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IMPORTANCE OF BIO FERTILIZERS AS ALTERNATIVE SOIL FERTILITY AMENDMENTS

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ABSTRACT

There is a current interest in agrarian sustainability with soil microorganisms instead of agro-chemicals. Key constraints in the use of bio fertilizers are; inadequate awareness about bio inoculants and lack of promotion network and publicity among the end users. This review discusses current technical information a way of creating awareness in order to promote the use of bio fertilizers. Publon, Google Scholar, Science Direct and Microsoft Academic data bases were used for the review 2021. Research and review articles published from 2019 onwards were considered as current information for the review. The findings of the review are that; both primary and secondary macronutrients can be provided by bio fertilizers. Potential microbes are; free-living nitrogen fixing bacteria and cyanobacteria, symbiotic nitrogen-fixing bacteria and fungi such as mycorrhiza. Other important functions of bacteria are; conferring to plants the ability for salt tolerance, lignin degradation and remediation of heavy metals from the soil. Bio Compost, vermicompost and termite soil with their rich microorganism content can be used as bio fertilizers for soil nutrient increase. In order to reap maximum benefit from bio fertilizers there is need to formulate them in appropriate materials. Apart from addition of nutrients to the soil, bio fertilizers play an important role in plant health, conclusion. This paper has brought to the fore the need to improve rhizosphere management in a sustainable way particularly at this point in time when there are strong indications that it has deteriorated in the face of continued use of chemical fertilizers.

Keywords: Bio fertilizer, Rhizosphere, Microorganisms, Microorganism consortia, Bacteria, Nitrogen-fixation, Soil amelioration

INTRODUCTION

Soil nutrients and fertility are decreasing with time and this continues to pose a challenge in ensuring food security. **(Fasusi *et al*., 2021)**. In order to meet the food security goal, the right environmental conditions and availability of fertile soils are key **(Glaser and Lehr, 2019).** There has been renewed interest in ensuring agrarian sustainability using beneficial soil microorganisms instead of chemical fertilizers and pesticides **(Yadav and Sarkar, 2019).** The upshot of this has been the need to improve rhizosphere management. The rhizosphere, according to **Enagbonma *et al*. (2019)** is a region with a high turnover of nutrients and a high microbial density where biotic and abiotic factors are under the strict control of each other It is the region of soil in the vicinity of plant roots in which the chemistry and microbiology is influenced by their growth, respiration and nutrient exchange. Simply put, it is the soil that surrounds and is influenced by the roots of a plant. Its management includes the process of improving the nutrient efficiency in the soil in order to enhance the elements needed for plant growth and improved yield **(Zia *et al*., 2020).** Studies by **Nwachukwu *et al.* (2021)** have reported that the abundance of nutrient accumulation in the rhizosphere soils has placed the rhizosphere as the 'epicenter' of bacterial concentrations. The author further emphasized that over the years, little attention has been given to bacterial inoculants and soil-like substrates. The diversity of bacterial species in the rhizosphere has been used as a biological indicator to estimate soil quality and fertility because they play a critical role in nitrogen fixation, hormone production and nutrient distribution. Similarly, they have contributed to the production and oxidation of methane and acetone, and have resulted in the enhancement of the soil pH, water composition, organic carbon content, and porosity **(Keswani *et al*., 2019; Ju *et al*., 2020).** The host plant induces selection pressure on the development of the rhizosphere microbiome, which favors and attracts a specific plant microbiota due to variations in the composition of the root exudate **(Bukhat *et al*., 2020)**

Olubukola *et al*. (2020) reported that the diversity of plant associated microbes is enormous and complex and that the microbiomes are structured and form complex interconnected microbial networks that are important in plant health and ecosystem functioning. Understanding the composition of the microbiome and their core function is important in unveiling their networking strategies and their potential influence on plant performance. All the microbial communities inhabiting the rhizosphere can be described by the term; 'rhizobiome' **(Olanrewaju et al. (2019).** Studies have shown that plant root exudates attract beneficial microbes to its rhizosphere **(Olubukola *et al*., 2020).**

Chemical fertilizers have been the soil nutrient amendments of choice. However, though the chemical fertilizers increase plant growth and vigour, it has been found that plants grown this way do not develop good characteristics such as good root and shoot system **(Randeep *et al*., 2019).** In addition the chemicals pose a big threat to human body and the environment through pollution. Due to the hazardous nature of chemical fertilizers, there has been a tendency towards sustainable agriculture using bio fertilizers **(Gortari *et al*., 2019). Chandini *et al.* (2019)** reported that the population of beneficial microorganisms is reduced by the practice of chemical fertilizer application resulting in a loss of soil fertility and high incidence of root diseases. Further, **s**tudies have established that the use of chemical fertilizers can be replaced with biological ones and achieve acceptable yields **(Gortari *et al*., 2019).** These biological fertilizers known in short as bio fertilizers, and also called microbial inoculants, are organic products containing specific microorganisms which are derived from plant roots and root zones **(Nosheen *et al*., 2021).** These microorganisms are majorly bacterial in nature **(Prabakaran *et al.* 2020),** the others being fungi. Both bacterial and fungal bio fertilizers have been defined as living microbes that enhance plant nutrition by either mobilizing or increasing nutrient availability in soil which is a prospect for agricultural development **(Macik *et al*., 2020; Mitter *et al*., 2021). Onyia *et al.* (2020)** defined bio fertilizers as preparations that contain microbes capable of nitrogen (N) fixation and phosphate solubilization that promote plant growth. Bio fertilizers are in actual fact microorganisms that add to the nutrient quality of the soil. They have been defined as formulations of living microbial strains that are applied to seeds, plants or soil to colonize the rhizosphere to enhance the supply or availability of nutrients and completely or partially replace agrochemicals **(Adekunle *et al*., 2021).** The application of bio fertilizers have been reported to increase the quantity and biodiversity of useful bacteria such as plant growth promoting rhizobacteria (PGPR) belonging to *Azotobacter, Bacillus, Burkholderia, Pantoea, Pseudomonas, Serratia* and *Streptomyces* **(Verma *et al*., 2019; Gou *et al*., 2020)**

