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Biofertilizers as an Alternative to Inorganic Fertilizers in Sub-Saharan Africa: Is the Adoption the Missing Link?

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ABSTRACT

Biofertilzers are substances obtained from living microorganisms with the potential to supply crops with useful nutrients. Commonly used Biofertilizers supply nitrogen and phosphorus, and these nutrients are the most limiting ones in Sub-Saharan African. Nitrogen has a higher leaching capacity and thus more losses are experienced in agriculture than what is up-taken by crops for growth while P sources are getting depleted. Despite many soils lacking these elements, the peasant farmers cannot afford their high cost. On the other hand, if supplied in higher amounts, lead to pollution of ground and surface bodies and eutrophication in the water bodies in the catchment areas. Biofertilizers are therefore considered to be eco-friendly and cost effective. These micro-organisms once inoculated in the soil show different modes of action that promote nutrient availability to crops. These mechanisms include; scavenging for nutrients from soil layers, solubilization of some inorganic compounds, and production of growth promoting metabolites, decomposition, and fixation of the free nitrogen from the atmosphere. However, the use of these biofertilizers has different challenges which may contribute for low adoption by farmers. The review therefore seeks to understand mode of application, mechanisms of plant uptake and the reasons that dissuade farmers from adopting these noble techniques.

1.0 Introduction

Biofertilzers are considered as substances containing living microorganisms that provide plants with essential nutrients (Mohammadi and Sohrabi, 2012). For instance, for plant growth promoters, the action mechanism involves colonization of the plant rhizosphere or the entire soil surface, hence enhancing the availability of the primary nutrients to the plants (Ahhemad and Kibret 2014). Bio-fertilizers add nutrient to the soil through the use of natural processes such as nitrogen fixation, mineralization, immobilization or phosphorus solubilization (Brahmaprakash, and Sahu, 2012). The current farming practices are faced with a lot of constraints due to less availability of the primary nutrients in the growing media. These challenges are speculated to be due the increased usage of the synthetic fertilizers for a long period (Venterea et al., 2012). Therefore, the long-term benefits of using biofertilizers to promote successful growth of plants may be an option for serious consideration. Masha *et al.*(2012), argue that indiscriminate use of inorganic compounds have led to pollution, contamination and destruction of beneficial micro-organisms in the soil. The cost of fertilizers is also increasingly becoming very high, making it less affordable to small scale farmers (Taiwo, 2006). This, therefore, implies that the use of biofertilizers would be an alternative and thus should be adopted to increase yields. Importantly, farmers may explore to embrace the aspect of integrated plant nutrient management to ensure there is sustainability in their productivity. It is also a major focus in the today's world to exploit the existing beneficial Micro-organism that enhances sustainable crop production practices (Shah, *et al.*, 2007). It is evident that such micro-organism-based products promote the diversity of microbes in the soil that improve soil physiochemical properties. Therefore, this paper gives a short overview on the potential use on biofertilizers by farmers on different crops. Importantly, the review focuses on the mechanisms of different biofertilizer action and stresses the need for its adoption as an alternative fertilizer source.

Microorganisme.g. bacteria such as *Pseudomonas, Bacillus* and *Erwinia* have been reported to have the ability to solubilize the insoluble forms of phosphates such as tricalcium and rock phosphates. The activities of these bacteria are highly experienced in the plant rhizospheres compared to other soil horizons (Durve-Gupta *et al.*, 2016). These bacteria also have been reported to produce plant growth promoting hormones that also facilitate the process of solubilization of nutrients. Treatment of cucumber seeds with Pseudomonas resulted into increased growth in terms of the fresh and dry weight by 50% compared to the control of the inorganic fertilizer (Mostafa and Abo-Baker, 2010).. Grain yield was also found to increase by 20% when compared with other forms of inorganic fertilizers that were used. Additionally, these substances have also been found useful in reduction of the nematode population in soils. During solubilization, some organic acid is produced which lower the pH of the soil (Mostafa and Abo-Baker, 2010). The acidic medium and extrusion of protons act as the principal mechanism through which bacteria species use to solubilize phosphorus from organic to inorganic form.

