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ROLE OF PLANT GROWTH PROMOTING RHIZOBIA STRAINS IN AGRICULTURE FOR SUSTAINABLE CROP YIELD (A REVIEW)

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ABSTRACT

One of the challenges of globalization to developing countries is how to increase agricultural production that will take care of the rapid increase in population.This can be achieved by the use of plant growth promoting rhizobium (PGPR) which are various species of beneficial microorganisms grown in the rhizosphere, participating in nutrient cycling and the production of plant growth promoting substances. Some of the PGPR are considered biofertilizer due to their biofertilization potential. Some biofertilizing-PGPRs produce phytohormones such as indole aceticacid, gibberellins and cytokinins that cause an increase in plant foliage, root elongation, and fruit yield. It increases crop yield and nutrient availability, low cost, prevent plant pests and diseases, stimulate plant growth, bio remediation, increase resistance to water stress, mitigate or reduce greenhouse gas emission, land sustainability and improve soil quality. It is currently use in developing countries as a biofertilizer to substitute chemical fertilizer which is unsustainable, causing soil degradation, environmental pollution, high cost, and energy expensive, causing serious health hazards, reduce biodiversity, leaching, acidification and denitrification. This paper is therefore, intends to review the role of plant growth promoting rhizobia strains as biofertilizer for sustainable crop yield.

Key Words: Biofertilizer, Chemical fertilizer, Pant growth, Rhizobium, yield

INTRODUCTION

Rhizobia are defined as nitrogen-fixing soil bacteria capable of inducing the formation of root or stem nodules on leguminous plants in which atmospheric nitrogen is reduced to ammonia for the benefit of the plant. Although majority of legumes form symbiotic relationship with members of genera that belong to the class Alphaproteobacteria *(Allorhizobium, Azorhizobium, Blastobacter, Bradyrhizobium, Devosia, Ensifer, Mesorhizobium, Methylobacterium, Rhizobium an Sinorhizobium*), some legumes, such as those in the large genus *Mimosa,* are nodulated predominately by members of the class *Betaproteobacteria* in the genera *Burkholderia* and *Cupriavidus* (Gyaneshwar *et al.*, 2011). During the symbiotic process, rhizobia reduce atmospheric nitrogen into a form directly assimilated by plants (ammonium).

Rhizobium is a genus of gram-negative, motile bacteria whose members are most notable for their ability to establish a symbiotic relationship with leguminous plants, such as peas, soybeans and alfalfa. This relationship leads to the establishment of specialized structures called nodules. In these structures the bacteria are able to convert atmospheric nitrogen into ammonia, a process called nitrogen fixation. The ammonia is used by the plant as a nitrogen source. Other genera, such as *Azorhizobium* and *Bradyrhizobium* can also nodulate leguminous plants and together with *Rhizobium*, they are referred to as rhizobia. Members of the genus *Rhizobium* specifically form root nodules, but some other rhizobia can also form nodules on plant stems. Rhizobia are *diazotrophic*bacteria that fix nitrogen after becoming established inside the root nodules of legumes*(Fabaceae*). To express genes for nitrogen fixation, rhizobia require a planthost and cannot independently fix nitrogen (Zahran, 1999).

It is the most well- known species of a group of bacteria that acts as the primary symbiotic fixer of nitrogen. These bacteria can infect the roots of leguminous plants, leading to the formation of lumps or nodules where the nitrogen fixation takes place.

The bacterium's enzyme system supplies a constant source of reduced nitrogen to the host plant and the plant furnishes nutrients and energy for the activities of the bacterium. About 90% of nitrogen required by the plant is provided as a result of legume-rhizobium symbiotic relationship .The soil is also enriched with nitrogen that can be used by subsequent crops (Chen, 1999).

The ability of rhizobia to fix nitrogen reduced significantly the use of chemical fertilizers in agriculture. The review is aimed to study the role of growth promoting rhizobium strain as a biofertilizer for sustainable crop yield, maintenance and restoration of soil fertility, less expensive, reduce groundwater's pollution and requirements for nitrogenous fertilizers during the growth of leguminous crops.