Presently, the global bio fertilizer market is expanding due to the rising acceptance of efficient soil nutrient management practices such as the application of bio fertilizers amongst farmers **(Adekunle *et al*., 2021).** Bio fertilizers play a key role in increasing crop yield and maintaining long term soil fertility which is essential for meeting global food demand **(Nosheen *et al*., 2021).** The microbes within a bio fertilizer can be single or multiple strains also known as microbial consortia **(Riaz *et al.* (2020).** In recent years, product development strategies have shifted from single strain to microbial consortia inoculation. These strategies are based on a greater chance of at least one strain escaping competitive exclusion and thus ensuring inoculant survival and function **(Tosi *et al*., 2020).** Microbial consortia can consist of two or more strains that are either closely or distantly related that provide an overall additive or synergistic bio-fertilization effect (**El Maaloum *et al*., 2020).** Nevertheless inclusion of microbial inoculants with biopesticides and phytostimulators does not qualify the resultant material as a bio fertilizer **(Macik *et al*., 2020).** Plant growth promoting bacteria (PGPB) and plant growth promoting rhizobacteria (PGPR) and bio fertilizers are not interchangeable terms as neither of them is a bio fertilizer. Plant growth promoting rhizobacteria (PGPR) colonize plant roots and promote plant growth by producing and secreting various chemical regulators in the rhizosphere **(Lin *et al*., 2019).** However it is worth noting that bio fertilizers can provide benefits for plant growth either directly or indirectly **(Liu *et al*., 2020; Shirmohammadi *et al.*, 2020).** Plant growth promoting bacteria (PGPB) are a consortia of bacterial species that colonize the plant root region, impacting plant growth and health advantageously. The PGPB are agricultural bio resources that stimulate plant growth and productivity. They also incite plants' resistance to different phytopathogens in a wide variety of crops including vegetables, fruits, and some trees **(Babalola *et al*., 2020).**

Singh *et al*. (2019) reported that bio fertilizers were first used in 1895 as Nitragin which was a *Rhizobium* laboratory culture. Despite this long history, the use of bio fertilizers is limited by constrains related to inconsistent responses over different soils, crops and environmental conditions, challenges in mass production, shelf-life, appropriate recommendations and ease of use by the farmers **(Debnath *et al.*, 2019). Vassilev *et al*., 2020)** reported that the two main problems that can be distinguished in the production and application of bio fertilizers are economical competitiveness based on the overall upstream and downstream operational costs and development of commercial products with a high soil-plant colonization potential in controlled conditions but not able to effectively mobilize soil nutrients and /or combat plant pathogens in the field. Advances in molecular technology have enabled scientists to describe soil microbial communities and their influence on plant nutrient acquisition and other plant growth promoting traits even though development of novel bio fertilizer technologies has not yet been achieved (**Qui *et al*., 2019; Saad *et al*., 2020).**

The increased dependency of modern agriculture on excessive synthetic input of chemical fertilizers has caused several environmental problems related to greenhouse effect, soil deterioration, and air and water pollution **(Thomas and Singh, 2019)**. The application of bio fertilizers is gaining more awareness since it is environmentally friendly and a cost effective means of enhancing crop productivity and soil fertility **(Glick, 2020b).** Another disadvantage with chemical fertilizers is that less than half of the applied chemical fertilizer of nitrogen is used by the target crops and much of the remaining pollutes air and the waterways **(Paungfoo-Lonhienne *et al*., 2020).** According to **Singh *et al.* (2019)** and **Adekunle *et al*. (2021)** bio fertilizers have the quality of being not only environmentally friendly but are also sustainable and cost effective. There has been an increasing need for pollutant-free crops. Consequently, bio fertilizers containing microorganisms like bacteria, fungi, and algae have been suggested as viable solutions for large-scale agricultural practices which not only are natural, ecofriendly, and economical but also maintain soil structure as well as biodiversity of agricultural land **(Thomas and Singh, 2019).** Nutrients in the soil migrate to the water body through runoff caused by rainfall, where it causes eutrophication and contamination of the water body **(Yu *et al*., 2019).** This causes a major threat to the natural environment. Thus, the application of nutrient-rich bio fertilizer made from plant growth-promoting microorganisms that have potentials such as; nitrogen fixation, potassium solubilization, and phosphate solubilization, are essential in the recovery of soil nutrients to enhance plant growth and yield performance **(Olanrewaju *et al*., 2019).**

A major concern in bio fertilizer use is the direct ecological interactions, either synergistic or antagonistic as well as horizontal gene transfer **(Glick, 2020a; Mawarda *et al*., 2020).** This calls for judicious selection of the appropriate bio fertilizer microbes particularly in situations where organic farming is key. Organic farming involves the use of bio fertilizers and bio pesticides that increase the nutrient quality of the crops and controls pests and pathogens. The global bio fertilizer market has an estimated value of 2.3 billion US dollars and it is projected to increase to 3.9 billion soon (Marketandmarkets, 2020). Despite their great potential and long-term effects, bio fertilizer products still face major challenges limiting their use in agricultural settings. These are often associated with limited shelf-life and the survival of inoculated strains in vastly different environments. There will therefore be need to find formulations that can address this shortcomings **(Vania *et al*., 2019).** The bio fertilizer industry in many African countries is underdeveloped due to several challenges and therefore the full adoption and benefits of bio fertilizers have not yet been realized (**Adekunle *et al.*, 2021).** According to **Nosheen *et al*., 2021,** among the key constraints in the use of bio fertilizers is inadequate awareness among the farming community about bio inoculants and lack of promotion network and publicity among the end users. Therefore a strong training and awareness program for farmer motivation and wide publicity of the bio fertilizers available should be done through scientific training. **Pirttila *et al*. (2021)** stated the other major challenge in the use of bio fertilizers as inconsistent field performance. This, according to the study, can be overcome by using combinations of several different types of microbial strains consisting various members of the full plant microbiome. The objective of this review was to discuss the latest technical information at this point in time as a way of creating awareness in order to promote the use of bio fertilizers.

