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Relevance of Biofertilizers to Agriculture

Tunde Ezekiel Lawal and Olubukola Oluranti Babalola*

Department of Biological Sciences, Faculty of Agriculture, Science and Technology, North-West University, Mahikeng Campus, Private Bag X2046, Mmabatho 2735, South Africa
Telephone: +27183892568, Fax: +27183892134,
**E-mail: olubukola.babalola@nwu.ac.za*

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ABSTRACT In the rhizosphere (the crop root or its close vicinity) microorganisms are abundantly present and they are in millions. The rhizobacteria do not only gain from the nutrients produced from the crop root but also positively affect the crop and this result in stimulation of the crop's growth. These bacteria are referred to as Plant Growth Promoting Rhizobacters (PGPRs) and they have been grouped according to their activities. PGPRs have the potential of acting as crop strengtheners, phytostimulators and plant health improvers. The objective of this write up is to shed light on the possibility of using these for the improvement of agriculture. Undoubtedly, if the use of these organisms is appropriately managed by farmers, it will help in effecting better wellbeing of crops and it will thereby improve food safety.

INTRODUCTION

In the last century, farmers were happy about the discovery and the use of chemical fertilizers due to increase in crop yield and subsequent financial benefits that accrued to them. Overtime, demerits in the use of chemical fertilizers came to surface and some of the disadvantages include: leaching and pollution of water basins, destroying microorganisms and friendly insects, making crops more susceptible to attack from diseases, reducing the soil fertility and hence, farmers were being discouraged to use them (El-Lithy et al. 2014; Ofori-Boateng and Lee 2014). However, overtime, it has been realized that the alternative to chemical fertilizers may be biofertilizers which can help in enhancing the yield and still avoid the harm inflicted by the use of chemical fertilizers. Biofertilizers are live formulates which contain living microorganisms which, when applied to seed, plant surfaces, root or soil, inhabit the rhizosphere and enhance the bioavailability of nutrients and increasing the microflora through their biological activities and thereby promoting plant's growth; they are preparations that readily improve the fertility of land using biological agents (Babalola 2010; Schoebitz et al. 2014)

Biofertilizers are from biological wastes and they are not hazardous to soil. They are very useful in that they help in enriching the soil with the microorganisms and these microorganisms produce organic nutrients for soil and help in fighting pathogens. Besides accessing nutrients, for current intake as well as residual, different biofertilizers also provide growth-promoting factors to plants and some have been successfully facilitating composting and effective recycling of solid wastes. Biofertilizers, depending on available or present microorganisms have come up as a replacement for chemical fertilizers to enhance soil fertility and crop yield in sustainable agriculture. Symbiotic, free-living soil bacteria are named as plant growth-promoting rhizobacteria (PGPR). They are involved in important ecosystem developments, and their activities include biological control of plant pathogens, N fixation, mineralization of nutrients and phytohormones production because of these qualities, they occupy a unique place in the sustainability of agroecosystems. The main sources of biofertilizers are bacteria, fungi, and cyanobacteria (blue-green algae). The relationship that these organisms have with plants is referred to as symbiosis. In this case, both partners derive benefits from each other (Babalola and Glick 2012a; Simmons et al. 2014).

Biofertilizers also stimulate plant growth, activate soil biologically, restore soil fertility and provide protection against drought and some soil borne diseases. Economically, it has been observed that biofertilizers are cost effective, eco-friendly, reduce the costs towards fertilizers use, especially regarding nitrogen and phosphorus. Rhizobacteria have exceptional ability to resist certain heavy metals and promote the growth of host plants by various mechanisms such as nitrogen fixation, solubilisation of minerals, production of phytohormones and siderophores and transformation of nutrient elements. They further stated that 1-aminocyclopropane-1-carboxylate (ACC) deaminase- producing bacteria play an important role in the alleviation of different types of stresses in plants, including the effect of heavy metals. In this regards, different heavy metal tolerance processes have been enumerated in different microorganisms. They include: exclusion, active removal, biosorption, precipitation or bioaccumulation both in external and intracellular spaces. These listed mechanisms can enhance the solubility and the mineralization of the metals and thereby making nullification of the toxic metals possible. It has been shown that the interaction between soil and its microorganisms positively influence the level of metal phytoextraction. For instance, the bacteria in the rhizoids facilitate the usage of trace elements. It is also imperative to state that there are some instances when they have minimal or no effects. Table 1 shows the names, description and possible locations of some microbes that are useful as biofertilizers.

