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Review Article

Potential Significance of Beneficial Microbes for Sustainable Soil Management and Plant Utilization

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Abstract

Soil beneficial microbes are the most abundant of all the biota in soil and responsible for driving nutrient and organic matter cycling, soil fertility, soil restoration, plant health and ecosystem primary production. Beneficial microorganisms include those that create symbiotic associations with plant roots (rhizobia, mycorrhizal fungi, actinomycetes, diazotrophic bacteria), promote nutrient mineralization and availability, produce plant growth hormones, and are antagonists of plant pests, parasites or diseases (biocontrol agents).This review paper investigated the significance of beneficial in sustainable soil management and plant utilization.

Keywords: Soil; Beneficial; Association; Hormones; Microorganism; Fertility

Introduction

In Nigeria and for agricultural purposes, sustainable soil management which combines technologies, policies and activities aimed at integrating socioeconomic principles with environmental concerns will simultaneously: maintain and enhance production reduce the level of production risk, and enhance soil capacity to buffer against degradation processes protect the potential of natural resources and prevent degradation of soil and water quality be economically viable be socially acceptable, and assure access to benefits from improved land management.

Conventional agriculture plays a significant role in meeting the food demands of a growing human population, which has also led to an increasing dependence on chemical Fertilizers and pesticides [1]. Chemical fertilizers are industrially manipulated, substances composed of known quantities of nitrogen, phosphorus and potassium, and their exploitation causes air and ground water pollution by eutrophication of water bodies [2]. In this regard, recent efforts have been channelized more towards the production of 'nutrient rich high quality food' in sustainable comportment to ensure bio-safety. The innovative view of farm production attracts the growing demand of biological based organic fertilizers exclusive of alternative to agro-chemicals [3]. In agriculture, encourage alternate means of soil fertilization relies on organic inputs to improve nutrient supply and conserve the field management [4]. Organic farming is one of such strategies that not only ensures food safety but also adds to the biodiversity of soil [5]. The additional advantages of biofertilizers include longer shelf life causing no adverse effects to ecosystem [6].

Organic farming is mostly dependent on the natural microflora of the soil which constitutes all kinds of useful bacteria and fungi including the arbuscular mycorrhiza fungi (AMF) called plant growth promoting rhizobacteria (PGPR). Biofertilizers keep the soil environment rich in all kinds of micro- and macro-nutrients via nitrogen fixation, phosphate and potassium solubalization or mineralization, release of plant growth regulating substances, production of antibiotics and biodegradation of organic matter in the soil [7]. When biofertilizers are applied as seed or soil inoculants, they multiply and participate in nutrient cycling and benefit crop productivity [8]. In general, 60% to 90% of the total applied fertilizer is lost and the remaining 10% to 40% is taken up by plants. In this regard, microbial inoculants have paramount significance in integrated nutrient management systems to sustain agricultural productivity and healthy environment [9] .The PGPR or co-inoculants of PGPR and AMF can advance the nutrient use efficiency of fertilizers. A synergistic interaction of PGPR and AMF was better suited to 70% fertilizer plus AMF and PGPR for P uptake. Similar trend were also reflected in N uptake on a whole-tissue basis which shows that 75%, 80%, or 90% fertilizer plus inoculants were significantly comparable to 100% fertilizer [10]. This review is intended to cater to the needs of soil scientists and plant biologists whose work focuses on creating clean and efficient means to improve the quality of soil by nourishing and maintaining the useful and natural flora of beneficial microorganisms. It further presents recent developments in the area of soil management that reveals the potential application of biofertilizers to increased nutrient profiles, plant growth, health and productivity.

Microbial interactions in the Rhizosphere

The rhizosphere, which is the narrow zone of soil surrounding plant roots, can comprise up to 1011 microbial cells per gram of root [11] and above 30,000 prokaryotic species [12] that in general, improve plant productivity [12]. The collective genome of rhizosphere microbial community enveloping plant roots is larger compared to that of plants and is referred as microbiome [13] whose interactions determine crop health in natural agro-ecosystem by providing numerous services to crop plants viz., organic matter decomposition, nutrient acquisition, water absorption, nutrient recycling, weed control and bio-control [14]. The metagenomic study provides the individual the core rhizosphere and endophytic microbiomes activity in *Arabidopsis thaliana* using 454 sequencing (Roche) of 16S rRNA gene amplicons [15]. It has been proposed that exploiting tailor-made core microbiome transfer therapy in agriculture can be a potential approach in managing plant diseases for different crops [16]. Rhizosphere microbial communities an alternative for chemical fertilizers has become a subject of great interest in sustainable agriculture and bio-safety programme.

