International Journal of Agriculture, Environment and Biotechnology
Citation: *IJAEB*: **14**(1): 63-73, March 2021
DOI: 10.30954/0974-1712.01.2021.7

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

AGRONOMY

Role of *Rhizobium* on Growth and Development of Groundnut: A Review

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Paper No. 882 **Received:** 17-01-2021 **Revised:** 24-02-2021 **Accepted:** 14-03-2021

ABSTRACT

To fulfill the demand of increased population it is very essential to enhance crop productivity with precise inputs. Non-judicious application of inorganic fertilizers and other agrochemicals is degrading soil health, creating environmental pollution and also contributing to climate change. Nowadays, people became more aware towards health risks and demand for quality foods with less chemical residues is increasing as there is a progression of demand for organic products. But it is very difficult to produce adequate quantity of organic foods for the raised population in the developing countries as per standard organic practices. That's why judicious use of inorganic fertilizers, organic manures and biofertilizers is required to supply nutrients to crops. Plant growth promoting rhizobacteria (PGPR), such as *Rhizobium* inoculation in groundnut (a major oilseed crop) can boost crop growth and enhance yield in a sustainable manner. Further, *Rhizobium* has multifaceted advantages in crop nutrient uptake and soil quality improvement. The article described the role of PGPR as well as *Rhizobium* in growth and productivity of groundnut towards production sustainability.

Highlights

- PGPR improves plant growth by increasing nutrient uptake, secreting growth promoting hormones, showing antagonistic effect to pest and diseases and reducing adverse effect of heavy metals and other pollutants.
- *Rhizobium* inoculation in groundnut results in higher growth and yield attributes which determines higher pod, kernel and oil yield.
- *Rhizobium* inoculation also helps in raising other beneficial micro-organisms such as *Arthrobacter simplex*, *Bacillus laevolacticus*, *B. amyloliquefaciens*, *Pseudomonas denitrificans*, and *P. rathonis* and residual soil fertility.

Keywords: Groundnut, growth, productivity, PGPR, *Rhizobium*, sustainability

In last decade, human population in the world has increased substantially and it is expected to increase by 2 billion people in next 30 years, 7.8 billion in 2020 to 9.9 billion in 2050 (IISD 2020) and this rise population is mainly in developing countries (Jewell *et al.* 2010). Focus on sustainable agriculture is most essential to feed this increased population (Meena *et al.* 2017). This raised population is over-exploiting cultivated land and other available natural resources that causing climate change. The anthropogenic causes triggering global warming and climate change are ultimately adversely impacting in adverse wayson crop growth, yield, quality and agricultural sustainability (Godfray *et al.* 2010; Kumar *et al.* 2017; Nath *et al.* 2017). According to Fixen (2005) to feed the increased population with adequate amount and good standard food at an

How to cite this article: Palai, J.B., Malik, G.C., Maitra, S. and Banerjee, M. 2021. Role of *Rhizobium* on Growth and Development of Groundnut: A Review. *IJAEB*, **14**(1): 63-73.

Source of Support: None; **Conflict of Interest:** None

economical price, higher yield per unit area should be achieved with low cost of cultivation to full fill the requirement. Aim of crop nutrient management is increase in yield per unit amount of applied nutrient keeping priority on soil health and nutrient loss reduction which will result in higher nutrient use efficiency and sustainability (Ramakrishna *et al.* 2017). Using plenty of chemical nutrients and plant protection chemicals in agriculture showed negative effect on environment, soil and water (Godfray *et al.* 2010; Kumar *et al.* 2017; Nath *et al.* 2017). Similarly, improper use of chemical nutrients and pesticides recorded detrimental impacts on soil properties like reduction of soil fertility, physical properties, organic matter, water holding capacity, quality reduction of food and water due to agrochemicals as well as negative impact on biodiversity (Kamdi *et al.* 2014). The country experienced with the advantages Green Revolution Technologies (GRTs) in enhancing food grain production and also the ill impacts of GRTs afterwards in terms of declinein soil fertility as well as land degradation, enhancement of soil salinity in green revolution tracts in India, loss of soil flora and fauna, genetic erosion, ecological imbalance, yield plateauing and uncertainty in livelihood of the small and marginal farmers. Now, maintenance of soil fertility and sustainability of agriculture production are of great tasks (Maitra *et al.* 2018)..

Nowadays, people are more concerned about their health because of increased awareness and that resulted in increased demand of organic foods all over world. Organic agriculture is a production system that can offer enough scope for controlling environmental degradation, assuring ecosystem services and agricultural sustainability (Maitra *et al.* 2020). Bulky organic manures, concentrated organic manures and biofertilizers are the organic sources of nutrients, but these are not available with adequate quantity for high nutrient demanding crops (Patel *et al.* 2018). Mariana *et al.* (2020) reported that in present scenario preference for chemical free food is increasing among the people, so it became a challenging task to improve crop productivity in sustained manner with high quality. Moreover, Singh and Singh (2002) reported that getting higher yield irrespective of soil health and environmental condition is not advisable, so it needs importance towards sustainability in agriculture. There is no single resource which can meet all nutrient demand by a plant. Keeping all these in consideration, combined and judicious application of chemical, organic and biological nutrients can increase soil quality and supply sustained crop productivity. (Nagaraj *et al.* 2018) also mentioned that integrated use of chemical fertilizer, organic manure and biofertilizers is the most efficient way of nutrient management for higher sustained crop yield and soil fertility. Groundnut is a leguminous edible oilseed crop. Both in world wide as well as in India share of groundnut to total oilseed is considerable. Among all plant growth promoting rhizobacteria (PGPR), *Rhizobium* has important role in the form of biofertilizer inoculation in groundnut to improve plant growth and yield attributes and yield. The present study describes details about PGPR, *Rhizobium* and its influence on groundnut performance, soil fertility and interaction with other microorganisms.