METHODS OF APPLICATION OF BIOFERTILIZER INOCULANTS FOR AGRICULTURAL PURPOSE

It is important to be mindful of the method(s) to be used for the application of the prepared inoculants (bacteria-carrier mixture) to the crops. Factors to be considered include: the type of plants or seeds to be biofertilized, availability of the biofertilizers carrier, season and age of the crop. It must be ensured that appropriate and effective strain(s) of organisms are used. Biofertilizers must not be used in company of strong doses of plant protection chemicals and other chemicals should not be mixed with the biofertilizers (Balasubramanian et al. 2013; Son et al. 2014). The environmental condition of agricultural soil must be taken into consideration: high soil temperature or low soil moisture, acidity or alkalinity in soil, poor availability of phosphorous and molybdenum, presence of high native population or presence of bacteriophages. In order to get good results from the use of biofertilizers, farmers must ensure that they use the right method of application and apply the fertilizer at the appropriate time (See Table 2).

Characteristics of Suitable Carriers for Agricultural Biofertilizers

Development of suitable inoculants has to do with procurement or availability of a suitable carrier substrate. This is important because it is the carrier that will host and thereby determine the growth of the organism and possibly maintain the inoculants bacteria such that they can grow and proliferate appropriately. A suitable carrier must contain a considerable level of organic matter and high nitrogen level and must be affordable and non-toxic. Deployment of inoculants in a carrier grants long-term storage and makes the handling easier and effective (Schoebitz et al. 2014). The preparation of seed carrier involves the milling of the material to powder to sizes which varies between 8-41 µm. Good carriers must: (1) maintain good moisture capacity (2) not be toxic to the inoculants bacterial strain (3) be easy to process and devoid of lump-forming materials (4) be easy to sterilize by autoclaving and irradiation (5) be available in adequate quantity (6) be inexpensive (7) have good adhesion to seeds (8) have good pH buffering ability and (9) not be toxic to plants. Apart from these mentioned criteria that determine the suitability of a material as a carrier, it must be stressed that it is also important that the carrier must be able to support the survival of the bacteria even before the seeds are sown or before the seedlings are transplanted. This becomes important because in the case of seed coating, the seeds are not always sown immediately. Besides, the survival of inoculant bacteria when the seeds are stored must be supported by the carrier materials. Desirably, the carrier material must be able to support the biofertilizers when in the soil. This is needed because the biofertilizers compete with the native soil microorganisms for nutrient and they will have to cope and survive in the soil in spite of the protozoa in the soil as well. Therefore, the carriers must offer a sufficient microporous structures that will ensure the survival of the inoculants bacteria (Singh et al. 2013a).

Some of the known carriers now include: various clays, animal manure such as poultry manure, composted plant materials or other complex organic matrices. Some users opined that animal manure possibly contains pathogens and antibiotic which can lead to serious soil degra-