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The decrease in pH and production of the organic acid have been reported to have a combined effect in solubilization of phosphorus (García-Fraile *et al.*, 2015). However, the exact population of bacteria responsible for solubilizing these compounds has not been established. Mycorrhizae mostly denoted as fungus roots are also known to act as phosphate absorbers. This is enhanced by the formation of a symbiotic association with the roots of the host plants (Sadhana, 2014). The fungus benefits by acquiring carbon that is released during the photosynthesis while the hosts benefits from the most beneficial nutrients such as phosphorous and calcium (Maiti, 2011). This is because the fungus has fine hyphae that facilities easier scavenging of the inaccessible nutrients by plants. The association has been found to promote yield in crops by more than 40%. Besides, they also enhance the uptake of water in plants (Sane and Mehta, 2015). Arbuscular mycorrhiza specifically improved the tolerance of heavy metals that are source of toxicity among plants. However, this fungus is not beneficial to some crops like those from the families of Chenopodiaceae, Amaranthaceae, and Brassicaceae. Additionally, its commercial utilization has become very difficult due to presence of the obligate symbiotic nature.

2.0 Why the use of Biofertilizers in cropping system?

Recently, there have been several reports concerning loss of major nutrients in the soils (Vitousek *et al*., 2009, Isbell *et al*., 2013, Bender and Heijden, 2015). The nutrient losses have in one way or the other caused the productivity of crops to decrease. Consequently, it has become increasingly difficult to provide food to the increasing populations in the world, particularly in the south (Bommarco et al., 2013).

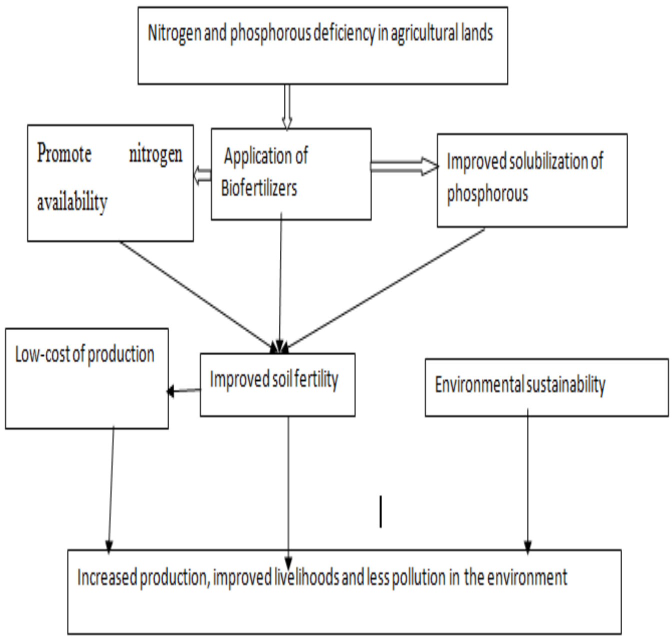

Figure 1. Flow chart showing the role of biofertilizers in transforming agriculture by reducing costs of production, environmental impacts due to chemical fertilizer and hence in overall improvement of the livelihoods.

This has caused the livelihood of the rural people who rely mainly on agriculture to deteriorate further. Importantly, the inorganic or chemical fertilizers have also been associated with a lot of pollution to the environment (Mekonnen and Hoekstra, 2015).

Therefore, Biofertilizers offer an alternative and promising method that can be used to increase agricultural productivity. This is because it has long term benefits of sustaining soil fertility unlike synthetic fertilizers (Kandiannan, 2015). It has been reported that inorganic fertilizers tend to accumulate high levels of salts in the soil after use for a long period that lead to depletion of the essential nutrients in the soil (Raja, 2013). Furthermore, biofertilizer use ensures production with lower cost as opposed to chemical fertilizers (Reddy, 2016). Moreover, there is expected increased output due to low release and the availability of nutrients for uptake by plants. This implies that farmers can get better income and thus improving their living standards as evident in figure 1. The biological activities in the rhizosphere also help other beneficial micro-organism to thrive well. This gives them the ability to suppress certain soil borne diseases and parasites that affect the health of crops (Dames, 2014).

