more likely to work together when there is a combination of forest and tree products used to diversify income sources. These alternatives also improve soil fertility, lessen the vulnerability of land-use systems to extreme weather events, and support the preservation and restoration of riparian corridors and forests. In the fight against global warming and food insecurity, sequestering carbon in soils and biota and compensating resource-poor farmers for ecological services given would be a timely and mutually beneficial solution. It is impossible to overstate the benefits of agroforestry, which include helping a significant portion of the rural population meet their basic needs for food and other materials (such as fuel wood, staking materials, fibers, timber, medicinal concentrates, oils, fruits, and animal fodder), as well as helping to restore soil fertility, control weeds, and lessen environmental degradation. One of its main advantages, according to proponents, is soil conservation.

Agroforestry systems containing woody perennials may have an impact on a number of biophysical and biochemical processes that assess the condition of the soil substrate Kohl *et al*., 2014 [11]. There is less disagreement about the benefits of trees for soil. These benefits include reducing erosion, which is mainly achieved through understory vegetation and surface litter cover; maintaining or increasing organic matter and diversity through ongoing root decomposition and soil erosion; fixing nitrogen; improving physical properties like soil structure, porosity, and moisture retention through the extensive root system and canopy cover; and improving nutrient use efficiency because the tree-root system can recycle and intercept nutrients in the soil that would otherwise be lost through leaching (Kumar *et al.*, 2015) [14].

Soil beneficial microorganisms in sustainable agriculture

An organic medium for plant growth and development is soil. Soil is the most diverse and complicated environment that comprises of the tiniest creatures in the soil and contains bacteria, actinomycetes, fungi, algae, *etc*. One important factor influencing the health and productivity of plants is their microbiome. Hunter (2016) [8]. And has attracted a great deal of attention lately. Trivedi *et al.*, 2017 [38]. Rhizosphere microbes can form varied degrees of positive, neutral, or negative relationships with their host plants. Particular relationships, such those found in Rhizobium-legume symbioses, between microorganisms and model plants are well studied. Nair (1993) [22]. Through roots, a substantial portion, 5-20%, of the photosynthetic products the photosynthate are discharged, primarily into the rhizosphere, or the soil-root interface. Sloughed cells, mucilage, and exudates from rhizo deposits are examples of these photosynthates. Root exudates include a range of substances, primarily organic acids and sugars, as well as information about the microbiome's function in sustainable agriculture. Vitamins, growth factors, hormones, amino acids, fatty acids, and antimicrobial substances. The structure of the rhizosphere microbiome is largely determined by root exudates. Depending on the age and developmental stage of the plant, as well as the species and cultivars, the root exudate composition can change Ellis (2017) [5]. Symbiotic relationships between nitrogen-fixing bacteria, primarily rhizobia, *Arbuscular mycorrhizal* fungi, and phosphate-solubilizing bacteria are typical examples of the microbiome for how plants receive nitrogen and phosphorus, respectively, among the many benefits of the microbiome for plants. 2014's Kohl *et al* 2014 [11]. The availability of nitrogen and phosphorus for plants is increased by the interaction of *Phosphate-solubilizing bacteria* and *Arbuscular mycorrhizal* fungi with nitrogen-fixing bacteria. This is because the fungi translocate the phosphorus ions to the plant, while the bacteria fix the nitrogen. Kumar *et al*., 2015 [14]. Phosphate solubilizers include the microorganisms *Bacillus, Azotobacter, Microbacterium, Erwinia, Beijerinckia, Enterobacter, Flavobacterium, Pseudomonas, and Rhizobium*. Other endophytic bacteria make up the legume nodule microbiome, which include rhizobia and is in charge of both direct and indirect plant growth promotion processes. *Cyanobacteria*