Taxonomy

Rhizobia are soil bacteria that can be classified fall into two: alphaproteobacteria and betaproteobacteria.Initially, all rhizobia were classified in the genus *Rhizobium*, with the species designation related to the legume species. However, many rhizobia are able to establish symbiotic interactions among taxonomically distinct legume families and the same legume may enter into symbiosis with distinct rhizobial species. Subsequently, more detailed bacterial classification was performed on the basis of the phenotypes and genotypes of the strains. In particular, the rhizobia were first broadly divided on the basis of generation time, with species grouped as fast growing genera (*Rhizobium*, *Allorhizobium*, *Sinorhizobium,* and*Mesorhizobium*) or slow growing genera (*Bradyrhizobium*) . Finer taxonomic differences and division of the species into distinct genera were then performed based on support of analyses of molecular phylogenies of taxonomic markers, such as the 16S rRNA encoding gene.

The taxonomy of bacterial endosymbionts of leguminous plants has experienced a profound series of extensions in the recent past (Young, 2003). Currently, there are seven genera of rhizobia containing about 40 species as Alpha-proteobacteria: *Allorhizobium, Azorhizobium*, *Bradyrhizobium, Mesorhizobium, Rhizobium, Sinorhizobium* (Wei *et al.,* 2002) and a species in the genus *Methylobacterium* (Sy *et al.,* 2001). New lines that contain nitrogen-fixing legumes symbionts include *Ochrobactrum* (Ngom *et al.,* 2004; Trujillo *et al.*, 2005; Rivas *et al.,* 2003), *Blastobacter* (Van Berkum and Eardly, 2002) and *Methylobacterium* (Jaftha *et al.,*2002; Jourand *et al.,* 2004) in the alpha-Proteobacteria; *Burkholderia* (Moulin *et al.,* 2001), *Cupriavidus* (Chen *et al.*, 2001;Vandamme and Coenye, 2004) in the beta-Proteobacteria; and some unclassified strains in the gamma-Proteobacteria (Benhizia *et al.*, 2004) were recently described.

Now a day, it is recognized that the rhizobia are paraphyletic and are present in unique taxonomic groups spread throughout the α- and β-subdivision (classes) of *Proteobacteria*. They are scattered among symbiotic, nonsymbiotic, photosynthetic, and pathogenic (for plants and animals) relatives. In particular, rhizobia are found within the genera *Allorhizobium*, Azorhizobium, *Bradyrhizobium*, *Mesorhizobium*, *Neorhizobium*, *Rhizobium*, *Sinorhizobium*, and *Methylobacterium* (*α*-rhizobia), as well as several *Burkholderia*and*Cupriavidus*strains, which in 2001 were discovered as the first examples of nodulating β-proteobacteria Despite their phylogenetic differences, as well as the large panel of metabolic capabilities that may also differ between species, presently any species capable of fixing nitrogen within legume nodules is referred to as a rhizobium (Alice *et al.,*2019).

Regardless of their phylogeny, the rhizobia of the α-proteobacteria and β-proteobacteria have large genome sizes and often contain a divided genome structure . In general, genes required for nodule formation and symbiotic interaction are situated on mobile genetic elements, for example, in symbiotic islands on the chromosome (as, for instance, in *Mesorhizobium loti* and *Bradyrhizobium diazoefficiens*) or on large plasmids (as in *Rhizobium leguminosarum*, *Rhizobium etli*, Sinorhizobium *meliloti*, *Burkholderia phymatum*, and *Cupriavidus taiwanensis*). The presence of symbiotic genes on mobile elements contributes to the spread of symbiotic genes through horizontal gene transfer, and the conversion of non symbiotic strains into symbiotic strains .At the same time, this may be related to the observation that symbiotic abilities in rhizobia are genetically unstable, which in turn could explain why non symbiotic rhizobia remain a consistent component of bacterial soil population (Alice *et al.,* 2019).

Root nodule formation and mechanism of action of rhizobium

Root nodules occur on the roots of plants primarily (*Fabaceae)* that associate with symbiotic fixing bacteria. Under nitrogen-limiting conditions, capable plants form a symbiotic relationship with a host-specific strain of bacteria known as rhizobia. This process has evolved multiple times within the *Fabaceae.* It includes legume crops such as beans and peas. Within legume nodules, nitrogen gas from the atmosphere is converted into ammonia, which is then assimilated into amino acids (the building blocks of proteins), nucleotides (the building blocks of DNA and RNA as well as the important energy molecule ATP), and other cellular constituents such as vitamins, flavones, and hormones.

