UMYU Scientifica, Vol. 3 NO. 1, March 2024, Pp 208 – 214
https://doi.org/10.56919/usci.2431.023
ISSN: 2955 – 1145 (print); 2955 – 1153 (online)
A periodical of the Faculty of Natural and Applied Sciences, UMYU, Katsina

REVIEW ARTICLE

The Attributes of Biofertilizer as an Alternative to Chemical Fertilizer: A Mini Review

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ABSTRACT

Traditional soil management relies heavily on inorganic fertilizers, raising environmental and health concerns. A fertile soil requires a precise ratio of inorganic and organic components, with topsoil crucial for plant growth. Essential plant elements include macronutrients (nitrogen, phosphorus, potassium) and micronutrients (zinc, iron). Soil composition must balance minerals, air, water, and living matter. Macronutrients (nitrogen, phosphorus, potassium) are pivotal in plant growth. Potassium influences water regulation, root development, and crop resilience. Phosphorus, crucial for seed development, is essential for legume development. Nitrogen from nitrates, ammonium, and urea is indispensable for protein synthesis and overall plant growth. Biofertilizers, containing active microorganisms, offer an alternative to inorganic fertilizers. They enhance soil fertility, water and nutrient uptake, and plant tolerance to environmental variables. Nitrogen-fixing bacteria, phosphate solubilizing microorganisms (PSM), silicate solubilizing bacteria (SSB), plant growth-promoting rhizobacteria (PGPR), and arbuscular mycorrhizal fungi (AM fungi) are common groups of bacteria that play different specific roles in defining biofertilizer. Bacterial genera such as *Rhizobium* (a symbiotic nitrogen fixer known for forming nodules on legumes), *Azotobacter* (a free-living nitrogen fixer known for enhancing sugar content in crops), *Azospirillum* (a bacterium known for enhancing nitrogen content in non-leguminous plants) and Anabaena-Azollae (a symbiotic relationship between a cyanobacterium and lower plants known in fixing nitrogen and promotes growth in various crops). As agriculture continues to evolve, embracing biofertilizers represents a promising step toward a more sustainable and resilient future.

ARTICLE HISTORY

Received July 28, 2023.
Accepted March 02, 2024.
Published March 30, 2024.

KEYWORDS

Biofertilizer, Soil, Plant, Soil fertility, Nitrogen fixers.

INTRODUCTION

Since the 12th century, agriculture has advanced significantly, and is now widely practiced worldwide (Vink, 2013). One-third of all workers worldwide were employed in agriculture in 2007. According to Food and Agricultural Development, agriculture provides a living for 55% of Africans (Fabiyi, 2007). Nigerians only rely on agriculture as their major source of income in many parts of the country's rural communities (Watts, 2013).

Recent techniques in soil management depend mostly on fertilizers with an inorganic formulation, and this has led to problems for the health of humanity and the environment (Bhardwaj, 2014). Fertilizers are organic or inorganic substances that, when applied to plants within the soil, can transform the proper and healthy growth of the plants (Thomas and Singh, 2019). They supply plants with abundant nutrient requirements such as molybdenum, iron, boron, copper, and zinc, as well as significant macronutrients, such as magnesium, nitrogen, calcium, sulfur, potassium, and phosphorus (Bhatla, 2018).

Plant nutrients are necessary for crop cultivation and providing healthful food for the world's rising population (Itelima *et al*., 2018). Bio-fertilizer has been identified as an alternative for boosting soil fertility and crop yield in sustainable farming. Increased nutrient and water uptake, plant development, and plant tolerance to abiotic and

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How to cite: Ibrahim, U. B., Fardami, A. Y., Sabitu, M., Aliyu, A., Jodi, A. M., Hauwau, H., Lawal, I., Isah, M., & Dalhatu, A. I. (2024). The Attributes of Biofertilizer as an Alternative to Chemical Fertilizer: A Mini Review. *UMYU Scientifica*, 3(1), 208 – 214. https://doi.org/10.56919/usci.2431.023

biotic variables are all benefits of using these biofertilizers. These potential biological fertilizers would be essential for soil production, sustainability, and environmental conservation because they are eco-friendly and economical inputs for farmers (Basu *et al.*, 2021). The use of beneficial microorganisms as bio-fertilizers has become crucial in the agricultural sector because of their potential to improve crop output and food safety (Itelima *et al.*, 2018). This mini-review aimed to highlight biofertilizer's attributes as an alternative to chemical fertilizers.