3.0 Bio-fertilizers' mode of action

3.1 Solubilization of phosphates

Based on comparison on other available plant nutrients in the soil, phosphorus has been reported to be less mobile regardless of it being a vital amendment (Scholz *et al*., 2014). This condition makes it is a limiting factor in promoting the growth and development of crop production. This has made it difficult to several farmers to attain the expected crop productivity. Importantly, the production of chemically processed form of phosphorous very expensive and thus less available to farmers. However, the bioavailability of beneficial micro-organism in the soil layers has proved to be very vital in farming systems. This is because biofertilizers have the potential of making the fixed forms of phosphorous available to plants and hence promoting the rate of growth (Vassilev *et al.,* 2014) at a cheaper cost. Among the rhizosphere genera's that have been tested for their efficacy in phosphorus solubilization include, *Pseudomonas*, *Bacillus*, *Aspergillus* and *Penicillum* (Sharma et al., 2013). Moreover, a nematofungus known as *Arthrobotrys oligospora* has recently been tested in both *in vitro* and *in vivo* experiments to determine its role in solubilizing different forms of phosphorous. It was reported to mobilize the following three types of rock phosphates Kodjari, Telemsi and Togolese (Pandit *et al*., 2014). It is also evident that there is a high number of phosphorus solubilizing micro-organisms in the rhizosphere of the soils. However, the ideal strains of these microbes responsible for this particular role have not been identified (Pandit *et al.,* 2014). Importantly, an evaluation of micro-organisms that can facilitate phosphorus availability in stressed ecological zones is also necessary (Pandit *et al.,* 2014).

3.2 Phosphate absorbers

Mycorrhiza fungi form symbiotic relationships with the rooting system of the host plants. The fungus benefits through the carbon released by the plant during photosynthesize process. In return the fungus supplies nutrients such as phosphorous to the roots that promote their growth. The fungus uses its fine absorbing hyphal structures in obtaining the nutrients that are not accessible to the roots of the plants (Sane & Mehta, 2015). Apart from phosphorous other nutrient elements such as copper and calcium are also made available to the plants.

3.3. Fixation of atmospheric nitrogen

Strains of rhizobium have widely been reported to have the potential of fixing atmospheric nitrogen into forms that are available to plants. They facilitate nodulations of the roots of leguminous crops which serves as factories for ammonia. This is due to the ability of the rhizobium to resist different temperature ranges and thus can colonize different soil layers. This fixation is enhanced by the creation of a symbiotic association between the host crop and the present bacterial strains (Olivares *et al.,* 2013). The nodules formed also increase the surface area through which the fixed nitrogen is taken up by plants.

Acetobacter is also another major type of symbiotic microorganism that is widely found in sugarcane crops. It has the potential to grow inside the roots and stem and thus enabling the plant to take up atmospheric nitrogen. Acetobacter has also been reported to secrete growth substances known as Indole Acetic Acid that stimulate growth of roots. The mode of application can be done either through soil treatment or root treatment at the time of planting. Its effects in plants are usually visible 5-6 weeks of application. This has specifically been used in sugarcane and has been shown to increase the size and length of internodes. Additionally, it was found to increase yields of sugarcane by 5-20 tons per hectare and also increase the sugar content in the cane stem by 5-15%. However, it has proved to be tough to isolate and multiply artificially. This is due to the lack of a suitable technique to reproduce it faster in the laboratory and thus limiting its commercial usage.

Microorganisms responsible for mobilizing plant nutrients belong to different categories. This makes them have different mechanisms that make nutrients available to plants. The nitrogen fixing bacteria like the rhizobium have been found to increase the plants yield when seeds are inoculated. This is due to the raised rhizobia activity, and thus more balanced nutrients are made available to the plants. Rhizobium is estimated to fix approximately 15-20kg of nitrogen per hectare and thus promoting the growth of crops (Singh *et al*., 2015). According to Youssef and Eissa (2014), Mucuna seeds, when inoculated with *Bradyrhizobium* strains were found to increase the growth of plants as well as reducing the population of weeds in the field. The increasing number of the microbial activities may be the reason as to why there were fewer plants in the growing field (Youssef and Eissa 2014). This, therefore, indicated that treatment of seeds using this particular *Bradyrhizobium* is beneficial to crops. Additionally, when lettuce seeds were inoculated with unknown strains of rhizobia, there were an increase was an increase of phosphorous concentration by 6% in the growing media which resulted in production of high yields. This also revealed that biofertilizers have high affinity to mobilize nutrient availability among non-leguminous plant species (Wang *et al.*, 2015). However, these studies fail to provide the particular strain of Bradyrhizobium that was initially inoculated in the seeds.