Table 1: The names, descriptions and habitats of some biofertilizers

Names	*Description*	*Where it lives*	*References*
Rhizobium	Genus of gram negative soil bacteria. It fixes Nitrogen and colonizes plant cells within root nodules.	Root nodules and stem nodules	(Qin et al. 2014)
Azotobacter	Genus of motile; it can be oval or spherical. They are aerobic, good in Nitrogen fixation. Useful as food additives and biopolymers. Produces antibodies that suppresses root pathogens	Soil	(Oldroyd and Dixon 2014)
Cyanobacteria	Also called blue-green bacteria, blue-green algae or cyanophyta. They are photosynthetic nitrogen fixers.	Soil, ocean and fresh waters	(Taylor et al. 2014)
Azospirillum	Gram negative aerobic bacteria. Beneficial at nitrogen fixations and plant nutrition. Produces growth promoting substances.	Soil	(Serelis et al. 2013)
Pantoea agglomerans	Gram negative bacteria formerly called *Enterobacter agglomerans*. It is a phosphate solubilizing bacteria.	Plant surfaces and animal faeces	(Kouvoutsakis et al. 2014)
Pseudomonas Putida	Gram-negative rod shaped saprophytic soil bacterium used as soil inoculant to remedy naphthalene contaminated soils.	Soil	(Annesini et al. 2014)
Trichoderma	A genus of fungi. They are opportunistic avirulent plant symbionts.	Soil	(Nawrocka and Ma³olepsza 2013)
Vermicompost	It has N, P, K, S, hormones, enzymes and antibiotics which help to improve the quality and quantity of crop yield.	Soil	(Gutiérrez-Miceli et al. 2007)
Bacillus	A genus of gram positive rod-shaped bacteria and a member of the phylum *Firmicutes*	Non sterile soil	(Kumari and Sarkar 2014)
Mycorrhiza	They are a group of fungi that include a number of types based on different structures formed inside or outside the root. They are specific fungi that match with a number of favorable parameters of the host plant on which it grows.	Soil	(Vos et al. 2013).
Burkholderia	It is a genus of proteobacteria. Genus name refers to a group of virtually ubiquitous gram negative, motile, obligately aerobic rod-shaped bacteria.	In wet soil	(Vandamme et al. 2002).
Klebsiella	Gram negative, non-motile, encapsulated, lactose fermenting, facultative anaerobic, rod shaped bacterium.	Soil	(Ku et al. 2014)
Enterobacter	Gram negative, anaerobic, shaped bacterium.	In water and soil but are common invaders of tissues in contaminated wounds of animals.	(Jin et al. 2014)
Herbaspirillum	Gram negative soil and water-based bacteria that rarely cause human infections.	Soil and water	(Lubambo et al. 2013)
Gluconobacter	The acetic acid bacteria are usually airborne and are ubiquitous in nature.	Air	(Guo et al. 2013)

Table 2: Methods of applying biofertilizers, descriptions and application of the methods to crops

Methods	*Description*	*Application of the methods to crops*	*References*
Seed Treatment	It is the most popular method. It is applied at the rate of 100gm per 5kg of seeds. Slurry is prepared with water and the biofertilizer is mixed with water at ratio 1:2.	Pulses, oilseeds and fodder crops	(Singh et al. 2013a)
Seedling Treatment	1 part of biofertilizers in 10 parts of water is prepared. The roots of the seedlings are dipped in the biofertilizers for about 40 minutes.	Tomatoes, potato, onion and paddy, marigold and jasmine.	(Andrade et al. 2013)
Set Treatment	The pieces of materials to be planted are immersed in biofertilizers mixture for 30 minutes. The sets are dried and planted in the field.	Sugarcane, banana and grapes	(Shen et al. 2013)
Soil Treatment	The biofertilizers are applied to the soil before planting or sowing. The possible carriers are: compost, farmyard manure, rice husks and lignite at the rate of 1 kg per 25 kg of carrier. Irrigation follows immediately after the application.	Maize and Wheat	(Schoebitz et al. 2014)
Spraying/Irrigation	Biofertilizers is mixed with water and other micronutrients in a tank. It reaches plants through irrigation or spraying.	Recommended for standing citrus plants, vines, mango, guava, custard apple and peach orchards.	(Singh et al. 2013b)

dation and phytotoxicity if uncomposted animal manure is applied to soil (Babalola and Glick 2012b; Yousefzadeh et al. 2013).