MATERIALS AND METHODS

Publon, Google Scholar, Science Direct and Microsoft Academic data bases were used to conduct the study in 2021. Only research and review articles published from 2019 onwards were considered as current information for this review. The basic key words in the literature search were "bio fertilizers" and "Scholarly articles on bio fertilizer formulation". Both experimental and non-experimental articles were used to provide the materials for the review. All articles that did not meet the criteria based on time of publication were excluded from this review. However, some articles with pertinent information on bio fertilizers but not showing the date of publication were included based on the notion that the information contained could be termed as fit for contemporary use.

RESULTS AND DISCUSSION

Acquisition of primary macronutrients via bio fertilizers

The primary macronutrients are Nitrogen (N), Phosphorus (P), and Potassium (K). Nitrogen (N) is the most essential nutrients for growth and productivity in plants **(Michelle (2021**; **Nusrat *et al*., 2021).** Although present in the atmosphere at 78%, Nitrogen remains unavailable for plant use. It must be converted to ammonia in order to be used by the plants. The plants assimilate it through the biological nitrogen fixing (BNF) process. This is accomplished by nitrogen fixing microbes that use enzymatic complex known as nitrogenase to convert atmospheric nitrogen to ammonia **(Nusrat *et al.*, 2021).** Nitrogen fixing microorganisms are classified as symbiotic and nonsymbiotic. The members of the Rhizobiaceae family are the symbionts while the free living Cyanobacteria are the nonsymbionts.

Phosphorus is one of the essential nutrients for plants growth and development. Phosphate solubilizing microorganisms, hydrolyze insoluble phosphorus compounds to the soluble form for uptake by plants. Many fungi and bacteria are used for the purpose such as *Penicillium*, *Aspergillus*, *Bacillus* and *Pseudomonas*. The efficiency of P in the soil can be increased by the use of phosphorus solubilizing microorganisms (PSM) which are able to solubilize phosphate into available forms **(Kalayu, 2019; Alaylra *et al*., 2020).** Phosphate-solubilizing bacteria (PSB) have beneficial effects on plant health and soil composition. Inoculation with these bacterial strains could promote the efficient cultivation and production of high quality plant materials **(Song *et al.*, 2021). Ma and Chen (2021)** have also reported that Nitrogen (N) and phosphorus (P) are the two predominant mineral elements, which are not only essential for plant growth and development in general but also play a key role in symbiotic N fixation in legumes. Nitrogen is a major component of chlorophyll and protein-building amino acids that are essential for plant health. However, changes in soil health and weather, along with decades of synthetic fertilizer application have left this natural process falling short of the needs of today's grower. Biological nitrogen fixation (BNF) is the microbial mediated process based upon an enzyme "Nitrogenase" conversion of atmospheric nitrogen (N2) into ammonium readily absorbable by roots **(Aasfar *et al*., 2021).** This process in rhizobia occurs primarily in root or stem nodules and is induced by the bacteria present in leguminous plants. The process uses solar energy to reduce the inert N_2 gas to ammonia at normal temperature and pressure making for sustainable food production **(Lindstrom and Mousavi, 2019).** N fixing microorganisms collectively termed as "diatrophs" are able to fix biologically N_2 in association with plant roots. **Aasfar *et al*. (2021)** further states that specifically the symbiotic rhizobacteria induce structural and physiological modifications of bacterial cells and plant roots into specialized structures called nodules. Nitrogen fixing is an energy-intensive process by which the enzyme nitrogenase converts atmospheric N_2 to ammonia (NH_3), which is readily available for assimilation by plants and the microbes themselves. The enzyme can be found in a small and diverse group of microorganisms called diazitrophs that include symbiotic and free living bacteria and archaea **(Moreira-Coello *et al*., 2019)**. A study was done by **Volkogon *et al.* (2021)** to evaluate the potential nitrogen fixation and denitrification in the rhizosphere soil of potato plants, crop yield and output quality in response to the different fertilization systems and inoculation with *Azospirillum brasillense* 410. The results indicated that despite its environmental expediency, inoculation combined with low fertilizer doses underperformed the action of inoculation combined with medium fertilizer rates. It showed that the latter as the compromise between the environmental requirements and crop productivity.

Phosphorus (P) is a major growth-limiting nutrient, and unlike nitrogen, it is not abundant as an atmospheric resource that can be made biologically available for root development, plant growth. In the soil phosphorous is found approximately 95-99% in the form of insoluble phosphates that cannot be utilized by the plants **(Vaishali and Chavada, 2021)**. Most soil P from soil is in occluded or insoluble form and therefore unavailable to plants. However soil microbes are capable of converting insoluble P into available forms (orthophosphate ions; H2PO^{-4} and HPO4^{2-}) through various mechanisms of solubilization and mineralization (**Soumare *et al*., 2020; Fitriatin *et al*., 2020).** Microbes can also release chelating compounds that capture and mobilize cations from different insoluble phosphates such as Ca^{+2}, Al^{+3} and Fe^{+3} resulting in the release of associated soluble phosphates (**Riaz *et al*., 2020**). The examples of bacteria with the capacity to solubilize P include *Pseudomonas, Bacillus, Rhizobium, Burkholeria, Achromobacter, Agrobacterium, Microccus, Aerobacter, Flavobacterium, Aspergillus* and *Erwinia* **(Nusrat *et al*. (2021).** According to **Ruiz *et al.* (2020)** the absorption of P nutrients is influenced by the ability of plant roots and plants as a whole because in some plants the root hair play an active role into the absorption of P.