A major focus in the coming decades would be on safe and eco-friendly methods by exploiting the beneficial micro-organisms in sustainable crop production [17]. Such microorganisms, in general, consist of diverse naturally occurring microbes whose inoculation to the soil ecosystem advances soil physicochemical properties, soil microbes biodiversity, soil health, plant growth and development and crop productivity [18]. The agriculturally useful microbial populations cover plant growth promoting rhizobacteria, N2-fixing cyanobacteria, mycorrhiza, plant disease suppressive beneficial bacteria, stress tolerance endophytes and bio-degrading microbes [19]. Biofertilizers are a supplementary component to soil and crop management traditions viz., crop rotation, organic adjustments, tillage maintenance, recycling of crop residue, soil fertility renovation and the biocontrol of pathogens and insect pests, which operation can significantly be useful in maintaining the sustainability of various crop productions [20]. *Azotobacter, Azospirillum, Rhizobium,* cyanobacteria, phosphorus and potassium solubilising microorganisms and mycorrhizae are some of the PGPRs that were found to increase in the soil under no tillage or minimum tillage treatment [21,22]. Efficient strains of *Azotobacter, Azospirillum, Phosphobacter* and *Rhizobacter* can provide significant amount of nitrogen to Helianthus annus and to increase the plant height, number of leaves, stem diameter percentage of seed filling and seed dry weight [23]. Similarly, in rice, addition of *Azotobacter, Azospirillum* and *Rhizobium* promotes the physiology and improves the root morphology [24].

Importance of Biofertilizers

Indiscriminate use of synthetic fertilizers has led to the pollution and contamination of the soil, has polluted water basins, destroyed micro-organisms and friendly insects, making the crop more prone to diseases and reduced soil fertility. Demand is much higher than the availability. It is estimated that by 2020, to achieve the targeted production of 321 million tonnes of food grain, the requirement of nutrient will be 28.8 million tonnes, while their availability will be only 21.6 million tonnes being a deficit of about 7.2 million tones1. Depleting feedstock/fossil fuels (energy crisis) and increasing cost of fertilizers. This is becoming unaffordable by small and marginal farmers, depleting soil fertility due to widening gap between nutrient removal and supplies, growing concern about environmental hazards, increasing threat to sustainable agriculture. Besides above facts, the long term use of bio-fertilizers is economical, eco-friendly, more efficient, productive and accessible to marginal and small farmers over chemical fertilizers [25].

Potential Role of biofertilizers in agriculture

The incorporation of bio-fertilizers (N-fixers) plays major role in improving soil fertility, yield attributing characters and thereby final yield has been reported by many workers. In addition, their application in soil improves soil biota and minimizes the sole use of chemical fertilizers. Under temperate conditions, inoculation of Rhizobium improved number of pods plant-1, number of seed pod-1 and 1000-seed weight (g) and thereby yield over the control. The number of pods plant-1, number of seed pod-1 and 1000-seed weight. In rice under low land conditions, the application of BGA+ Azospirillum proved significantly beneficial in improving LAI and all yield attributing aspects. It is an established fact that the efficiency of phosphate fertilizers is very low (15-20%) due to its fixation in acidic and alkaline soils and unfortunately both soil types are predominating in India accounting more than 34% acidity affected and more than seven million hectares of productive land salinity/alkaline affected. Therefore, the inoculations with PSB and other useful microbial inoculants in these soils become mandatory to restore and maintain the effective microbial populations for solubilization of chemically fixed phosphorus and availability of other macro and micronutrients to harvest good sustainable yield of various crops.