Sterilization of the Carrier Materials for Biofertilizers

It is important to sterilize carrier materials to ensure that they are devoid of other microorganisms that may hinder the survival of the inoculants and also to prolong the shelf life of the inoculants. Essentially, there are two major ways of sterilizing the carrier materials, gamma irradiation and autoclaving. But, the more adopted or recommended is the gamma irradiation. This is because this method does not alter the chemical or physical properties of the carrier materials (Babalola and Oladele 2011; Minaxi and Saxena 2011). Most of the times, the irradiation is done by packing the carrier material in a polyethylene bag and gamma irradiate at 50 k Gy (5 Mrads). Gamma rays effect the sterilization by colliding with the atoms of nutrients such as protein, carbohydrates, lipids and nucleic acid. The rays ionize the atoms and thereby damage them. From the above listed materials, the most susceptible to ionizing radiation from the gamma rays is the nucleic acid and it is only 1% of the total composition of the cell. Furthermore, during the radiation treatment, the DNA strand breaks and base is subsequently damaged. The break of the DNA strands leads to break in the flow of genetic information and this destroys replication process and subsequently, death of the cell results (Li et al. 2012). Moreover, the sterilization by autoclaving is carried out by putting the carriers in polyethylene bags and autoclaved at 121^{o}C for 60 minutes. However, it should be known that during autoclaving, some carriers undergo changes and their physicochemical properties may change and produce toxic substances to some bacteria strains (Li and Yu 2011).

RHIZOSPHERE COMPETENCE OF BIOFERTILIZERS

Bacteria inoculation is often carried out when coating the seeds or when placed very close to the plant via a carrier. The inoculated bacteria should have the ability to establish themselves in the vicinity of the rhizoids at such a number that will be enough to have beneficial influence on the plants. Expectedly, inoculants bacteria should not only live in the vicinity of the rhizoids, but they should be able to maximally use nutrients produced from the root, multiply, and subsequently colonize the entire root area (Son et al. 2014). In summary, biofertilizers function as soil microbes and they thereby convert ambient nitrogen into forms that the plants can use (nitrate and ammonia), increases soil porosity by gluing soil particles together, defend plants against pathogens by outcompeting pathogens for food and worthy of note is the fact that saprophytic fungi in the soil break leaf litter down into usable nutrients. It is important to note that at present, biofertilization is responsible for approximately 65% of the nitrogen supply to crops all over the world. The biofertilizers bacteria form a host-specific relationship with legumes. This relationship begins by initiation of root or stem nodules as a result of the presence of the bacterium. Lipooligosaccharide information activates molecules that are produced by the bacterium and plays an important role in this process. The bacteria percolate the cortex, stimulate formation of root nodules, increase and eventually break into bacteroids, which elicit the nitrogenase enzyme production. In the root nodules, the plant provides a low oxygen concentration, which promotes bacterial nitrogenase to change nitrogen in the atmosphere into ammonia. As a result of this, the plant supplies the bacteria with needed carbon source for multiplication and existence (Beneduzi et al. 2013).

Agricultural soil is said to be healthy if among other things, it contains sufficient strains of microorganisms that can terminate, prevent or hinder bacteria, fungi and species of nematodes that can cause root rots. Moreover, organisms like mycorrhizal fungi produce compounds that are antibiotic or bactericidal to many plant pathogens (Babalola 2010). For the decomposition of the toxic materials, through the process of cooxidation, bacteria and fungi need organic materials to feed on with the toxic compounds (Asensio et al. 2013).