Although Potassium (K) is a vital plant macronutrient, 98% of soil K is present in a non-exchangeable form that is trapped within crystal structures of minerals feldspar and mica with another 1-2% adsorbed onto clay particles and organic matter so that only 0.1-0.2% is directly available for plant uptake **(Srivastava *et al*., 2019).** A large number of potassium solubilizing microorganisms live in the soil and have been reported in different studies (**Sattar *et al.*, 2019**). These include some bacteria, such as *Bacillus mucilaginous*, *Azotobacter chroococcum*, and *Rhizobium* spp., which have been reported for potassium solubilization, resulting in increased maize, chili, cotton, pepper, sorghum, and wheat productivity (**Zhao *et al.*, 2019).** According to **Sattar *et al.*, 2019**, microorganisms are able to release K availability via solubilization in a mechanism similar to P solubilization by synthesis and discharge of organic acids such as tartaric, citric, oxalic, gluconic, lactic and malic acid that lead to the acidification of the surrounding environment and therefore the release (acidolysis) of K^+ from minerals **(Sattar *et al*., 2019).** In addition, several groups of soil bacteria such as *Bacillus, Rhizobium, Acidithiobacillus, Paenibacillus, Pseudomonas,* and *Burkholderia* and fungi such as *Aspergillus, Cladosporium, Macrophomina, Sclerotinia, Trichoderma, Glomus* and *Penicillium* can also solubilize K minerals **(Kour *et al.*, 2020).** Sulfur oxidation in the soil is carried out by a variety of archaea and bacteria such as *Xanthobacter, Alcaligenes, Bacillus, Pseudomonas, Streptomyces* and *Thiobacillus* as well as fungi including *Fusarium, Aspergillus and Penicillium* **(Macik *et al.*, 2020).** In agricultural plants, siderophore production by *Pseudomonas fluorescens* was shown to play a role in Fe nutrition in pea and sorghum **(Lurthy *et al*., 2020; Abbaszadeh-Dahaji *et al*., 2020). Pourbabaee *et al*. (2020)** reported the positive effect of *Thiobacillus* spp. on maize plants by increasing plant height, yield, and nitrogen uptake. Similarly, the positive effect of sulphur-oxidizing microorganisms on garlic plants was reported to increase plant height, fresh and dry leaf mass, as well as bulb weight and diameter. In a bid to get increased yields, farmers have always had recourse to the use of chemical fertilizers for the provision of the primary macro nutrients. However as it can be deduced from the foregoing discussion, microbes, and especially bacterial microbes have been shown to have a potential in the amelioration of soils if and when applied appropriately.

Acquisition of secondary macronutrients via bio fertilizers

Secondary macronutrients are also essential, even though they are consumed in smaller quantities than N, P, K, that is, primary macronutrients. The secondary macronutrients are Calcium (Ca) Magnesium (Mg) and Sulfur (S). Attempts to give plants the secondary macronutrients via foliar feeds has been the norm. According to a publication by the **University of Missouri (2019),** the practice of foliar feeding involves applying water-based fertilizers to the leaves of plants to enhance their nutritional status. Claims of yield increases up to 20 percent have been made based on the assumption that leaves are more efficient at taking up nutrients than are roots. This rationale dates back to research conducted at Michigan State University in the 1950's using radio-isotopes of certain essential mineral elements. However, the same publication by the **University of Missouri (2019)** reported that the larger molecules and ions of the secondary macronutrients with greater positive charges tend to stay fairly close to their point-of-entry as they adhere to the negatively-charged cell walls. Examples of fairly tightly held (immobile) nutrients include calcium (Ca++), iron (Fe++), manganese (Mn++), zinc (Zn++), and copper (Cu++). This makes the use of bio fertilizers for the acquisition of these secondary macronutrients imperative.

Recently, the application of sulphur-oxidizing microorganisms has been recommended in the formulation of bio fertilizer for onion, oats, ginger, grape, garlic, and cauliflower under alkaline soil conditions **(Macik *et al*., 2020).** Also, the effect of bio fertilizer made from a plant growth-promoting *Bacillus pumilus* strain TUAT-1 was evaluated on two forage rice genotypes. The result obtained suggested that bio fertilizer made from the *s* species increased rice productivity when compared to uninoculated **(Win *et al*., 2019).**

The microbial diversity of the rhizosphere is determined by the diversity and quantity of organic nutrients exuded, root system architecture, root branching order, root chemistry and is used by the biotic community including plants themselves **(Pervaiz *et al*., 2020).**

Zinc deficiency in crop plants can also be corrected by incorporation of microbes. Despite the fact that zinc is now incorporated into chemical fertilizers and applied along with NPK, most of the water soluble form (96-99%) is rapidly converted to insoluble forms leaving only 1-4% to be used by the plants **(Kushwaha *et al*., 2020).** Application of Zn-solubilizing microbes (ZSM) as biofertolizer was reportd to increase Zn in the soil **(Sammauria *et al*., 2020).** Zinc is an essential micronutrient. The results of zinc deficiency in plants are reduction in leaf size, chlorosis, increase in plant susceptibility to heat, light stress, and pathogenic attack **(Dubey *et al*., 2020).** The application of Zn fertilizers has been suggested to pose a threat to the environment **(Rajput *et al*., 2020).** Thus, the application of zinc solubilizing microorganisms as an alternative to Zn supply is gaining traction. Several strains of Zn solubilizing microorganisms have been applied in the production of bio fertilizers. These include *Pseudomonas* spp., *Rhizobium* spp., *Bacillus aryabhattai*, *Thiobacillus thioxidans*, and *Azospirillum* spp. **(Ijaz *et al*., 2019).** Solubilization of Zn by microorganisms depends on both soil pH and capacity of cation exchange. Application of Bacillus spp. AZ6, as a Zn solubilizing bio fertilizer on maize, was reported by **Hussain *et al*. (2020)** to have a positive impact on total maize biomass and increase plant physiology, chlorophyll content by 90%, and yield when compared to uninoculated plants. The effect of inoculation of these microorganisms enhances uptake of nutrients and production of the wheat plants with better quality. Additionally, the effect of zinc solubilizing bacterium *Bacillus megaterium* was recently reported by **Bhatt and Maheshwari (2021)** to increase growth parameters resulting in maximum zinc content in *Capsicum annuum* L. fruit.

Potential bio fertilizer microbes

The microbes that are used as bio fertilizers are N-fixing bacteria, P-solubilizing microorganisms, mycorrhizae and PGPR **(Chaudhary *et al.*, 2019).** Volatile organic compounds (VOCs) produced by PGPR play a crucial role in influencing systemic resistance in plants and inhibiting the effect of phytopathogens on plant productivity **(Raza and Shen, 2020).** In addition to the potential of plant growth-promoting microorganisms in enhancing water and nutrient uptake in plants, they also synthesize and secrete various compounds, among which are amino acids **(Hassan *et al*., 2019).** The major microbes that have been reported to have potential as bio fertilizers have been summarily classified as; free living nitrogen fixing bacteria, free living nitrogen fixing cyanobacteria, loose association of nitrogen-fixing bacteria, symbiotic nitrogen fixing bacteria and fungal bio fertilizers. Fungal bio fertilizers include plant growth stimulating fungi, compost producing enzymatic fungi, P-solubilizing fungi and K-solubilizing fungi.