(Anabaena, Nostoc, Calothrix), Azotobacter, Azospirillum, and Gluconacetobacter are a few nitrogen-fixing endophytes. Kumar and associates, 2015. Fixators, on the other hand, can also live freely and spread throughout non-leguminous plants. This is the case, for instance, with the genera *Bacillus, Klebsiella, and Beijerinckia*. A further technique is phytostimulation, also known as biostimulation, which is inherently connected to plant growth and consists of the microbiome producing phytohormones like *auxin, gibberellins, cytokinins, indole-3-acetic acid* (IAA), and *salicylic acid* (SA). Additionally, several bacteria have the ability to release the enzyme 1-carboxylic acid-1-aminocyclopropane (ACC) deaminase, which lowers the plant's ethylene content. According to Aguiar-Pulido *et al*. (2016) [1], the hormone IAA was created by bacteria found in the tomato rhizospheric microbiome, which also encouraged plant development. Discovered rhizospheric bacteria, identified as Pseudomonas spp. That produced the enzymes IAA and ACC deaminase in the roots of oilseed (soybeans) and cereals (wheat). Additionally, the microbiome is critical to a plant's ability to withstand harsh environmental factors like salt, dehydration, and heavy metal exposure. Gaiero *et al*. (2013) [6] Plant growth rates have been hampered and yields have decreased due to salt in the soil. However, the microbiome's production of phytohormones can reduce the detrimental effects of high salt levels in the soil, increasing plant tolerance to these harsh conditions. In salinity, the rhizosphere microbiome was able to support Hibiscus hambo germination and growth. In 2019, Kumar *et al* 2020 [4]. A recently proposed model explains how the degrading and helpful microbiomes grow and persist in the rhizosphere of soil-contaminated plants. To ensure that the microbial population is kept under control in contaminated environments, four tactics were identified: feeding of supply lines, disturbance, interference from root exudates, and plant selection based on the microbiome. The microbiome of plants in oil-contaminated soils is essential to their survival, development, and biomass output Stringlis *et al*, 2018 [35]. Simultaneously, the microbiome's makeup shifts in favor of microbes linked to plant growth that break down hydrocarbons when contamination in these areas grows. Human interventions are required to maximize the plant-microbiome interaction and encourage the breakdown of contaminants because this interaction will not always be effective for phytoremediation. Knowing how to use the microbiome for agriculture can help choose more productive microbial groups for plant development or use it as an inoculant. Furthermore, a key component of developing sustainable agriculture methods is minimizing the usage of chemical fertilizers and pesticides by taking advantage of the plant microbiome's potential. Another application for the microbiome is as a biocontrol agent. Here are some instances of the plant-associated microbiota's biocontrol. Kumar *et al*. (2018) [16] by modulating phytohormone levels and producing siderophores, volatile chemicals, enzymes, and antibiotics. Through parasitism, antibiosis, and the immunity they bestow upon the plants, the plant microbiome also prevents pathogen growth and activity by competing with them for resources and microenvironments. Certain soil bacteria have the ability to defend plants against pathogens from the genera Pseudomonas, Streptomyces, Bacillus, Paenibacillus, *Enterobacter*, Pantoea, Burkholderia, and Paraburkholderia (Rascovan *et al*., 2016) [27]. The pathogen Gaeumannomyces graminis, which caused take-all wheat, was managed by Endophytes serratia and *Enterobacter*, while the Phyla acidobacteria, Actinobacteria, and Firmicutes in the soil microbiome were able to control the wilt brought on by Fusarium oxysporum. Plant development is encouraged by the soil microbiome through the biocontrol mechanism. Through bio-fertilization that is, by regulating the availability and uptake of nutrients by plants the microbiome promotes development. The possible benefits of manipulating the plant microbiome include decreased plant disease incidence, increased agricultural yield, less chemical inputs, and decreased greenhouse gas emissions. According to Thijs *et al.* (2016) [37], leading to more environmentally friendly farming methods. This objective is thought to be essential to supporting the world's expanding population. Plant microbiomes have a larger probability of success when used because of the eco-evolutionary connections between plant species and their microbiomes, despite the fact that both soil and plant microbiomes play significant roles in crop performance and yield.

Impact of microbial biotechnology in agriculture

Midway through the 20th century, agricultural advancements brought about a green revolution, but they also came with significant ecological implications, including increased global pollution, adverse climate change, and biodiversity loss (Gu *et al*., 2020) [44]. Together, biotechnology and microbiology provide a wide range of research opportunities for enhancing crop productivity, quality, and sustainability in current systems to generate more and higher-quality agricultural goods through transgenic and genetically modified organisms (GMOs). Many applications of microbial biotechnology, such as biofertilizers, biopesticides, bioherbicides, and bioinsecticides, contributed to sustainable agriculture. By controlling biotic and abiotic stressors, microbial biotechnology helps sustainable agriculture become less reliant on agrochemicals. The selection of targets, microbes, and genes from related or unrelated genetic resources are just a few of the processes in this management process. Genetic engineering in conjunction with microbial biotechnology will progress the development of disease-diagnostic instruments, microbial agents for biological control of plant and animal pests, new and improved microbial agents for bioremediation, and modifications of plant and animal pathogens for reduced virulence. One of the key elements of the microbial biotechnology tools for sustainable agriculture is thought to be the soil microbiome. Because of this, the rhizosphere serves as a microhabitat and is home to a wide variety of microorganisms (Ardanov *et al*., 2016) [2].