Use of Bacteria as Strengtheners of Agricultural Plants

Plant strengtheners refer to "plant resistance improvers". It is now commonly referred to as agents and it maintains plant health or which guide crop plants against non-parasitic adverse conditions. The association of Plant with microorganisms explains important roles for plant wellbeing and health. Microbes are able to influence plants' health by improving nutrient uptake and hormonal stimulation. Different methods or ways are involved in the minimization of activities of plant pathogens, and this will influence and affect plant growth (Manivasagan et al. 2013). Although, bacterial genera *Azospirillum* and *Rhizobium* are known to be good for plant growth improvement, other microorganisms like: *Bacillus*, *Pseudomonas*, *Serratia*, *Stenotrophomonas*, *Streptomyces*, *Ampelomyces* and *Coniothyrium* are yet to be fully explored. Developments in recent agricultural practices aim at developing harvest yields and directed towards minimizing pre harvest and postharvest losses occasioned by devastating abiotic and biotic agents (Harish and Tharanathan 2007). These developments have potential of reducing the effects of pests and diseases by about 20-40%. Recent pest management strategies in crop plants involve the use of classical and molecular marker-based resistance breeding, genetic manipulation of plant tolerance and the use of chemicals as pesticides or strengtheners of plant wellbeing (Gomes and Silva 2007).

Use of Bacteria as Phytostimulators for Agricultural Plants

Phytostimulators promotes crops growth. Plant growth promoting rhizobacteria (PGPR) include *Azospirillum*, which is a popular genus among the PGPR that exhibit positive effects on plants growth. A considerable volume of carbon gets below ground through the activities of plants' roots. Invariably, plants release exudates which serve as nutrients (carbohydrates, proteins and other nutrients) for microbes around the roots area (Ramos et al. 2011). By this, crops get the right types of microbes around its roots. Eventually, these "well fed" microbes will produce enzymes and growth hormones and protect the plants against pathogens. It is estimated that averagely, a gram of healthy soil should have or contain 100 million organisms (Drogue et al. 2012). Meanwhile, in the proximity of crops roots, there can be up to a trillion organisms per gram of soil and they live symbiotically. Many strains of *A. brasilense* and *A. lipoferum* have been explored in recent times as crop inoculants to maximize yield. The results obtained when *Azospirillum* was used as a phytostimulatory PGPR has elicited comprehensive studies on the biology of these bacteria. Among other benefits from the use of *Azospirillum* are: nitrogen fixation, deamination of the ethylene precursor1-aminocyclopropane-1-carboxylate (ACC) and production of nitric oxide properties and phytohormones, chiefly indole-3-acetic acid (IAA) (Aimey et al. 2013). Moreover, these benefits have the ability to promote or enhance good rooting system which enhances root hair density and invariably, this will lead to better water mineral uptake by crops.

Plant Growth Promoting Bacteria as Crop Health Improvers

For about sixty years, PGPR have been confirmed to prompt development of various host plants and they also benefit from the root exudates. The PGPR are classified into different groups according to their actions on crops. Firstly, the phytostimulating rhizobacteria that promotes crop growth directly by providing nutrients and phytohormones. Secondly, mycorrhiza and root nodule symbiosis which assist rhizobacteria and this positively affect functioning of plant and microorganisms in the symbiotic relationship; and thirdly, the biocontrol rhizobacteria that defend plants and crops from pathogens via exudates from antimicrobial agents or by promoting plant resistance (Manivasagan et al. 2013). Due to their potential use as biofertilizers and biopesticides, their *modus operandi* has been largely studied in model bacteria such as *Azospirillum* spp. and *Pseudomonas* spp. The genotype of the host plant determines PGPR densities both in terms of the number, size and composition. Furthermore, plant growth-promoting effects of these bacteria have been shown to rely both on host plant genes and bacterial strain (Son et al. 2014).