FERTILITY OF THE SOIL

The area of the ground where plants grow is referred to as soil (Purves *et al.*, 2000). Topsoil, subsoil, and parent material are the three layers that constitute its structure. But since the topsoil encourages plant growth, we are more focused on that area. In addition to minerals, air, water, living beings, and living matter, fertile soil must have a precise ratio of inorganic and organic components and a pH of at least roughly 6.5. Purves et al. (2000) state that good grade soil contains 45% minerals (sand, silt, and clay), 25% water, 25% air, and 5% organic and living material. Minerals, including silica, aluminum, and iron oxides, make up roughly 93% of the soil volume.

There are also extremely minute amounts of many other elements, including zinc (Zn), nitrogen (N), molybdenum (Mo), chlorine (Cl), phosphorous (P), sulfur (S), copper (Cu), Boron (B) and Manganese (Mn), etc. However, only fourteen of these minerals, known as essential elements, are required by plants (Purves *et al.,* 2000).

MICRO AND MACRONUTRIENTS

The essential nutrients are separated into macronutrients and micronutrients, according to Barak (1999). Plants require more macronutrients than micronutrients, which are needed in much smaller amounts. Although macronutrients are made up of substances like nitrogen, potassium, magnesium, calcium, phosphorus, and sulfur, micronutrients are made up of substances like chlorine, iron, boron, manganese, and zinc. The macronutrients are further divided into secondary macronutrients and primary macronutrients, which are always in short supply in the soil (those that are rarely limited). The three primary nutrients are nitrogen, phosphorus, and potassium.

Potassium

After nitrogen, this element is crucial to plant growth. Potassium affects the water economy and crop growth due to how it affects water intake, root development, turgor maintenance, transpiration, and stomatal regulation (Mfilinge *et al.*, 2014). The following are some of the functions of potassium:

i. Improves plants' resilience to bacterial and fungal infections and their ability to survive cold temperatures.

ii. It causes the cell walls of cereal grains to thicken by accelerating the synthesis of high molecular carbohydrates.

iii. It promotes the production and accumulation of particular vitamins in plants and catalyzes the activity of some enzymes (such as thiamin and riboflavin).

iv. It is essential for guard cell activity and aids some plants in increasing the number of guard cells (Barak, 1999; Ifokwe, 1988).

Potassium ions (K+), which are insoluble in water, are absorbed by plants. Fertilizer, decomposing organic materials, and wood ash all add to the soil. Ifokwe (1988) said potassium deprivation affects plant metabolism, inhibits the functioning of particular enzymes, and interferes with the metabolism of proteins and carbohydrates. The author also claimed that a lack of potassium affects the viability of seeds, makes plants more susceptible to illnesses, and makes it challenging to maintain harvested plants in sellable condition. Additional elements that plants need in great amounts are oxygen, carbon, and hydrogen. They are plentiful since they can be obtained from air and water (Barak, 1999). The interaction of light, air, water, micro and macronutrients, and pH has been found to impact the overall crop yield.

Phosphorus

Although phosphorus is required in less proportion than nitrogen and potassium, it is still required in high amounts. It encourages nodule number and mass, and legume development and yield. Its roles include the increase of crop yield and quality, phospholipids in membranes, and phosphoproteins for life processes. It is crucial to the development of seeds. According to research, it comprises a sizeable portion of seeds and fruits (Scalenghe *et al.*, 2012). Plants take up phosphates, which are released into the soil through fertilizers like bone meal and superphosphates. Phosphorus is phloem mobile. Therefore deficiency symptoms can be seen all across the plant, claims Barak (1999), but still, its deficiency is frequently linked to delayed maturation and limited growth.

Grassy plants, like corn, exhibit leaf reddening in severe situations. Scalenghe *et al.* (2012) claim that too much phosphorus is bad since plants can't adequately absorb it since most phosphorus is inorganic. Early plant maturation and low crop production are signs of excess phosphorus in plants.