Genetic engineering in conjunction with microbial biotechnology will progress the development of disease-diagnostic instruments, microbial agents for biological control of plant and animal pests, new and improved microbial agents for bioremediation, and modifications of plant and animal pathogens for reduced virulence. Molecular biotechnology methods have improved plant breeding precision through gene cloning, DNA isolation, and the transfer of desired genes from one species to another. Lugtenberg, (2015) [19] Together, soil microbes are regarded as the most crucial components for the production of nutritious and sustainable food. A vast range of microorganisms enrich the microhabitat of microorganisms in the rhizosphere. Rhizospheric microbes, according to biotechnology frontiers, are essential for achieving agricultural sustainability through a variety of strategies, including boosting N2 fixation, increasing P, S, Zn, and Fe availability, controlling abiotic and biotic stressors, raising crop productivity and quality, and bioremediation. Ruaysoongnern and Noble, 2010 [24]. There are numerous main advantages to microbial biotechnology. It facilitates crop production with minimal use of chemical pesticides, herbicides, fertilizers, etc. Additionally, it maintains our environment pristine and safe for usage by coming generations. Microbial biotechnology offers the advantage of reducing our reliance on waste products and dangerous contaminants that deplete our natural resources and harm the ecosystem. The way that civilization develops should be such that it both contributes to the preservation and advancement of our environment. Together, biotechnology and microbiology provide a wide range of research opportunities for enhancing crop productivity, quality, and sustainability in current systems to generate more and higher-quality agricultural goods through transgenic and genetically modified organisms (GMOs). Here are a few instances of genetically modified crops that are beneficial to everyone on the planet: Herbicide tolerance improves weed control (*e.g*., soybeans, tomatoes, corn, cotton, oilseed rape canola, and grapes); control ripening improves shelf life and quality (*e.g*., tomatoes, peas, peppers, tropical fruits, broccoli, raspberries, and melons); fungal resistance reduces fungicide use (*e.g*., peppers, tomatoes, and cucumbers); viral resistance reduces plant virus-caused diseases and, since insects carry viruses, reduces the use of insecticides (*e.g*., potatoes, tomatoes, cantaloupe, squash, cucumbers, corn, soybeans, and grapes); and viral resistance reduces plant virus-caused diseases (Lugtenberg 2015) [19].

In this situation, biotechnological intervention is essential for identifying the microbiota. Recently, the detection of microbes in the microbiomes of various agro-ecologies has made extensive use of genetic material sequencing and increased computing power. This has made it possible to identify the microbiome in any feasible environment without isolating and cultivating microbes. It is very beneficial to extrapolate such a wide range of knowledge to create strategies for manipulating the microbiomes to increase nutrition uptake and improve biotic and abiotic stress tolerances, leading to improved yield of agricultural products. In reality, sequencing technology combined with bioinformatic tools has not only allowed for quick microbiome detection but has also sped up the process of rapid gene microbiome annotation. The recently developed technology known as next-generation sequencing (NGS) is currently in use due to its notable benefits over the traditional sanger sequencing approach. High-throughput sequencing has been made possible by this technological breakthrough, which has supplementarily improved the many outcomes that, when approached using traditional methods, seemed difficult and laborious (Bharati *et al*., 2020) [4]. The finished genome sequences exhibit excellent characterisation, provide more accurate genomic information, and can be applied to model species and microbes that are significant to agriculture. 2020; Singh *et al*. Metagenomics, a recently developed sequencing technique that uses high-throughput sequencing technologies to analyze the genetic material of microbes found in environmental samples, is a step forward in this area. Metagenomic analysis holds great promise for providing adequate information regarding the discovery of novel genes, microbial pathways, interactions, and microbial composition and diversity in the study of the aboveground and belowground microbiomes. Owing to the low cost of sequencing, a remarkable number of microbiomes have been found and identified in the earlier modern era by metagenomics research Moronta *et al*. (2018) [21] by directly evaluating the 16S/18S rDNA amplicon sequence. Furthermore, a PCR procedure that depends on a single DNA molecule is not necessary for the third-generation sequencing method known as "single-molecule real-time sequencing," or SMRT (single-molecule real-time sequencing).

The current global application of agricultural methods is based on a variety of approaches that are being directed toward sustainable economic and environmental advancements, ultimately preserving production while protecting the biosphere. Agricultural microbiology is presented as a synthetic research field that facilitates the transfer of knowledge between agricultural biotechnology and general microbiology/microbial ecology. To recreate the microbiota's layout in agricultural and natural environments, an analysis of the frequent movement of microorganisms between plants, animals, and soil-borne niches is necessary (Bais and Spence, 2013) [34].

Conclusion

We looked at how microbes fit into sustainable farming practices. Microorganisms found in the rhizosphere and soil are primarily responsible for the health of the soil in sustainable agriculture. The variety and quantity of soil microorganisms affect the productivity, sustainability, and composition of plants. Because the same microbes may help restore soil health and productivity and play a part in low-input, sustainable agriculture, using them to increase agricultural output is a highly profitable and low-cost strategy. To further improve our understanding of how production practices and environmental factors affect the physical, biological, and chemical traits and dynamics of the soil-plant-rhizosphere ecosystem and its impact on sustainability in agriculture, extensive studies on soil health indicators are required.

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