Plant growth promoting rhizobacteria (PGPR) have been studied for long. It has been suggested in the last few years that endophytic N2-fixing bacteria may be more important than rhizospheric bacteria in promoting plant growth because they escape competition with rhizosphere microorganisms and achieve close contact with the plant tissues [26,27]. The well known genera of PGPR are *Azospirillum, Azotobacter, Bacillus, Burkholderia, Enterobacter, Klebsiella,* and *Pseudomonas*, but some of these genera include endophytic species as well. The best-characterized endophytic bacteria include *Azoarcus* spp, *Gluconacetobacter diazotrophicus,* and *Herbaspirillum seropedicae.* Novel Burkholderia species, for instance, *B. unamae* [28] and *B. tropica* [29] have the potential for promoting plant growth [30] and are found in rhizospheric and endophytic association with different agricultural crops. Bacterial mechanisms of plant growth promotion include biological nitrogen fixation (BNF), synthesis of phytohormones, environmental stress relief, synergism with other bacteria-plant interactions, inhibition of plant ethylene synthesis, as well as increasing availability of nutrients like phosphorus, iron and minor elements, and growth enhancement by volatile compounds. However, the expression of such bacterial activities under laboratory conditions does not guarantee in association with a host plant. This is especially true of nitrogen fixation as abundantly expressed in culture media by many bacterial species. The mechanisms of plant growth promotion have been analyzed in different organisms, especially in *Azospirillum* spp. and in few other PGPR [31,32]. In this review, *Azospirillum* as a model for studying mechanisms of plant growth promotion will only be covered briefly but some other models and new mechanisms will be presented in more depth. Many definitions and interpretations of the term biofertilizer exist [33]. In this chapter, a biofertilizer is a product that contains living microorganisms, which exert direct or indirect beneficial effects on plant growth and crop yield through different mechanisms. The term biofertilizer as used here could include products containing bacteria to control plant pathogens, but these are frequently referred to as biopesticides [35], [36,37].

Potential Characteristic Features of Some Biofertilizers Fixing Nitrogen

Rhizobium: belongs to family *Rhizobiaceae*, symbiotic in nature, fix nitrogen 50-100 kg/ ha in association with legumes only. It is useful for pulse legumes like chickpea, red-gram, pea, lentil, black gram, etc., oil-seed legumes like soybean and groundnut and forage legumes like *berseem* and *lucerne*. Successful nodulation of leguminous crops by *Rhizobium* largely depends on the availability of compatible strain for a particular legume. It colonizes the roots of specific legumes to form tumor like growths called root nodules, which acts as factories of ammonia production. *Rhizobium* has ability to fix atmospheric nitrogen in symbiotic association with legumes and certain non-legumes like *Parasponia. Rhizobium* population in the soil depends on the presence of legume crops in the field. In absence of legumes, the population decreases. Artificial seed inoculation is often needed to restore the population of effective strains of the *Rhizobium* near the rhizosphere to hasten N-fixation. Each legume requires a specific species of *Rhozobium* to form effective nodules. According to Ahmad., et al. 2008 rhizo-bacteria are plant growth promoting rhizobacteria that enhances growth of plants and can be found in the rhizosphere. Rhizosphere is the soil environment where the plant root is available and a zone of maximum microbial activity resulting in a confined nutrient pool in which essential macro and micronutrients are gotten [38]. reported that the microbial population present in the rhizosphere is relatively different from the ones in the surrounding due to the presence of root exudates that function as a source of nutrients for microbial growth. The term "plant growth promoting rhizobacteria (PGPR)" for these beneficial microbes was introduced by [39] which paved the way for greater discoveries on PGPR. PGPR are not only associated with the root to exert beneficial effects on plant development but also have positive effects on controlling phytopathogenic microorganisms [40], [41]. The PGPR serve as one of the active ingredients in biofertilizer formulation. Due to their interactions with plants, PGPR can be separated into symbiotic bacteria, whereby they live inside plants and exchange metabolites with them directly, and free-living rhizobacteria, which live outside plant cells [42].

The mode of action of PGPR that promotes plant growth includes; abiotic stress tolerance in plants; nutrient fixation for easy uptake by plant; plant growth regulators; the production of siderophores; the production of volatile organic compounds; and the production of protection enzyme such as chitinase, glucanase, and ACC-deaminase for the prevention of plant diseases [43,44].

Azospirillum belongs to family *Spirilaceae*, heterotrophic and associative in nature. In addition to their nitrogen fixing ability of about 20-40 kg/ha, they also produce growth regulating substances. Although there are many species under this genus like, *A. amazonense, A. halopraeferens, A. brasilense,* but, worldwide distribution and benefits of inoculation have been proved mainly with the *A. lipoferum* and *A. brasilense*. The *Azospirillum* form associative symbiosis with many plants particularly with those having the C4-dicarboxyliac path way of photosynthesis (Hatch and Slack pathway), because they grow and fix nitrogen on salts of organic acids such as malic, aspartic acid. Thus it is mainly recommended for maize, sugarcane, sorghum, pearl millet etc. The Azotobacter colonizing the roots not only remains on the root surface but also a sizable proportion of them penetrates into the root tissues and lives in harmony with the plants. They do not, however, produce any visible nodules or out growth on root tissue.