Free-living nitrogen fixing bacteria

An example is and *Rhodospirillum*. *Azotobacter* protects the roots from pathogens present in the soil and plays a crucial role in fixing the atmospheric nitrogen. They are free-living nitrogen fixers found in all types of upland crops. They also provide certain antibiotics and growth substances to the plant. **Aasfar *et al*. (2021)** reported that some strains of *Azotobacter* (such as *Atropicalis tropicalis*, *Azorrhizophilus paspali* and *A. vinelandii*) have been characterized by their capacity to synthesize antifungal substances that inhibit the development of some phytopathogenic species such as *Helminthosporium* sp., *Macrophomina* sp., Fusarium *solani* and *Rhizoctonia solani*. *Azotobacter* has other important plant promoting traits such as nutrient use efficiency, and phytohormone biosynthesis **(Aasfar *et al*., 2021)**. Inoculation of maize plants with *Azotobacter* was found to improve growth in saline stress conditions by improving sodium exclusion and potassium uptake **(Latef *et al*., 2020).** *Azotobacter* based bio fertilizers possess unique characteristics such as cyst formation conferring resistance to environmental stresses. The abundance of *Azotobacter* in the soil has been reported to improve not only N availability but P as well **(Velmourougane *et al*., 2019; Azaroual *et al*., 2020).** According to **Rana *et al.* (2020),** there is strong evidence that *Azotobacter* members could colonize internally plant tissues, even if endophytic microbes are theoretically able to fix more N_2 as compared to rhizospheric microorganisms because of partial oxygen pressure in tissues compared to external surrounding soil. Despite various experimental data available on *Azotobacter* biostimulation traits on overall plant growth, the exact mode of action by which *Azotobacter* can enhance plant growth is not yet fully understood **(Sumbul *et al*., 2020).** According to **Reginawanti *et al.* (2020),** the mechanisms by *Azotobacter* in plant growth enhancement are as bio fertilizer, bio stimulant and bio protectant.

Free-living nitrogen fixing Cyanobacteria

They are the blue-green algae. These are free-living and nitrogen-fixing present only in wet and marshy lands. However they don't survive in acidic soils. *Anabaena* and *Nostoc* are a group of photosynthetic bacteria some of which are nitrogen-fixing that live in a wide variety of moist soil and water either freely or in a symbiotic relationship with plants or lichen–forming fungi (as in the lichen genus *Peltigera*). **Zahra *et al*. (2020)** reported that continual increase in human population and growing concerns related to the energy crisis, food security, and disease outbreaks, global warming and other environmental issues require a sustainable solution for nature such as cyanobacteria also known as the blue - green algae. These require simple ingredients to grow and possess a relatively simple genome. Their remarkable growth rates enable their potential use in a wide range of applications in the field of agriculture.

Loose association of nitrogen-fixing bacteria

Bacteria like *Azospirillum* that can carry out several PGP functions that are known to enhance N availability and acquisition in more than 113 plant species **(Zeffa *et al*., 2019).** In Fabaceae, *Azospirillum* is used in association with *Rhizobium* bacteria to promote biological nitrogen fixation, making the plant tolerant to water stress and resulting in better nutrient utilization, obtaining a plant more productive and vigorous and increase roots for better nutrient uptake **(Franko *et al*., 2020).** *Azospirillum,* unlike *Azotobacter*, can be utilized in wetland areas. They are found inside roots of plants (non-free-living) where they fix the atmospheric nitrogen. On the other hand, *Rhizobium* form nodules in leguminous plants and fix the atmospheric nitrogen into an organic form. They also have no negative effect on the soil quality and improve nutrient content and therefore plant growth. According to **Mendoza-Suarez *et al.* (2020)**, increasing legume use and maximizing the in agriculture requires matching the plant to elite *Rhizobia* that are both competitive for nodulation and capable of high rates of nitrogen fixation. In another study by **Schaefar *et al.* (2019)** to evaluate the effect of corn seed inoculation with *Azosporillum brasilense* under different nitrogen levels and post–grazing residual heights, *A. brasilense* was found to help plant growth and yield but did not replace the effect of N fertilization.

Symbiotic nitrogen-fixing bacteria

According to **Mahmud *et al*. (2020),** in agro ecosystems, nitrogen is one of the major nutrients limiting plant growth and to meet the increased nitrogen demand, synthetic and environmentally unsound fertilizers have been used. Biological nitrogen fixation (BNF) by legumes and associative, endosymbiotic and endophytic nitrogen fixation in non-legumes play major roles in reducing the use of synthetic nitrogen fertilizers. One of the most common applications is the co-inoculation of rhizobia and AMF on legumes that show synergistic effect on plant growth promotion **(Kamaei *et al*., 2019**). There is also the added advantage of disease control with *Rhizobium*. *Bradyrhizobium* has been found to produce antibiotics, secrete enzymes that can degrade the cell wall of plant–pathogen and produce hydrogen cyanide and siderophores in its bio control traits and at the same time increase growth parameters and seed yield in mungbean plants **(Garcia *et al*., 2019).** However, examples in the literature show negative effects of AMF on nodule development or non-significant effects on crop yield **(Mendez and Paco, 2020).** Nodule formation is enhanced by the low availability of nitrogen, but microorganisms that produce an enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase, have the potential to degrade 1-aminocyclopropane-1-carboxylate before its conversion to ethylene **(Kour *et al*., 2019**) and may also enhance the formation of a nodule. Such formation is part of a common strategy developed by leguminous plants and Rhizobiaceae bacteria to decrease the concentration of oxygen to which the nitrogenase is exposed due to the inhibitory effect of oxygen on nitrogenase activity. However, there are other nitrogen-fixing microorganisms, such as those of the *Acetobacter* genus, able to fix nitrogen even under aerobic conditions. Various studies have been carried out on rhizobacteria and their reported potential as bio fertilizers and bio control agents are presented in Table 1.