The rhizobia ability to fix nitrogen depends more on the species of the host plant. This means that the selection of an effective strain should be considered to ensure a potential biofertilizer. The most common practice of application of the rhizobia inoculum is through the use of granules or powder form (Tiyagi *et al.*, 2015). However, the success rate is dependent upon environmental conditions which illustrate that a critical evaluation of the inoculation is required.

3.4 Azotobacter and Azospirillum

Azotobacter and Azospirillum are considered to be the most important bacteria in non-leguminous crops. These micro-organisms initiate various activities in the rhizosphere of the plant and thus enhancing nutrient availability (Bhardwaj *et al*., 2014). Importantly, Azotobacter works with close association with other nitrogen fixing bacteria like Rhizobium that promote the production of siderophores in the soil thus enhancing the role of nutrient availability. When sunflower seed was inoculated with Azotobacter at planting, there was an increase in the rate of growth and yield. Seed inoculation with Azotobacter was reported to increase number of green leaves per plant of maize. Azotobacter also produces antifungal antibiotics that help to keep off most of the soil borne pathogens. This promotes reduction of root and seed mortality and thus increasing the germination percentage of crops. However, it is primarily affected by soil physiochemical factors such as pH, temperature and soil depth. The bacteria also occur in low populations in crop plants rhizosphere and also in uncultivated soil (Taiwo, 2006). Azospirillum has been reported by Habib & Zhagloul, (2012) to be an effective source of nutrient to cereals since it can add up to 20-40kg N/ha. Therefore, it is recommended for crops such as maize, sugarcane, millet, pearl and sorghum. According to Bhardwaj *et al.* (2014), this microorganism was observed to change the morphology of the root through the production of plant growth regulating compounds. Importantly, it develops associative symbiosis with plants that have the C4 carboxylic photosynthetic pathways. The sources were found to have more hairs that enhanced active uptake of sufficient nutrients and water. This indicates that it is very effective in water-stressed crops. When both Azotobacter and Azospirillum where inoculated in tomato seed, there was a significant difference in number of leaves, height of plants and yield than when they were inoculated singly.

3.5 Blue-green algae

The blue-green algae also known as the cyanobacteria are also among the most important micro-organisms in enriching plant nutrients in poor soils. For instance, they are very efficient in fixation of the atmospheric nitrogen in paddy fields soils which is a challenge to most farmers (Vaishampayan *et al.*, 2001). Additionally, they also secrete other growth-promoting substances that make the crops have a more vibrant growth. This ensures that plant matures early and outdo other challenges such as pests and diseases which reduce the cost of production to farmers (Joseph, 2014). However, in Kenya, the efficient mode of application of this type of bio-manure is yet to be availed. Importantly, most farmers have less knowledge on the benefits of blue-green algae since they consider it as a weed. Therefore, this makes most of the farmers to have low yields due low levels of available nutrient to paddy crops especially rice.

4.0 What is limiting adoption of Biofertilizers?

4.1 Lack of the effective strain

Regardless of Biofertilizers having friendly benefits as an alternative amendment source to synthetic chemical farmers, they have been reported to face various challenges in using them. Most of the Biofertilizers that have been tested for the application in farms have given poor results due to the use of ineffective strain (Mahdi *et al*., 2010). This is due to the reason that some Biofertilizers are genotype- specific and thus can only work well in particular species compared to others. For resistance, a specific strain of rhizobium is required to form nodulation with a given crop and this implies that they have to be compatible to ensure successful results. The selected strains should also show a competitive action over other strains that are present. Therefore, it is essential that before release of any commercial products it should be tested for its efficacy on particular crops from which recommendation can be drawn.