Azotobacter belongs to family *Azotobacteriaceae*, aerobic, free living, and heterotrophic in nature. Azotobacters are present in neutral or alkaline soils and *A. chroococcum* is the most commonly occurring species in arable soils. *A. vinelandii, A. beijerinckii, A. insignis* and *A. macrocytogenes* are other reported species. The number of *Azotobacter* rarely exceeds of 104 to 105 g-1 of soil due to lack of organic matter and presence of antagonistic microorganisms in soil. The bacterium produces anti-fungal antibiotics which inhibits the growth of several pathogenic fungi in the root region thereby preventing seedling mortality to a certain extent. The population of *Azotobacter* is generally low in the rhizosphere of the crop plants and in uncultivated soils. The occurrence of this organism has been reported from the rhizosphere of a number of crop plants such as rice, maize, sugarcane, bajra, vegetables and plantation crops.

Blue Green Algae (Cyanobacteria) and *Azolla* These belongs to eight different families, phototrophic in nature and produce Auxin, Indole acetic acid and Gibberllic acid, fix 20-30 kg N/ha in submerged rice fields as they are abundant in paddy, so also referred as "paddy organisms‟. N is the key input required in large quantities for low land rice production. Soil N and BNF by associated organisms are major sources of N for low land rice4. The 50-60% N requirement is met through the combination of mineralization of soil organic N and BNF by free living and rice plant associated bacteria. To achieve food security through sustainable agriculture, the requirement for fixed nitrogen must be increasingly met by BNF rather than by industrial nitrogen fixation. BGA forms symbiotic association capable of fixing nitrogen with fungi, liverworts, ferns and flowering plants, but the most common symbiotic association has been found between a free floating aquatic fern, the *Azolla* and *Anabaena azollae* (BGA). *Azolla* contains 4-5% N on dry basis and 0.2-0.4% on wet basis and can be the potential source of organic manure and nitrogen in rice production. The important factor in using *Azolla* as biofertilizer for rice crop is its quick decomposition in the soil and efficient availability of its nitrogen to rice plants. Besides N-fixation, these biofertilizers or biomanures also contribute significant amounts of P, K, S, Zn, Fe, Mb and other micronutrient. The fern forms a green mat over water with a branched stem, deeply bilobed leaves and roots. The dorsal fleshy lobe of the leaf contains the algal symbiont within the central cavity. *Azolla* can be applied as green manure by incorporating in the fields prior to rice planting. The most common species occurring in India is A. pinnata and same can be propagated on commercial scale by vegetative means. It may yield on average about 1.5 kg per square meter in a week. India has recently introduced some species of *Azolla* for their large biomass production, which are *A.caroliniana, A. microphylla, A. filiculoides* and *A. mexicana.*

Phosphate solubilizers

Several reports have examined the ability of different bacterial species to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate. Among the bacterial genera with this capacity are p*seudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Microccocus, Aereobacter, Flavobacterium* and *Erwinia.* There are considerable populations of phosphate solubilizing bacteria in soil and in plant rhizospheres. These include both aerobic and anaerobic strains, with a prevalence of aerobic strains in submerged soils. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere in comparison with non rhizosphere soil. The soil bacteria belonging to the genera Pseudomonas and *Bacillus* and *Fungi* are more common.

Phosphate absorbers (Mycorrhiza)

The term Mycorrhiza denotes "fungus roots". It is a symbiotic association between host plants and certain group of fungi at the root system, in which the fungal partner is benefited by obtaining its carbon requirements from the photosynthates of the host and the host in turn is benefited by obtaining the much needed nutrients especially phosphorus, calcium, copper, zinc etc., which are otherwise inaccessible to it, with the help of the fine absorbing hyphae of the fungus. These fungi are associated with majority of agricultural crops, except with those crops/plants belonging to families of *Chenopodiaceae, Amaranthaceae, Caryophyllaceae, Polygonaceae, Brassicaceae, Commelinaceae, Juncaceae* and *Cyperaceae.*

Zinc solubilizers

The nitrogen fixers like *Rhizobium, Azospirillum, Azotobacter*, BGA and Phosphate solubilizing bacteria like *B. magaterium, Pseudomonas striata,* and phosphate mobilizing Mycorrhiza have been widely accepted as bio-fertilizers. However these supply only major nutrients but a host of microorganism that can transform micronutrients are there in soil that can be used as biofertilizers to supply micronutrients like zinc, iron, copper etc.,The zinc can be solubilized by microorganisms viz., *B. subtilis, Thiobacillust thioxi-*

dans and *Saccharomyces sp.* These microorganisms can be used as bio-fertilizers for solubilization of fixed micronutrients like zinc. The results have shown that a *Bacillus sp*. (Zn solubilizing bacteria) can be used as bio-fertilizer for zinc or in soils where native zinc is higher or in conjunction with insoluble cheaper zinc compounds like zinc oxide (ZnO), zinc carbonate ($ZnCO_3$) and zinc sulphide (ZnS) instead of costly zinc sulphate.