Nitrogen

The production of alkaloids and miscobiochemicals like mescaline and quinine, as well as base pair formation for RNA and DNA, protein phosphate group formation (for example, the hemp group of chlorophyll), hormones like cytokines, metal uptake, transport in xylem and phloem (for example, copper with amines), and osmoregulation (for example, in lettuce and spinach) are all functions of nitrogen, one (Barak, 1999). Ifokwe (1988) claimed that plants occasionally absorb nitrogen in the form of nitrates, ammonium, and urea.

Moreover, fertilizer, biological N fixation, fertilizer runoff, rain and thunder, and the decomposition of organic items all contribute nitrogen to the soil. According to Barak (1999), plants short in nitrogen show signs of delayed growth and light green or yellow leaves. One of the most severe deficiency symptoms is necrosis, forming a "v" shape at the tip of older leaves.

BIOFERTILIZERS

In essence, a bio-fertilizer is a chemical that contains active microorganisms. Increasing the supply or availability of nutrients to the host plant encourages seeds or plants to penetrate the rhizosphere and stimulate development when applied to soil (Vessey, 2003). Also, it is a more sophisticated organic fertilizer that includes helpful microbes (Swathi, 2010). For marginal and small farmers, biofertilizers are more economical than chemical fertilizers. Most microorganisms used to produce microbial biofertilizers belong to the bacterial, fungal, and cyanobacterial phyla and are symbiotic with plants (Thomas and Singh, 2019).

COMMON MICROORGANISMS USED AS BIOFERTILIZER

The control of integrated nutrients is important for bio-fertilizers. Among the microbes that are widely used as biofertilizer components are nitrogen fixers, potassium and phosphorus solubilizers, growth-promoting rhizobacteria (PGPRs), endo and ectomycorrhizal fungi, cyanobacteria, and other beneficial microorganisms (Itelima *et al.*, 2018).

NITROGEN FIXERS

The most restricting ingredient for plant growth is nitrogen (Edwards, 1977). Around 80% of the nitrogen in the atmosphere exists as free nitrogen, but most plants cannot utilize this nitrogen (Bhattacharjee *et al.*, 2008). A certain group of microbes must fix this nitrogen before making it available to the plant. These organisms fall under the category of biological nitrogen fixers (BNFs). They transform inert nitrogen into a plant-friendly organic form (Bhat *et al.*, 2015). Fixing nitrogen can supply 300-400 kg N/ha/yr and increase crop production by 10–50%. N-fixation provides up to 25% of the total nitrogen in plants. Chemicals that the plant roots emit into the soil help to stimulate bacterial colonization of the rhizosphere and nitrogen fixation. They can efficiently substitute chemical fertilizers to varying degrees, reducing the chemical load on the environment.

Blue-green algae, symbionts like *Rhizobium, Frankia*, and *Azolla*, and free-living bacteria like *Azotobacte*r and *Azopirillium* are the three groups they fall into. N2-fixing bacteria that are connected to legumes include *Rhizobium*, *Mesorhizobium*, *Azorhizobium*, *Bradyrhizobium, Sinorhizobium*, and *Allorhizobium;* those connected to non-legumes include *Achromobacter, Alcaligenes, Arthrobacter, Acetobacter, Azomonas, Beijerinckia, Clostridium, Bacillus, Enterobacter, Erwinia*, and (Nosheen *et al.*, 2021). Although many additional species have been isolated from the rhizosphere, representatives of the genera *Azospirillum* and *Azotobacte*r have been widely studied for their capacity to increase the yield of cereals and legumes under field circumstances (Mohammadi and Sohrabi, 2012). The following is an overview of the main N_2-fixing bacteria.

The Rhizobium (Symbiotic Nitrogen Fixer)

Rhizobium, a bacterium in the family *Rhizobiaceae*, is the greatest example of symbiotic nitrogen fixation. It can also fix N2 in crops other than legumes. *Rhizobium* has been proven to fix up to 300 kg N/ha/year in a number of legume crops (Nosheen *et al.*, 2021). The bacteria infect the roots of the legumes and produce nodules, which the plant uses to produce proteins, vitamins, and other compounds containing nitrogen by breaking down molecules of nitrogen into ammonia. These root nodules act as ammonia producers (Stambulska *et al.*, 2018). Non-legumes develop faster because *Rhizobium* species encourage changes in root shape and growth physiology. The application of *Rhizobium* increased crop development by enhancing plant height, seed germination, leaf chlorophyll, and N content (Mia and Shamsuddin, 2010).