Their ability to fix gaseous nitrogen makes legumes an ideal agricultural organism as their requirement for nitrogen fertilizer is reduced. Indeed high nitrogen content blocks nodule development as there is no benefit for the plant of forming the symbiosis. The energy for splitting the nitrogen gas in the nodule comes from sugar that is translocated from the leaf (a product of photosynthesis). Malate as a breakdown product of sucrose is the direct carbon source for the bacteroid. Nitrogen fixation in the nodule is oxygen sensitive. Legume nodules harbor an iron containing protein called leghaemoglobin, closely related to animal myoglobin, to facilitate the conversion of nitrogen gas to ammonia (Wagner, 2011).

Sets of genes in the bacteria control different aspects of the nodulation process. One Rhizobium strain can infect certain species of legumes but not others e.g. the pea is the host plant to *Rhizobium leguminosarum* biovarviciae, whereas clover acts as host to *Rhizobium leguminosarum biovar trifolii*. Specificity genes determine which .Rhizobium strain infects which legume. Even if a strain is able to infect a legume, the nodules formed may not be able to fix nitrogen. Such rhizobia are termed ineffective. Effective strains induce nitrogen-fixing nodules. Effectiveness is governed by a different set of genes in the bacteria from the specificity genes. Nod genes direct the various stages of nodulation. The initial interaction between the host plant and free-living rhizobia is the release of a variety of chemicals by the root cells into the soil. Some of these encourage the growth of the bacterial population in the area around the roots referred to rhizosphere. Reactions between certain compounds in the bacterial cell wall and the root surface are responsible for the rhizobia recognizing their correct host plant and attaching to the root hairs (Indge, 2000).

Flavonoid secreted by the root cells activates the nod genes in the bacteria which then induce nodule formation. The whole nodulation process is regulated by highly complex chemical communications between the plant and the bacteria. Once bound to the root hair, the bacteria excrete nod factors. These stimulate the hair to curl. Rhizobia then invade the root through the hair tip where they induce the formation of an infection thread. This thread is constructed by the root cells and not the bacteria and is formed only in response to infection. The infection thread grows through the root hair cells and penetrates other root cells nearby often with branching of the thread. The bacteria multiply within the expanding network of tubes, continuing to produce nod factors which stimulate the root cells to proliferate, eventually forming a root nodule. Within a week of infection small nodules are visible to the naked eye. Each root nodule is with thousands of living Rhizobium bacteria, most of which are in the form known as bacteroids. Portions of plant cell membrane surround the bacteroids. These structures, known as symbiosomes, which may contain several bacteroids or just one, it is in this structure where nitrogen fixation takes place (Moran, 1999).

An enzyme referred to as nitrogenase catalyses the conversion of nitrogen gas to ammonia in nitrogen-fixing organisms. In legumenous plants, it ooccurs within the bacteroids. For the process to take place, hydrogen as well as energy from ATP is required. The nitrogenase enzyme is sensitive to oxygen and has different mechanisms for protecting it, including high rates of metabolism and physical barriers.

Azobacter overcomes oxygen sensitivity by having the highest rate of respiration, thus maintaining a low level of oxygen in its cells. Rhizobium oxygen levels in the nodule is enhance by leghaemoglobin.It is a red iron-containing protein has a similar function to that of haemoglobin; binding to oxygen. This provides sufficient oxygen for the metabolic functions of the bacteroids but prevents the accumulation of free oxygen that would destroy the activity of nitrogenase. (Chen, 1999).

Legumes release organic compounds as secondary metabolites called flavonoids from their roots, which attract the rhizobia to them and which also activate *nod* genes in the bacteria to produce nod factors and initiate nodule formation (Esseeling, 2003; Eckardt, 2006) .These *nod* factors initiate root hair curling, within the root tip, a small tube called the infection thread forms, which provides a pathway for the *Rhizobium* to travel into the root epidermal cells as the root hair continues to curl (Slonczewski, 2017).

Partial curling can be achieved by *nod* factor (Esseling, 2003).This was demonstrated by the isolation of *nod* factors and their application to parts of the root hair. The root hairs curled in the direction of the application, demonstrating the action of a root hair attempting to curl around a bacterium. Even application on lateral roots caused curling. This demonstrated that it is the *nod* factor itself, not the bacterium that causes the stimulation of the curling (Esseling, 2003).