Table 1 Some rhizobacteria used in bio fertilizer production, bio control traits, and their effect on plant productivity **(adopted from Fasusi *et al*., 2021)**

Microbial Strains	Plant Growth-Promoting Traits	Biocontrol Traits	Effect on Plant Productivity	References
Bradyrhizobium sp.	Production of siderophore, indole acetic acid, nitrogen fixation, phosphate solubilization	Production of antibiotics, enzyme that can degrade the cell wall of plant–pathogen, hydrogen cyanide, siderophore	Increases growth parameters and seed yield in mungbeans plant	**Garcia *et al.* (2019)**
Rhizobium meliloti	Production of siderophore, nitrogen fixation	Production of antibiotics against Phytopathogens, chitinases	Increases peanuts growth, yield attributes, quality of pods, and efficiency in the use of nitrogen	**Mondal *et al*. (2020)**
R. leguminosarum	Phosphate solubilization	Production of antibiotics, enzyme that can degrade the cell wall of plant pathogens, enhanced production of phytoalexins in plant	Increases growth of soybean and yield performance under drought stress	**Igiehon *et al*. (2019)**
Bacillus spp.	Production of phytohormone, such as auxin, phosphate solubilization	Formation of endospore and biochemical compound against phytopathogens, induces systemic resistance and competition in plant	Increases strawberry fresh and dry weight parameters, increases yield over the control plant	**Ali *et al*. (2019)**
Chryseobacterium sp.	Production of siderospores, phosphate solubilization	Production of proteases	Increases grain yield, shoot mass, and nodule mass in chickpea	**Glick (2020b)**
Herbaspirillum spp	Synthesis of indole acetic acid, nitrogen fixation	Production of siderophore	Enhances mineral uptake in maize plant and increases yield	**Avila *et al.* (2020)**
Phyllobacterium	Production of siderophore	N/A	Increases grain yield in sorghum	**Breitkreuz *et al.* (2020)**
Enterobacter cloacae	Nitrogen fixation, phosphate solubilization, siderophore production	Production of the lytic enzyme for chitinolytic activity, production of ACC deaminase	Enhances potato growth and promotes yield performance	**Macedo-Raygoza *et al.* (2019)**
Erwinia	Phosphate solubilization	Ethylene synthesis	Promotes growth and yield parameters in wheat	**Paiter *et al*. (2019**)

Other important functions of bacteria

In a study with halophytes (plants that are adapted to grow in saline soils), **Kearl *et al.* (2019)** isolated bacteria from the rhizosphere and as root endophytes of *Salicornia rubra*, *Sarcocornia utahensis* and *Allenrolfea occidentalis* and identified by 16S rRNA gene sequencing analysis and tested for maximum salt tolerance. The results showed that they were able to grow in the presence of up to 4M NaCl. Further studies suggested that *Halomonas* and one *Bacillus* isolate when

used to inoculate young alfalfa seedlings stimulated plant growth in the presence of 1% NaCl, a level that significantly inhibits growth of uninoculated plants.
Cellulolytic enzymes such as monospecific endo-β-1,4-glucanase were obtained from rhizosphere soil through a metagenomics-based strategy for bioethanol production **(Wierzbicka-Wo´s et al., 2019).** Cellulolytic bacteria such as *Erwinia, Sporocytophaga, Ruminococcus, Clostridium, Fibrobacter*, and *Cellulomonas* from the rhizosphere degrade cellulolytic materials containing small amounts of lignin **(Rai *et al*., 2019).** Significantly, the degradation mechanism of lignocellulose by aerobic and anaerobic bacterial species differs due to its macromolecular arrangement **(Valliammai *et al*., 2021).**
Xu *et al.* (2020) did some work on bioremediation using bacteria. The result from this investigation revealed that the rhizosphere soil absorbed Pb up to 97.31 ppm and 188.3 ppm Cu. They concluded that the rhizosphere remediation using *C. ciliaris* is a compelling and effective green innovation for remediation of heavy metals from soil. They used cadmium (Cd^{2+}) resistant *Pseudomonas* sp. strain 375 from heavy metal polluted rhizosphere soil as an adsorbent to remediate water body polluted with Cd^{2+}. *Pseudomonas* sp. was used as an inexpensive and potential bio adsorbent for bioremediation of Cd^{2+} from wastewater.

Fungal bio fertilizers

According to **Bisma *et al.* (2021),** fungi are useful in light of the fact that they can break down organic matter and discharge them into the soil. Significant development of the plant can occur when fungi live in symbiotic association with the plant. This is an advantageous association called mycorrhizal. The fungi give the plant required nutrients while they gain sugars from the plant. Mycorrhiza can thus be defined as a symbiotic association between the fungi and the roots of a plant. Mycorrhizal fungi play a key role in enhancing the uptake of water and nutrients, such as phosphorus from the soil, which is needed for plant growth and productivity. Similarly, the inorganic phosphate transporter (Pi) in mycorrhiza, *Glomus versiformis* hyphae was reported to enhance the absorption of phosphate from the soil to the host plant **(Parihar *et al*., 2020).** Mycorrhizal fungi may also facilitate the detoxification of both organic and inorganic soil pollutants that may harm plant productivity. They bind the soil together to improve the activity of microbes. They also help the plants to survive under various environmental stresses. Over the last decades, several companies manufactured and commercialized arbascular mycorrhizal fungi (AMF) inoculants and the global mycorrhiza-based bio fertilizer market is projected to be worth 621.6 USD by 2025. These products are especially being encouraged in Asia Pacific regions such as India and China **(ReportLinker, 2020).** Besides AMF other root colonizing dark septate endophytes (DSE) mostly belonging to the phylum Ascomycota have the benefit ranging from stress and disease tolerance to nutrient acquisition (**Spagnoletti and Giacometti, 2020).** Endomycorrhizal fungi are very important actors for improving phosphorus bioavailability, and some genera (*Scutellospora, Glomus*, *Acaulospora,* and *Gigaspora*) are already in use as bio fertilizers. Since the fungal hyphae can penetrate the soil pores, sites where the root system cannot reach, the mycorrhizal plant root can efficiently explore a bigger soil volume than non-mycorrhizal plants **(Pandey *et al*., 2019).**
The application of mycorrhizal fungi in agriculture is low cost and eco-friendly and increases plant yield when compared to the cost of purchase of chemical fertilizers without any negative effect on the environment **(Begum *et al*., 2019).**