Rhizobium, Bradyshzodium, Sinorhizobium, Azorhizobium, and *Mesorhizobium* are *Rhizobia.* They can operate directly by fixing nitrogen, changing plant hormones, or indirectly by reducing the inhibitory effects of pathogens (Nosheen *et al.*, 2021*). Rhizobium* is frequently used in agronomic methods to ensure adequate nitrogen levels because around 80% of biologically fixed nitrogen comes from symbiosis, and it has the potential to replace chemical nitrogen fertilizers (Mabrouk *et al.*, 2018).

Azotobacter (free-living, nitrogen-fixer)

A diazotrophic, free-living, nitrogen-fixing bacterium called *Azotobacter* plays a crucial metabolic part in the nitrogen cycle (Aasfar *et al.*, 2021). All non-leguminous plants, particularly rice, cotton, vegetables, sugarcane, sweet potatoes, and sweet Sorghum, use it as a biofertilizer. It belongs to the family *Azotobacteriaceae.* Although it increases sugar content by 10% and cane productivity by 25–50 tons/hectare, it is mostly used commercially for cane crops. Furthermore, it repairs around 30 kg/N/year. Both acidic and alkaline soils contain a bacterium called *azotobacter* (Nosheen *et al.*, 2021).

Azospirillum (free-living, nitrogen-fixer)

Azospirillum spp. is one of the most productive N2 fixers in the field when all the prerequisites for biological nitrogen fixing are satisfied. Most studies on *Azospirillum* inoculation have shown that nitrogen fixation was the main mechanism of plant development (Saikia *et al.*, 2012). The nitrogen content of crops including sugarcane, Panicum maximum, and Paspalum notatum may be up to 50% supplied by related nitrogen fixers, particularly *Azospirillum* spp., according to Sivasakthivelan and Saranraj (2013). This bacterium is particularly important because of the sizeable amount of nitrogen that it fixes in the soil. It fixes up to 20 to 40 kg of nitrogen per hectare in non-leguminous plants like grains, millets, oilseeds, cotton, and Sorghum because it is related to the rhizosphere (Krishnaprabu, 2020). Most of its interactions with plants are symbiotic. Several studies have shown that *azospirillum* can benefit crops (Sahoo *et al.*, 2012).

Anabaena Azollae (free-living, nitrogen-fixer)

It is a symbiotic bacterium that is primarily utilized to fix atmospheric nitrogen in rice growing (Dent and Cocking, 2017). It is permanently joined to the Azolla fern, which is free to float. Azolla leaves degrade quickly, supplying the plant with nitrogen by containing 4-5% nitrogen (on a dry weight basis) and 0.2-0.4% nitrogen (on a wet weight basis). According to the Azolla-Anabaena system, which contributes 1.1 kg N/ha/day, one crop of Azolla provided 20–40 kg N/ha to the rice crop in about 20–25 days (Nosheen, 2021). Numerous countries employ Azolla as a biofertilizer, including Vietnam, China, Thailand, and the Philippines (NN and Malam, 2020). Another advantage of employing this biofertilizer is its ability to tolerate metal; as a result, it can be used in places with significant metal pollution (Perotto and Martino, 2001).

Blue-green algae (Cyanobacteria)

Nitrogen fixers are the most prevalent type of cyanobacteria on earth. They are essential in supplying the soil with growth-promoting substances like auxins, indole acetic acid, and gibberellic acid, which all hasten plant growth, as well as nitrogen and vitamin B complex. In rice fields submerged in water, they fix 20–30 Kg/N/ha when sprayed at 10 Kg/ha, enhancing crop productivity by 10%–15%. According to reports, employing cyanobacteria in agriculture increased the amount of nitrogen plants could access, especially in rice fields (Nosheen, 2021). It has been proven that cyanobacteria increase the yield of wheat and rice by encouraging shoot and root growth. In rice fields, blue-green algae may fix 25–30 kg of nitrogen per acre per season (Kaushik, 2014).