Soil Food Web

The term soil food web means the interactions among the wide range of living organisms that exist in the soil. It is made up of non-living things and the living things. The non-living things are the minerals while the living things are the creatures otherwise called soil biota (Hansen et al. 2010). There are two types of soil biota. The first ones are beneficial while the second ones are pathogenic ones which can cause root rots and other diseases. However, both are very important and needed in the cycle. The beneficial bacteria improve soil's drainage, aeration, and texture and in general, they improve the soil's health by recycling organic matter (Baudoin et al. 2010). In certain instances, they have products that inhibit the growth of soil-borne pathogens to the advantage of the plant root. Beneficial bacteria are explored in the quest to improve soil fertility and to reduce the negative impacts of chemical fertilizers on the environment. One of the mechanisms by which bacteria are absorbed into the soil particles is by simple ion exchange. In addition, a soil is accepted to be fertile if its organisms release inorganic nutrients from the organic matter in order to effect and aid plant growth (Kalinina et al. 2013).

Destinies of Soil and Crops without Food Web

When chemical fertilizer is added to the soil, there is availability of much N. Plants will take the needed quantity and use it for growth while the rest will be leached away. This will take place because there are no microorganisms that will retain and use the rest (Liu et al. 2013). Besides, other nutrients like phosphorus, copper, iron and zinc will be easily changed to unavailable or insoluble forms. When and if there is no food web, the opportunistic organisms will increase and multiply rapidly. The opportunity for the plant to have good water and nutrient holding capacity is abased. So, the plant may not be able to have resistance during drought or adverse conditions (Sheelanere et al. 2013).

Levels in Agricultural Soil Food Web

There are levels in the soil food web. The first level is the level of organisms that capture nutrients before they are lost. In this level, bacteria and fungi play prominent role. They mop up the available nitrogen in the soil that the plants do not need at that time. They do this in order to prevent them from being leached away and besides, N in this form cannot be lost like gas (Creamer et al. 2014). They use the N for the formation of protein in their bodies. They convert nutrients like P, K and S to body biomass and their body wastes, like that of fungi are summarily converted into humus soil. The soil fungi are able to biodegrade the cellulosic materials. They degrade tougher biodegradable materials like lignin and pectin. They actively do this by the release of enzymes in course of feeding on these materials having formed rhizoids on the substrates (Bartley et al. 2014). By this process or procedure, nitrogen and other nutrients are prevented from being lost in that they are "kept" as part of biomass in bacteria and fungi, but plants do not also have access to these nutrients. In order to make the nutrients available, there must be predators that will feed on the bacteria and the fungi; hence we have the second level in the soil food web. At this level, there are protozoa, nematodes and microarthropods. These organisms feed on fungi and bacteria in the soil and the "kept" nutrients are metabolized and gradually given back to the soil such that the soil will not lack the nutrients always (Wang et al. 2014). Worthy of note is the fact that microarthropods, apart from feeding on bacteria and fungi in order to release nutrients in them for plant use, also feed on some nematodes that feed on plants' roots and attack them. On top of the second level of soil food web are the higher level predators that include millipedes, centipedes and earthworms. They feed on nematodes and protozoa and put them in check so as to prevent them from expanding in population and over feeding on bacteria and fungi. Other higher organisms like birds and rodents feed on earthworms and insects; then birds and rodents may be fed on by mammals (Arthur et al. 2013). On the whole, there are about six trophic levels. The above process results in continuous and sustained supply of nutrients to plants by preventing leaching and loss of nutrients in gaseous form as bacteria and fungi would have used them and retained these nutrients in their bodies as part of the biomass (Senechkin et al. 2014).

CONCLUSION

Ultimately, the use of biofertilizers are attractive because they act as plant strengtheners, phytostimulators, plant health improvers, and have the potential to fix nitrogen, which plants can use to improve its growth when there, is insufficient quantity of nitrogen in the soil. Furthermore, because they originated from the soil they seem to be rhizosphere competent.

RECOMMENDATIONS

Although farmers still prefer the use of chemical fertilizers, carrier material for biofertilizer and inoculum stability are the main obstacles for mass production of biofertilizer. The research on the genetically engineered microbes, will improve the biofertilizers. Special attention needs to be addressed towards N_2O gas emissions which can be minimized by developing sustainable manure management strategy. Besides, it is important to embrace the use of biofertilizers because it has the potential of enriching farmers.

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