4.2 Inadequate population of micro-organism

The performance of the micro-organism depends largely on the population that is present in the soil. This is because higher number of micro-organisms enhances increased activity in the rhizosphere and hence more and fast release of nutrients (Herrmann & Lesueur, 2013). It has been shown that there is limited number of these micro-organisms that are present in the soil and thus leading to challenges in adopting this organic method. This fact illustrates that alternative means of supplying more microorganism at friendly costs should be encouraged. This has been attributed by the inadequate and inexperienced technical experts who are available in the field.

4.3 Ineffective carrier material

In spite of the considerate research that has been carried out concerning Biofertilizers, the researchers have not come up with an effective carrier material for these substances. The fact that Biofertilizers tend to have short shelf life the most appropriate carrier material is a major constraint (Mahdi *et al*., 2010). A quality carrier substance should have the potential of retaining moisture and be free from toxic elements. Importantly, this constrict has made it difficult to determine the right application needed for particular strain of Biofertilizers. This shows that there is missing knowledge concerning the rate of use and thus leading to ignorance by most farmers. Therefore, extensive research is required on this aspect so that adoption can be enhanced easily.

4.4 Soil factors

Most of the soils that have high levels of acidity and alkalinity are also a major challenger to the use of Biofertilizers. This is because extremes of these conditions hinder growth and multiplication of microbial and thus poor performances. It also affects the rate of growth and development of the crops in the field which consequently affect their rate of production. High soil temperatures and drought are also known to affect the effectiveness of these microbes to crops (Taiwo, 2006). Deficiency rates of P and Cu and also presence of toxic elements in the soils also have detrimental effects on thriving of micro-organism. Therefore, this implies that soil testing should be done before recommending particular Biofertilizers product to a certain ecological zone.

4.5 High population of native micro-organism.

The native antagonistic micro-organisms hinder the new inoculums from establishing in the soil. This is through the competition they create and thus making it difficult for newly inoculated beneficial strain to show any effects to the crops (Rajendra, 2013). They also compete for the available sources of food making the new organisms to starve. Therefore, a mechanism on how the inoculum can tolerate the competition from other organisms need to be developed understood urgently to fill the gap.

4.6 Mutation of the micro-organism

During preparation process, most of the Biofertilizers micro-organism have been reported to change their genetic forms. This happens mostly in the fermentation phase and thus this causes the cost of the production to be extremely high (Pandit, 2012). The quality of the products is also altered since undesirable changes occur during the preparatory phase. This calls upon a comprehensive study to be carried out to ensure that these undesirable changes are eliminated and enhance efficiency.

4.7 Poor inoculation methods and lack of quality assurance personnel

Most of the commercial agents dealing with Biofertilizers are not aware of the effective methods of inoculation. This misleads many farmers since they use wrong methods of application and thus achieve undesirable results. Biofertilizers being living organisms should be handled with techniques that will enhance their shelf life after inoculation (Herrmann & Lesueur, 2013). Importantly, their storage should be also technical since extreme temperature and humidity affect their growth. Inappropriate quality assurance skill is also big challenge in the industry of Biofertilizers. Farmers are given products that are below the standards and thus have no positive impact on the growth of crops. This makes many farmers to avoid such products and thus convincing them again requires a comprehensive prove. Therefore, better methods of inoculation and quality inoculation are urgent tasks that needed to be developed in the field of organic amendments of Biofertilizers.

4.8 Lack of awareness among farmers

Farmers have less knowledge concerning this technique of organic farming. Lack or poor extension services have led to this situation due to lack of connectivity with the farmers (Mahdi *et al*., 2010). Importantly, research and extension have poor linkage and thus developed technologies are less disseminated to the local farmers. Therefore, research organization should be encourage to work more closely with the farmers to facilitate sharing of the new developed technologies.