Table 2 Contribution of arbuscular mycorrhizal fungi to plant growth promotion and soil nutrients

Mcorrhizal fungi	Plant	Effect on plant	Effect on soil	Reference
Glomus versiforme Glomus mosseae	Tomato	Promotes growth and yield under water stress and more efficient conditions	Increases phosphorus concentration in the soil	**El Maaloum *et al*. (2020)**
Glomus etunicatum	Maize	Improves chlorophyll content and nutrient uptake in maize	Increases soil quality	**Xu *et al*. (2019)**
Acaulospora lacunosa	Strawberry	Enhances nutrient uptake in strawberry	Increases soil nutrient for horticultural crops productivity	**Chiomento *et al*. (2019)**
Glomus spp. and *Mortierella* spp.	Seashore mallow	Increases shoot and root weight under salt stress	Increases soil nutrient and enhances its absorption by plants	**Mota *et al.* (2019)**

There are several other important components of bio fertilizer including bio-compost, vermicompost and termite mound soils that are important in soil fertility improvement

Bio Compost

Bio compost is eco - friendly and organic fertilizer received as a result of decomposition of different organic substances through the activity of microorganisms, created by composting of bird droppings and other substances during the process of aerobic solid state fermentation. It contains no pathogens, helminth eggs and weed seeds. It contains a unique community of microorganisms useful for soil and plants. When these microorganisms are added to the soil they inhabit it, excrete phytohormones, antibiotics, fungicidal and antibacterial compounds that displace pathogenic microflora, improve soil and eliminate many wide-spread plant diseases. This organic fertilizer is intended for use in farming, farm and backyard plots. It is used for growing of plants of all types of agricultural crops, flowers, fruit, decorative and small-fruit crops, for growing of sprouts of all types of vegetable, flower and fruit crops, pottery decorative plants, for creating of decorative lawns as well as improving of agrochemical properties of soil in all climatic zones. It is easily and gradually assimilated by plants during their life cycle and can be used in any soils and any season. According to **Ming and Ahmad (2020),** composited green waste is a recycled material which can be produced locally, adding value to the environmental credentials. As the organic component of green roof growing media, composited green waste can contribute positively to the physical requirements as well as improve environmental performance in addition to containing nutrients for plant growth. Vegetable market have become major sources of organic waste **(Murugesan and Amarnath, 2020).** Some of such waste when being diverted to landfills not only increase the landfill loading but also contribute to increased greenhouse gas emission. Compositing, according to **Murugesan and Amarnath (2020)** has proven very effective.

Vermicompost

According to **Kavita and Garg (2019),** vermicomposting is regarded as a clean, sustainable, and zero-waste approach to manage organic wastes. Vermicomposting on a large scale is required to solve the problem of waste disposal effectively and on a global level. One of the major constraints is the lack of awareness and proper knowledge regarding vermicomposting and the use of vermicompost. **(Kaur, 2020)** reported that vermocomposting is a low cost, eco-biotechnological process of waste management in which earthworms are used to cooperate with microoganisms in order to convert biodegradable wastes into organic fertilizer. Earthworm excreta (vermicast) is a nutritive organic fertilizer rich in humus, NPK, micronutrients, beneficial soil microbes, nitrogen fixing, phosphate solubilizing bacteria, actinomycets, and growth hormones. It is an Eco-friendly organic fertilizer comprises of vitamins, hormones, organic carbon, sulfur, antibiotics that help to increase the quantity and quality of yield. Vermicompost is one of the quick fixes to improve the fertility of the soil. **Cortivo *et al.* (2020)** investigated the effects of three commercial bio fertilizers on rhizosphere bacterial biomass, biodiversity and enzymatic activity and on wheat plant growth and grain yield in a field trial. The microorganisms used were; (i) a bacterial consortium (*Azospirillium* spp. + *Azoarcus* spp. + *Azorhizobium* spp.) (ii) *Rhizophagus irregularis* + *Azotobacter vinelandii* and (iii) *R. irregularis* + *Bacillus megaterium* + *Fratueria aurantia.* The comparisons were made with non-inoculated controls. The results suggested that seed applied bio fertilizers may be effectively exploited in sustainable wheat cultivation without altering the biodiversity of the resident microbiome and that attention should be paid to the composition of the microbial consortia in order to maximize their benefits in crop cultivation. In another study, **Wang *et al.* (2021)** investigated the effect of bio fertilizers on the structure and diversity of the rhizosphere bacterial community of maize. The results suggested that treatment with *Bacillus licheniformis* and *B. amyloliquefaciens* as bio fertilizers increased the soil organic matter, total nitrogen, total phosphorus, available phosphorus and available potassium contents indicating that plant-growth promoting rhizobacteria in the bio fertilizers might help the host plant to produce exudates that in return recruit beneficial communities due to available sugars, amino acids, vitamins and polymers.

In flower production, microbial cultures were applied to the corms at planting time using the dip method followed by shade drying before planting. This not only helped in improvement in nutrient uptake by the plants, releasing of growth hormones and antibiotics but also improved the quality of produce along with reduced cost of production **(*Slathia et al*., 2021).** In dry lands, the soil usually has low organic matter content, low macro nutrients and low microbial activity and in improving soil quality, it is necessary to increase nutrients availability via bio fertilizers **(Fitriatin *et al*., 2021).**

Termite mound soil

Enagbonma and Babalola (2020) studied the potential of bacteria in termite mound soil as bio fertilizer and suggested it as a promising tool for sustainable agriculture. Many termite colonies construct large mounds built from soil material or build their nest in soil **(Chiri *et al.*, 2020).** Agricultural and wood residues produced after harvesting and processing of plants are abundant biomass on earth, and these biomass resources have remarkable energy capacity **(Chen *et al*., 2020)**. Termites are key in breaking down these materials. When constructing these mounds, the termite perform a significant contribution in upholding soil's chemical and physical properties by excavating and breaking down organic materials. Additionally, the guts of termites contain numerous microscopic single-celled organisms of which several are principally bacteria that can too help in many metabolic processes like decomposition of organic matter. The genus of bacteria present in termite guts are such as *Lactobacills. Peptococcus, Eubacterium, Fusobacterium* and *Bifidobacterium*. These bacteria could serve as a remarkable means of reducing the reliance on the usage of chemical fertilizers and pesticides in farming thereby increasing crop yield **(Enagbonma and Babalola (2020).**