Potentialities of non- mycorrhizal fungi as inoculants for biofertilizers

Fungi are ubiquitous in soil, and can be dominant components of the microbiota in many soil types [45], [46]. For example, fertile soil may contain a fungal network up to 10,000 km/m [47]. By adapting their metabolism to the availability of varying nutritive compounds in the soil environment, fungi produce a wide range of oxidative and hydrolytic enzymes that allow them to efficiently break down organic matter like ligno-cellulosic materials but also other natural or human-derived compounds, like in the field of xenobiotic and organic pollutant degradation [48].

The plasticity of fungi biology and the plethora of functions that can be attributed to fungal

Metabolisms suggest that there are several potential uses and forms of exploitation of non mycorrhizal fungi for the production of biofertilizers. The ability of some fungal groups or species in the dissolution or leaching of minerals and elements' chelation and translocation has been very little evaluated and even less exploited as a potential for the production of innovative soil amendments. The biological activity of fungi can cause the enrichment of C, N, and S in the soil, making these as well as other nutrients available to plants. Moreover, fungi are capable of transporting substances in their hyphae that act as pipes connecting microenvironments with different concentration of nutrients and can actually transport ions against a chemical osmotic gradient [49]. Translocation across distant parts of the mycelium enables fungi to colonize places with low initial resource availability and to actively change the microenvironment and the availability of nutrients in the substrates, turning the colonizing mycelium from a resource sink into a source [49].

Plant growth promoting traits

Production of phytohormones

Plant growth regulators participate in the growth and development of cells, tissues, organs, and in fact the entire plant. These compounds are active in plants in very minute amounts and their synthesis is extremely regulated. Plants not only produce phytohormones but also, numerous plant associated bacteria both beneficial and harmful, produce one or more of these substances [50]. The phytohormone-mediated roles of bacterial ephyphitic communities on plants are yet not clear.

The future of biofertilizers based on hormone-producing bacteria seems very promising. Large numbers of experiments have shown that bacterial participation raises the phytohormone levels in plants. This may be via bacterial synthesis or through bacterial induction of plant hormone synthesis but both offer economical and ecological advantages.

ACC deaminase activity

Ethylene exposition induces different observable changes in plants, including reduction in the growth rate. This is especially true in stressed dicot plants, since monocots are less sensitive to ethylene. It has been proposed that PGPR may enhance plant growth by lowering the plant ethylene levels [31] In these cases, the immediate precursor of ethylene is 1- aminocyclopropane-1-carboxylate (ACC). This compound is hydrolyzed N by bacteria-expressing ACC-deaminase activity. Ammonia and α-ketobutyrate, products of this hydrolysis, are used by the ACC-degrading bacterium as nitrogen and carbon sources [32] Bacteria belonging to phylogenetically distant genera such as *Alcaligenes sp., Bacillus pumilus, Pseudomonas sp.* and *Variovorax paradoxus* as well as, *Azoarcus, Azorhizobium caulinodans, Azospirillum spp., Gluconacetobacter diazotrophicus, Herbaspirillum spp., Burkholderia vietnamiensis* and others [31] were identified by their ability to grow on minimal media containing ACC as sole nitrogen source.

Environmental stress relief

Several associations between plants and beneficial bacteria show a protective response under restrictive environmental conditions. The production of microbial metabolites like polysaccharides modifies the soil structure, and has a positive effect on plants grown in water stress. Growth parameters of sunflower plants under water stress inoculated with an exopolysaccharide (EPS)-producing Rhizobium sp. were greater than in uninoculated plants [43] Overall, PGPR can protect a plant, against aggressive environmental and particularly hostile soil conditions through the bacterial release of soil structure-improving substances, and by inducing the plant to activate stress responsive mechanisms. In hostile soils, the use of bacteria that allow plants to thrive are probably the best option to obtain good yields at lesser ecological costs.

Conclusion

Efficient and sustainable practices should be adopted to allow cost-efficient production of adequate nutrition for the growing populations. To overcome the ecological problems resulting from the loss of plant nutrients and to increase crop yields in the absence of resources for obtaining costly fertilizers, beneficial microbes which serves as biofertilizers that allow more efficient nutrient use or increase nutrient availability in the soil can provide sustainable solutions for present and future agricultural and forest management practices.

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