When the nod factor is sensed by the root, a number of biochemical and morphological changes occur: cell division take place which triggered the formation nodule, and the root hair growth is redirected to curl around the bacteria until it fully encapsulates one or more bacteria. The bacteria encapsulated divides , forming a micro colony. From this micro colony, the bacteria enter the developing nodule through the infection thread, which grows through the root hair into the basal part of the epidermis cell and onwards into the root cortex; they are then surrounded by a plant-derived symbiosome membrane and differentiate into bacteroids that fix nitrogen (Mergaert *et al.,*2006).

Effective nodulation takes place approximately four weeks after crop planting, with the size, and shape of the nodules dependent on the crop. Crops such as soybeans or peanuts will have larger nodules than forage legumes such as red clover, or alfalfa, since their nitrogen needs are higher. The number of nodules, and their internal color, will indicate the status of nitrogen fixation in the plant (Adjei, 2016).

Nodulation is controlled by numerous of processes, both external (heat, acidic soils, drought, nitrate) and internal (auto regulation of nodulation, ethylene) (Reid, 2011). Auto regulation of nodulation controls nodule number per plant through a systemic process involving the leaf. Leaf tissue senses the early nodulation events in the root through an unknown chemical signal and then restricts further nodule development in newly developing root tissue. The Leucine rich repeat (LRR) receptor kinases (NARK in soybean (*Glycine max*); HAR1 in *Lotus japonicus*, SUNN in *Medicago truncatula*) are essential for autoregulation of nodulation (AON). Mutation leading to loss of function in these AON receptor kinases leads to super nodulation or hyper nodulation. Often root growth abnormalities accompany the loss of AON receptor kinase activity, suggesting that nodule growth and root development are functionally linked. Investigations into the mechanisms of nodule formation showed that the ENOD40 gene, coding for a 12–13 amino acid protein is up-regulated during nodule formation (Mergaert *et al.,* 2006).

Legume–rhizobium interaction

Rhizobia are bacteria capable of entering their legume hosts through root hairs, sites of lateral root emergence, or directly through root epidermis (Sprent and sprent*,* 1990), where they can induce the development of nodules for biological nitrogen fixation (Gage and Margolin, 2000). The formation of root nodules involves complex molecular signaling pathways between legumes and rhizobia (Stacey *et al.,* 1995). Various bacterial nodulation genes (so-called Nod genes) respond to plant root exudates (typically flavonoids) by producing nodulating factors (nod factors), leading to the initiation of root nodule formation. These nod factors are thought to be important determinants of legume–rhizobium specificity. Nod genes are located on symbiotic plasmids or symbiotic islands, highly mobile genetic elements that can be transferred between different rhizobial species and even genera by horizontal gene transfer (HGT). Within root nodules, organic forms of reduced atmospheric nitrogen produced by the bacteria are utilized by the host plant and ultimately enter the earth's food webs. In exchange, bacterial symbionts acquire carbohydrates from legumes, rhizobia are not monophyletic and represent a diverse array of bacteria found in both the Alphaproteobacteria ('alpha rhizobia', e.g. genera *Rhizobium* and *Bradyrhizobium*) and Betaproteobacteria ('beta rhizobia', e.g. genera *Burkholderia* and *Cupriavidus*) classes (Gyaneshwar *et al.,* 2011).

The unique partnership between legumes and rhizobia has been suggested as a major contributing factor to the success of some legumes as prominent invasive species in many parts of the world and that the ability to find 'compatible' rhizobia in introduced regions plays an important role in establishment success of legumes. Two scenarios are plausible, either invasive legumes form interactions with native rhizobia, or they are co-introduced with their symbionts. The former would be facilitated by generalism in invasive legumes (i.e. increasing the probability of encountering suitable rhizobia in the invasive range) or by evolutionary change allowing establishment of novel interactions with native rhizobia. Novel associations and co-introductions of legumes and rhizobia will result in very different interaction network signatures. Under co-invasion, the introduced legume–rhizobium partnership should form an isolated module within the interaction network; while under the alternative scenario there is overlap in rhizobial partners between native and invasive legumes (i.e. they should be connected by shared rhizobia).

ROLE OF GROWTH PROMOTING RHIZOBIA STRAINS IN AGRICULTURE

Some of the roles of growth promoting rhizobium in agriculture include the followings:

Increased yield and nutrient availability

Growth promoting rhizobium synthesize volatile organic compound such as acetone, 3-butanediol, terpenes, jasmonates and isoprene which are good source of natural compounds that can increase crop productivity.