Formulation of bio fertilizers

Application of bio formulated plant beneficial microorganisms is accepted as an effective alternative of chemical agro-products **(Vassilev *et al*., 2020).** Formulation is a crucial step in the production of a bio fertilizer since it has to maintain the viability of the microorganism used while maintaining its activity at low levels **(Soumare *et al*., 2019).** The formulation of bio fertilizer has efficiently enhanced agricultural productivity by increasing high retention in soil moisture content and increasing essential nutrient due to the direct and indirect effects of nanomaterial coating on plant growth-promoting microorganisms, and its application has been reported to increase yield performance in cereal and leguminous plants by stimulating the germination potency in plants **(Kumari *et al*., 2019).**

Microbial consortia (MC)

According to **Chuks *et al*. (2020),** microbial formulations could be organism-specific or a consortium of organisms. Microbial consortium bio fertilizers have been reported as contributing significantly to plant adaptation to various abiotic stressors in "extreme" habitats. Many soil microorganisms are endowed with an array of capabilities ranging from production of growth-enhancing substances to the release of substances which ameliorate the effects of various abiotic stress conditions such as drought, salinity, pH stress, heat stress, pollutants, and nutrient deficiency. Besides exploring the MC bio fertilizer operations and mechanisms, it also relies on a network of intraspecific and interspecific interactions for sustainable growth and development of crops in challenged environments. Among these organisms are plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), mycorrhizal-helping bacteria (MHB), and a host of others that work together in consortium bio fertilizer formulations.

The spatial organization of microbial communities arises from complex interplay of biotic and abiotic interactions, and is also a determinant of ecosystem function. Studies by **Gupta *et al*. (2020)** have shown that the interaction network and stability of the communities are highly sensitive to temporal perturbations and spatial arrangements **(Cao *et al*., 2019).** Studies by **Murkherjee and Bassler (2019)** and **McBride and Strickland (2019)** have shown that microbes communicate via chemical signals to monitor their population size, coordinate gene expression and efficiently allocate intracellular resources. These quantitative features of microbial interactions are critical to understanding and engineering multi-species community stability and diversity **(Ratzke *et al*., 2020).**

Bio fertilizers and plant health

Plant diseases may be controlled through the application of chemical fungicides, insecticides, and herbicides. The application of these pesticides in pest management is a crucial aspect of modern agricultural practice. However, their excessive use is hazardous to the environment and poses a threat to human health and living organisms **(Meftaul *et al*., 2020).** Thus, the use of beneficial microorganisms in controlling pests has gained more attention because of its potential to be eco-friendly and cost-effective **(Sammauria *et al*., 2020).** More importantly, research is emerging on the application of beneficial microorganisms as a substitute to control the negative effects of pesticides. Plant growth-promoting microorganisms have been subjected to various investigations for their implementation as biopesticides in protecting the environment and forestry. The application of some microbial strains in the formulation of bio fertilizer to enhance plant yield also protects plants against pathogenic diseases, either directly by preventing the proliferation of plant pathogens or indirectly by competition for nutrients. Currently, a report has shown the effectiveness of microorganisms, such as *Azotobacter, Bacillus, Enterobacter, Paenibacillus*, and *Pseudomonas,* in reducing pesticide toxicity **(Shahid *et al*., 2019).** Interestingly, the symbiotic association of nitrogen-fixing microorganisms with a leguminous plant promotes the synthesis of cyanogenic defense compounds that prevent herbivore attacks on the plant **(Naseer *et al*., 2019).** One of the major factors that affect plant productivity is the attack by phytopathogens. Thus, the application of beneficial microorganisms that produce antimicrobial substances, such as chitinases and β-glucanases, in high concentration assist in limiting disease attack in plants **(Suresh and Abraham, 2019).** *Pseudomonas fluorescens* and *Sinorhizobium* produce chitinase and β-glucanases when used in the formulation of bio fertilizers and can suppress *Fusarium* wilt and soft rot in potato caused by *Fusarium udum* and *Erwinia carotovora*. Recently, the application of *G. intraradices* has been reported by **Deja-Sikora and Kowalczyk (2020)** to improve potato yield and suppress the attack of the potato virus in the plant tissue. Similarly, **Beris and Vassilakos (2020)** reported that inoculation of tomatoes with *G. mosseae* suppresses the effect of tomato yellow leaf curl Sardinia virus (TYLCSV).

CONCLUSION

This paper has brought to the fore the need to improve rhizosphere management in a sustainable way particularly at this point in time when there are strong indications that it has deteriorated in the face of continued use of chemical fertilizers. The paper has shown that the roles of these microorganism are not limited to making available essential nutrients but also work to improve the plant's salt tolerance for enhanced growth and increased yields. It can be concluded that there is a need to understand the composition of the soil microbiome and their core function in their role as important in unveiling their networking strategies and their potential influence on plant performance. The inconsistent responses over different soils, crops and environmental conditions, challenges in mass production, shelf-life, appropriate recommendations and ease of use by the farmers could be redressed if the farmers embrace the knowledge brought forth by this review if they could keep themselves updated by reading it. The type of bio fertilizers to choose for the different soils, the kind of formulation materials to select along with the microbial consortia to use can be known by the farmers as a way of beating the challenges in bio fertilizer application.

The process of improving the nutrient efficiency in the soil in order to enhance the elements needed for plant growth and improved yield is imperative if sstainable agriculture has to be undertaken.

These bacteria from the rhizosphere soil can be harnessed and used in an ecofriendly approach as promising biotechnology for the production of antimicrobials, and can serve as biocontrol, bioremediation, and bio fertilization agents, thereby improving soil health, soil fertility and crop yield, and ensuring environmental sustainability. The paper has laid emphasis on the factthat the problem of limited shelf-life and the survival of inoculated strains in different environments can be solved by formulating the microbes in appropriate and materials such as maize and wheat bran that are easily available.

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