4.9 Poor availability of insoluble form of phosphates.

It also been reported that most of the soil have poor availability of phosphate forms to be solubilized (Herrmann & Lesueur, 2013). This therefore, makes the micro-organism responsible for this role to be inactive. This means that no significant results will be obtained since the nutrients are less available to plants. These micro-organisms can be applied in the soil through inoculation in seed before planting. This will ensure that the seeds germinate with their enhanced mechanism to scavenge for the less available but essential nutrients in the soil (Herrmann & Lesueur, 2013). This is also the most commonly used traditional method that has promoted enhancement of nutrient availability in the poor soils. However, this method is associated with weakness such as limited number of micro-organisms that can adhere to the soil surface. Most of the micro-organisms applied near the seeds have a tendency of moving away from the rooting zone and thus becoming less ineffective. Additionally, the exposure to the environmental stress makes them to have undesired effects to the crops. It has also been documented that the success rate of these micro-organism in the soil after inoculation depends highly on its ability to survive various soil factors (Paul Khurana, 2013). Such factors that may hinder its performance include physiological status, temperature, pH and moisture content. Phosphate solubilizing bacteria associated with release of lower molecular weight organic acids ("Phosphate Solubilization: Their Mechanism Genetics And Application", 2011). Through this process the hydroxyl, carboxyl chelate the cations and get bound and thus converting phosphate into soluble form.

5.0 Conclusion

Biofertilzers are associated with long-term sustainability of soil fertility that enhances increased crop yields. The current management practices that are used by farmers as source of nutrients are pausing a significant threat to the environment through depletion of soil fertility and increasing pollution. Therefore, this problem can be solved through adoption and applications of the products of Biofertilzers extracted through help of potentials micro-organisms. Additionally, the modern agricultural practices should encourage use Biofertilzers so as to produce enough food for sustaining the world's increasing populations. This also implies that more comprehensive research is required to address the current problems associated Biofertilizers effectiveness. This will increase the adoption rate of different farmers and hence leading to sustainability to crop production. Importantly, adoption of this technology to cropping system will be an alternative strategy to inorganic fertilizers that are associated with detrimental effects in productivity of crops due to nutrients depletion.

References

Bender, S. F., & Heijden, M. G. (2015). Soil biota enhance agricultural sustainability by improving crop yield, nutrient uptake and reducing nitrogen leaching losses. *Journal of applied ecology*, *52*(1), 228-239.

Bhardwaj, D., Ansari, M., Sahoo, R., &Tuteja, N. (2014). Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microb Cell Fact*, *13*(1), 66. http://dx.doi.org/10.1186/1475-2859-13-66

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: harnessing ecosystem services for food security. *Trends in ecology & evolution*, *28*(4), 230-238.

Brahmaprakash, G. P., & Sahu, P. K. (2012). Biofertilizers for sustainability. *Journal of the Indian Institute of Science*, *92*(1), 37-62.

Dames, J. F. (2014). Biological Control: PGPR and Arbuscular Mycorrhizal Fungi Working Together. In *Use of Microbes for the Alleviation of Soil Stresses* (pp. 39-53). Springer New York.

Durve-Gupta, A., Devaguptapu, B., & Lobo, V. (2016). Isolation and evaluation of isolated bacteria as potential biofertilizer. *IJAR*, *2*(2), 429-435.

García-Fraile, P., Menéndez, E., & Rivas, R. (2015). Role of bacterial biofertilizers in agriculture and forestry. *AIMS Bioengineering*, *2*(3), 183-205. http://dx.doi.org/10.3934/bioeng.2015.3.183

Habib, A. M., &Zhagloul, S. M. (2012). Effect of chemical, organic and bio-fertilization on growth and flowering of Chrysanthemum frutescens plants. *Journal of Horticultural Science and Ornamental Plants*, *4*(2), 186-194.

Herrmann, L. & Lesueur, D. (2013). Challenges of formulation and quality of biofertilizers for successful inoculation. *Appl Microbiol Biotechnol*, *97*(20), 8859-8873. http://dx.doi.org/10.1007/s00253-013-5228-8

Isbell, F., Reich, P. B., Tilman, D., Hobbie, S. E., Polasky, S., & Binder, S. (2013). Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity. *Proceedings of the National Academy of Sciences*, *110*(29), 11911-11916.

Joseph, S. (2014). ISOLATION OF BLUE GREEN ALGAE AND THEIR APPLICATION AS BIO FERTILIZER. *St. Stephen's Journal of Multidisciplinary Studies and Research*, 46.