A study looked at how cyanobacterial strain exudates affected the growth traits of *Helianthus annuus* and *Sorghum durra*. Shoot length increased by about 120–242% over the control, along with other beneficial effects (Essa *et al.*, 2015). The strains exhibited potential for releasing bioactive compounds and enhanced plant growth and output. A different study found that inoculating rice with cyanobacteria from rice fields had positive effects on both the rice plant and the soil at the same time (Chittapun *et al.*, 2018). Farmers struggling financially and cannot afford to invest in pricey chemical fertilizers can benefit from using cyanobacteria as biofertilizers. A range of biomes and settings (such as terrestrial, wet, or dry) can benefit from using cyanobacterial biofertilizers (Nosheen, 2021).

PHOSPHATE SOLUBILIZING MICROORGANISMS (PSM)

Many soil bacteria and fungi, including species of *Bacillus, Pseudomonas, Penicillium, Aspergillus,* etc., release organic acids and lower the pH in the area around them to promote the breakdown of bound phosphates in soil. It has been demonstrated to increase wheat and potatoes yields by inoculating peat-based cultures with *Bacillus polymyxa* and *Pseudomonas striata.*

SILICATE SOLUBILIZING BACTERIA (SSB)

Microbes can change silicates, including aluminum silicates, into other compounds. As a result of microbial metabolism, several organic acids are formed, which play a dual role in silicate weathering. The organic acids like citric, oxalic, keto, and hydroxy carbolic acids that form complexes with cations improve their elimination and retention in the medium in a dissolved state. They encourage hydrolysis and add hydrogen ions to the medium (Abdelaal *et al.*, 2013).

PLANT GROWTH PROMOTING RHIZOBACTERIA (PGPR)

Crops benefit from "plant growth-boosting" rhizobacteria infiltrating the soil around roots or the rhizosphere (PGPR). The PGPR inoculants act as "bioprotectants," "biofertilizers," or "phytohormone producers" to prevent plant disease, improve nutrient uptake, or otherwise promote growth (termed Biostimulants) (Das *et al.*, 2022). The absorptive surface of plant roots increases water and nutrient uptake due to phytohormones or growth regulators that allow crops to have more fine roots (Verma *et al.*, 2023). These hormones can be produced by Pseudomonas and Bacillus species. They are still not well understood, though. These PGPRs, sometimes called biostimulants, produce phytohormones such as indole-acetic acid, cytokinins, gibberellins, and inhibitors of ethylene synthesis (Verma *et al.*, 2023).

ARBUSCULAR MYCORRHIZAL FUNGI (AM FUNGI)

The transfer of nutrients from the soil milieu to the cells of the root cortex is mediated by the intracellular obligate fungal endosymbionts of the *genera Glomus, Gigaspora, Acaulospora, Sclerocysts,* and *Endogone*, which have vesicles for storing nutrients and arbuscles for funneling these nutrients into the root system with phosphorus serving as the primary carrier (Kumar *et al.*, 2017). *Glomus*, a genus with multiple species found throughout the soil, appears to be the most prevalent (Kumar *et al.*, 2017).

ADVANTAGES OF USING BIOFERTILIZERS

The following are just a few benefits of using biofertilizers as outlined by Bhadrecha *et al.* (2023):

i. They are both economically and environmentally friendly.

ii. As a result of their use, the soil becomes more enriched and gets better with time.
iii. Even if they don't provide results immediately, the results are amazing over time.
iv. By capturing atmospheric nitrogen, these fertilizers make it readily available to plants.
v. Releasing and solubilizing inaccessible phosphorus raises the soil's phosphorous content.
vi. Due to the production of hormones that promote development, biofertilizers increase root proliferation.
vii. Microorganisms transform complicated nutrients into basic nutrients so that plants can get them.
viii. Biofertilizers contain microorganisms that support the host plants' proper development of growth and physiological regulation, as well as their adequate supply of nutrients.
ix. They contribute to a 10–25% increase in crop output.
x. Biofertilizers confers plants the ability to fight some transmittable diseases from the soil.

CONCLUSION

In conclusion, the attributes of biofertilizers make them a compelling alternative to chemical fertilizers in modern agriculture. As a sustainable and eco-friendly solution, biofertilizers contribute to enhanced crop yield and long-term soil health and environmental conservation. The shift towards biofertilizers aligns with sustainable agriculture principles, promoting a balance between economic viability, environmental stewardship, and public health. As agriculture continues to evolve, embracing biofertilizers represents a promising step toward a more sustainable and resilient future.

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