It causes an increase in the biosynthesis of essential oil and growth parameters in *Mentha piperita* (Peppermint) (Santoro *et al.*, 2011), during metabolic activities and play important roles in stimulating plant growth and as signals in plant-microbe interactions (Insam and Seewald, 2010).

Legume yield among smallholder farmers can be increased by using N-fixing biofertilizers such as *Rhizobium* and *Bradyrhizobium* (Hassen *et al.*, 2016). For example, inoculation of soybean causes an increase in yield, improves soil organic matter while also fixing about 80% of soybean Nitrogen need (Chianu *et al.*, 2010). It was revealed by the same report that biofertilizer could replace about 52% of Nitrogen fertiliser and cause an increase in rice yield over the control. *Rhizobium* biofertilizer alone can supplement about 50% of the fertilizer need of crops in most arid and semiarid marginal lands of Zimbabwe, Tanzania, and Kenya, which are deficient in Nitrogen .

Nutrient Supply

Biological nitrogen fixation (BNF), a natural process of fixing Nitrogen in the soil, has been put at different values. Galloway (1998) estimated the annual BNF to be about 90–130 Tg N year^{-1} while Boyer *et al.* (2004) reported it to be roughly 107 Tg N year^{-1}. Bhattacharyya (2014) estimated BNF on land to be 140 Tg N year^{-1}. Interestingly, the energy bill of this process is fully paid by nature. Similarly, it has been reported that about 48–300 kg N/ha can be fixed by BNF on a grain legume plot in a season (Ngetich *et al.,* 2012). This low-cost method of supplying nutrient to the soil has made the use of biofertilizer economical for smallholder farmers. In addition, the quantity of biofertilizer required to achieve the same amount of nutrients supplied by inorganic fertiliser is relatively lower.

Prevention of plant pests and diseases

Rhizobium biofertilizer prevent plant diseases by directly inhibiting pathogens through their metabolic activities or indirect competition (Rudrappa *et al.,* 2008; García-Fraile *et al.,* 2015).The nodule-forming symbiotic association of legumes with *Rhizobium* has been established to enhance the synthesis of cyanogenic defense substances, which increases plant resistance to herbivore attack (Mazid *et al.,*2011 ; Megali *et al.,* 2015) . Bacterial and fungal attacks are major factors affecting smallholder productivity, especially in sub-Saharan Africa (Strange and Scott, 2005). It increases plant protection by influencing cellulase, protease, lipase, and β- 1, 3 glucanase productions and enhance plant depense by triggering induced systematic resistance through lipopolysaccarides, flagella, homoserine, lactones, acetoin, and butane diol against pest and pathogens (Subramaniam *et al.*, 2014).

Bioremediation

Rhizobacteria are now being employed to increase the solubility and cleanup of heavy metals in contaminated agricultural soil, thereby increasing the available arable land for smallholder farmers (Singh *et al.,* 2011; Khan, 2014). El-Kabbany (1998), evaluated the economic importance of beneficial microbes in bioremediation of major pesticides (organophosphate, carbamate, and chlorinated organic compounds) in Egypt. It was reported that PGPRs are potential remediation agent for pesticide-contaminated soil.

Bioremediation technology has been successfully used in many sub-Saharan African countries.

For instance, in crude oil contaminated soil of Ogoni land, in Delta state, Nigeria and in creosote-contaminated soil in South Africa. The technology has also been proposed for the clean-up of the pesticide-contaminated soil in Tanzania (Kishimba *et al.*, 2004). Biofertilizers such as cyanobacteria, *Azospirillum* and *Burkholderia* (Mathew *et al., 2014*), *Pseudomonas, Bacillus* (Adeleke *et al.,* 2012), Rhizobium and Enterobacter (Jain and Khichi, 2014) and *Aspergillus* and *Penicillium* (Abdel-Aziz, 2004) have also been found useful in bioremediation. The dual functions of these beneficial organisms in bioremediation and soil fertilization have made them a significant Integrated Soil Fertility Management (ISFM) technology (Bello *et al.,* 2015).

Water stress resistance

Many African countr*ies*, especially the arid and semi- arid areas, have long drought season and this has caused limitation to plant growth (Falkenmark and Rockström, 2008).In this situation, biofertilizers,which enhance plant water-stress tolerance, are of immeasurable importance (Dimkpa *et al.,* 2009 ; Hassen *et al.,*2016). The production of auxins, cytokinins, gibberellins and 1-aminocyclopropane-1-carboxylate (ACC) deaminase by some rhizobium biofertilizers has been reported to improve plant water stress tolerance (Mayak *et al.,* 2004; Khalil and El-Noemani, 2015).