Kandiannan, K., Sivaraman, K., Anandaraj, M., & Krishnamurthy, K. S. (2015). Growth and nutrient content of black pepper (Piper nigrum L.) cuttings as influenced by inoculation with biofertilizers. *Journal of Spices and Aromatic Crops*, *9*(2).

Kundan, R. & Pant, G. (2015). Plant Growth Promoting Rhizobacteria: Mechanism and Current Prospective. *Journal Of Biofertilizers & Biopesticides*, *06*(02). http://dx.doi.org/10.4172/jbfbp.1000155

Mahdi, S., Hassan, G., Samoon, S., Rather, H., Showkat, A., & Zehra, B. (2010). REVIEW ARTICLE BIO-FERTILIZERS IN ORGANIC AGRICULTURE. *Journal Of Phytology*. Retrieved from http://www.journal-phytology.com

Maiti, D. (2011). Improving Activity of Native Arbuscular Mycorrhizal Fungi (AMF) for Mycorrhizal Benefits in Agriculture: Status and Prospect. *J BiofertilBiopestici*, *02*(03). http://dx.doi.org/10.4172/2155-6202.s1-001

Mekonnen, M. M., & Hoekstra, A. Y. (2015). Global gray water footprint and water pollution levels related to anthropogenic nitrogen loads to fresh water. *Environmental science & technology*, *49*(21), 12860-12868.

Mohammadi, K., & Sohrabi, Y. (2012). Bacterial biofertilizers for sustainable crop production: a review. *ARPN J Agric Biol Sci*, *7*(5), 307-316.

Mostafa, G. & Abo-Baker, A. (2010). Effect of Bio- and Chemical Fertilization on Growth of Sunflower (Helianthus annuus L.) at South Valley Area. *Asian Journal Of Crop Science*, *2*(3), 137-146. http://dx.doi.org/10.3923/ajcs.2010.137.146

Olivares, J., Bedmar, E. J., & Sanjuán, J. (2013). Biological nitrogen fixation in the context of global change. *Molecular Plant-Microbe Interactions*, *26*(5), 486-494.

Pandit, N. (2012). Vermicomposting Biotechnology: An Eco-Loving Approach for Recycling of Solid Organic Wastes into Valuable Biofertilizers. *J Biofertil Biopestici*, *03*(01). http://dx.doi.org/10.4172/2155-6202.1000113

Pandit, R., Kunjadia, P., Mukhopadhyaya, P., & Kunjadia, A. (2014). Inorganic phosphate solubilizing potential of Arthrobotrys conoides and Duddingtonia flagrans, a nematode trapping fungi a potential biocontrol agent. *Journal of Agricultural Technology*, *10*(3), 559-570.

Paul Khurana, M. (2013). An Inoculating Potential of Phosphate-Solubilising Microbes as Biofertlizers. *J Biofertil Biopestici*, *04*(01). http://dx.doi.org/10.4172/2155-6202.1000e110

Phosphate Solubilization: Their Mechanism Genetics And Application. (2011). *IJMB*, *9*(1). http://dx.doi.org/10.5580/2327

Raja, N. (2013). Biopesticides and Biofertilizers: Ecofriendly Sources for Sustainable Agriculture. *J Biofertil Biopestici*, *04*(01). http://dx.doi.org/10.4172/2155-6202.1000e112

Rajendra,M. (2013). Botanical Pesticides: Current Challenges and Reverse Pharmacological Approach for Future Discoveries. *J Biofertil Biopestici*, *05*(02). http://dx.doi.org/10.4172/2155-6202.1000e125

Reddy, P. P. (2016). Integrated Nutrient Management. In *Sustainable Intensification of Crop Production* (pp. 193-206). Springer Singapore.

Sadhana, B. (2014). Arbuscular Mycorrhizal Fungi (AMF) as a biofertilizer. A review. *Int J CurrMicrobiolApplSci*, *3*, 384-400.

Sane, S. & Mehta, S. (2015). Isolation and Evaluation of Rock Phosphate Solubilizing Fungi as Potential Biofertilizer. *Journal Of Biofertilizers & Biopesticides*, *06*(02). http://dx.doi.org/10.4172/jbfbp.1000156.

Scholz, R. W., Roy, A. H., & Hellums, D. T. (2014). *Sustainable phosphorus management: a transdisciplinary challenge* (pp. 1-128). Springer Netherlands

Shah, S., Shah, R., Xu, H., &Aryal, U. (2007). Biofertilizers: An Alternative Source of Nutrients for Sustainable Production of Tree Crops. *Journal Of Sustainable Agriculture*, *29*(2), 85-95. http://dx.doi.org/10.1300/j064v29n02_07

Sharma, S. B., Sayyed, R. Z., Trivedi, M. H., & Gobi, T. A. (2013). Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus*, *2*(1), 587.

Singh, R., Kumar, P., Prasad, B., & Singh, S. (2015). Effect of biofertilizers on growth, yield and economics of rice (Oryza sativa L.). *IRJAES*, *6*(2), 386-391. http://dx.doi.org/10.15740/has/irjaes/6.2/386-391

Suseelendra Desai, P. (2012). Plant Growth Promoting Pseudomonas spp. from Diverse Agro-Ecosystems of India for Sorghum bicolor. *J Biofertil Biopestici*, *03*(03). http://dx.doi.org/10.4172/2155-6202.s7-001 Schenck zu Schweinsberg-Mickan, M. & Müller, T. (2009). Impact of effective microorganisms and other biofertilizers on soil microbial characteristics, organic-matter decomposition, and plant growth. *J. Plant Nutr. Soil Sci.*, *172*(5), 704-712. http://dx.doi.org/10.1002/jpln.200800021

Taiwo, L. (2006). Growth response of tomato (<i>Lycopersicumesculentum</i> Mill) inoculated with <i>Azotobacter croococcum</i> in an alfisol. *Moor Journal Of Agricultural Research*, *5*(1). http://dx.doi.org/10.4314/mjar.v5i1.31794

Tiyagi, S., Ansari, S., Rizvi, R., Mahmood, I., & Khan, Z. (2015). Evaluation of Organic Matter, Bio-inoculants and Inorganic Fertilizers on Growth and Yield Attributes of Tomato with Respect to the Management of Plant-Parasitic Nematodes. *Emir. J. Food Agric*, *17*(1), 1. http://dx.doi.org/10.9755/ejfa.2015.04.036

Vaishampayan, A., Sinha, R., Hader, D., Dey, T., Gupta, A., Bhan, U., & Rao, A. (2001). Cyanobacterial biofertilizers in rice agriculture. *Bot. Rev*, *67*(4), 453-516. http://dx.doi.org/10.1007/bf02857893

Vassilev, N., Mendes, G., Costa, M., & Vassileva, M. (2014). Biotechnological Tools for Enhancing Microbial Solubilization of Insoluble Inorganic Phosphates. *Geomicrobiology Journal*, *31*(9), 751-763. http://dx.doi.org/10.1080/01490451.2013.822615

Venterea, R. T., Halvorson, A. D., Kitchen, N., Liebig, M. A., Cavigelli, M. A., Del Grosso, S. J., ... & Stewart, C. E. (2012). Challenges and opportunities for mitigating nitrous oxide emissions from fertilized cropping systems. *Frontiers in Ecology and the Environment*, *10*(10), 562-570.

Vitousek, P. M., Naylor, R., Crews, T., David, M. B., Drinkwater, L. E., Holland, E., ... & Nziguheba, G. (2009). Nutrient imbalances in agricultural development. *Science*, *324*(5934), 1519-1520.

Wang, L., Lu, X., Yuan, H., Wang, B., & Shen, Q. (2015). Application of Bio-organic Fertilizer to Control Tomato Fusarium Wilting by Manipulating Soil Microbial Communities and Development. *Communications In Soil Science And Plant Analysis*, *46*(18), 2311-2322. http://dx.doi.org/10.1080/00103624.2015.1081694

Youssef MMA, &Eissa MFM, (2014). Biofertilzers and their role in management of plan parasitic nematodes. Review .*E*3 .J *Biotechnol. Pharm., Res*.5:1:001-006.