Food safety

Current soil management strategies are mainly dependent on inorganic chemical-based fertilizers, which caused a serious threat to human health and environment. The exploitation of beneficial microbes like rhizobium as a biofertilizer has become paramount importance in agricultural sector for their potential role in food safety and sustainable crop production.

The eco-friendly approaches inspire a wide range of application of plant growth promoting - rhizobacteria (PGPRs), endo- and ectomycorrhizal fungi, cyanobacteria and many other useful microscopic organisms (Megali, 2013).

Bio diversity

It improves biodiversity of the soil since it depends on the natural micro flora of the soil which constitutes all kinds of useful bacteria such as rhizobium and fungi including the arbuscular mycorrhiza fungi (AMF) called plant growth promoting rhizobacteria (PGPR). Biofertilizer is one of such strategies that not only ensures food safety but also adds to the biodiversity of soil (Megali, 2013).Growth of micro organisms and beneficial soil worms are impelled.There is suppression or control through competition of pathogenic population of micro organism present in the soil, and also increase in microbial diversity creating suitable condition for the development of beneficial microorganism (Chen, 2006).

Biocontrol

Biocontrol is a process through which a living organism limit the growth of undesired organism or pathogens.Several rhizobial strains are reported to have the biocontrol properties.The mechanism of biocontrol by rhizobia include, competition for nutrient (Arora *et al .,*2001), production of antibiotics (Deshwal *et al*., 2003; Bardin *et al*.,2004; Chandra *et al*.,2007;) production of enzymes to degraded cell wall.The production of metabolites such as Hydrogen cyanide (HCN),phenazines,pyrrolnitrinviscoinamides,and tensin by rhizobia are also reported as other mechanisms for bio control (Bhattacharyya and Jha, 2012).

Abiotic stress resistance

Plant growth promoting microbes tend to tolerate abiotic stress like extremes of pH, salinity and drought, heavy metals and pesticide pollution which tend to enhanced plant growth and yield even under a combination of stresses.The mechanism for drought stress resistance include : drought-escapism,dehydration, postponement, and dehydretion tolerance (Turner *et al.,* 2000). Rhizobium delayed leaf senescence by the action of zeatin and anti oxidant enzymes .It produces metabolites known as compatibles solutes (such as trehalose,N-acetyl glutaminyl glutamine amide (NAGGN) and glutamel),osmoprotectants(betaine,glycerin-betaine,proline- betaine, glucans) and pipecolic acid and cations (calcium and potassium as tolerance mechanism (Streeter,2003; Sugawara *et al.,* 2010 Chen, 2011).In heavy metals contaminated soil,after successful symbiotic relationship,heavy metals tend to accumulate in the nodules there by removing heavy metals from the soil,enhance soil and plant health ,hence contributing to food and nutritional secuirity (Lucy *et al*., 2004).

Constraints of Growth Promoting Rhizobium as a biofertilizer

It is difficult to store and may have a short shelf-life span than chemical fertilizer. Main macro nutrients may not be available in sufficient quantities for growth and development of plant. Nutritional deficiencies could exist, caused by the low transfer of micro and macro nutrients (Carvajal-munoz and Camona-garcia 2012).It requires specific set of machinery or equipments for storage and is more perishable. It targeted specific nutrient.There is inconsistency of beneficial result of microbial use when single microbe was used \in the field.Some biofertilizer intended to fix nutrient in to the soil resulted in lower yield and in some cases less effective (Bashan and De bashan, 2005).

CONCLUSION

The role of growth promoting rhizobium strain in agriculture is of paramount importance in improving nutrient availability, eco-friendly, crop yield and growth, improve soil fertility, low cost of nutrient supply, prevent plant pests and diseases In addition, it could also protect natural environment, reduce health hazards, bioremediation, mitigation of gas emission and improve water stress

How ever , the extent of success in realizing the benefits of growth promoting rhizobium tends to diminishe as it moves from laboratory to green house and to fields, which reflect the scarcity of research on the beneficial effects of plant growth promoting microbes. Hence comprehensive research to exploit the potential of plant growth promoting rhizobium would provide an expansion of this research,commercialization and improve sustainability in agricultural production and also reduce or discourage the application of chemical fertilizer.

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