PGPR: Role in Plant Nutrient Management

Rhizosphere was first studied by Hiltner (1904) and according to him soil within the vicinity of root system is having more bacterial population than nearby soil. Those bacteria also get profit as root secrets some metabolites which are the sources of nutrient for them and around 5-21% of plant fixed carbon is released from root exudates (Marschner 1995). Vessey (2003) reported that in plant rhizosphere several species of soil bacteria increase their population through various processes that promote plant growth are known as plant growth promoting rhizobacteria (PGPR). There are about 2-5% of PGPR in soil and they enhance the growth of the plant by plant infection (Kloepper and Schroth 1978). According to Somers *et al.* (2004), there are four types of PGPR as per the growth promoting traits and they are biofertilizers, phyto-stimulators, rhizo-remediators and biopesticides (Fig. 1).

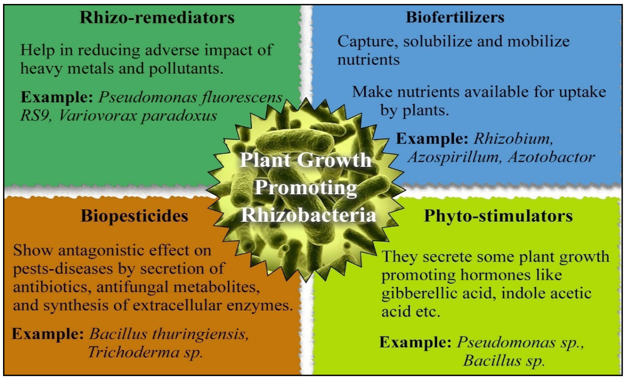

Fig. 1: Classification of plant growth promoting rhizobacteria (PGPR) (Somers *et al.* 2004)

Another classification of PGPR has given by Gray and Smith (2005) as per the plant tissue compartment.

Extracellular PGPRs (ePGPRs) that exist in the rhizosphere, on the rhizoplane or in the spaces between cells of the root cortex. Example of these PGPRs are *Agrobacterium*, *Arthrobacter*, *Azotobacter*, *Bacillus*, *Burkholderia*, *Caulobacter*, *Chromobacterium*, *Enterobacter*, *Enterococcus*, *Erwinia*, *Flavobacterium*, *Klebsiella*, *Micrococcus*, *Pseudomonas*, *Serratia* and so on.

Intracellular PGPR (iPGPR) that exist inside root cells, generally in specialized nodular structures. Ex. *Azorhizobium*, *Allorhizobium*, *Bradyrhizobium*, *Mesorhizobium*/*Ensifer*, *Rhizobium*and so on.

Most of the rhizobacteria are gram '–'ve and pleomorphic in nature and may be rod or cocci shaped with various colours such as creamy, white or translucent. Most of them show positive effect on plant growth. Microbial variation observed in rhizosphere are mainly with different plant growth promoting traits (Bhattacharyya and Jha 2012).

Rhizobium, the Most Widely Used Biofertilizer for Legumes

Legumes are well known soil fertility improver since ancient times and rhizobia was identified on later period. A publication on root nodulation in legumes was first written by Leonhard Fuchsius in 1542 (Fuchsius 1542) and Malpighi (1679) also found root nodules of *Phaseolus vulgaris* and *Vicia faba.* Boussingault (1838) in an experiment on legume crops and he recorded that there was increase in soil N content. Further, he was also the first who gave the concept of biological nitrogen fixation (BNF). Moreover, Lachmann (1858) took root nodules for microscopic study and reported that it consisted of vibrio like particles. After few years, Woronin (1866) mentioned that those particles were having properties like bacteria and the root nodules obtained from legumes belonging to a specific class of bacteria. Henceforth, in 1886, German scientists Hellriegel and Wilfarth observed that root nodules were able to fix atmospheric nitrogen and that created a milestone on symbiotic relation of *Rhizobium* and legumes. After two years,i.e., in 1888,the Dutch microbiologist Beijerinck for the first time identified and isolated one bacterium from root nodule and he named it as *Bacillus radicicola* (Beijerinck 1888). But one year later, another microbiologist, Frank (1889) named it as *Rhizobium leguminosarum*. To utilize *Rhizobium* culture in agriculture commercially it was used as biofertilizer production in the name of Nitragin and it was patented by Nobbe and Hiltner (1896). In 1921, Löhis and Hansen classified them into two types as per their growth ability, as fast growers and slow growers. Concept of cross inoculation between some *rhizobium* species and legume plants as a host was given Baldwin and Fred (1929). At very beginning, people used to transfer soil from leguminous crop field to non-leguminous crop fieldor to seeds before planting, but later on, solid carrier-based formulations used for inoculation of *Rhizobium* (Fred *et al.* 1932) and liquid carrier-based formulation used in later period (Van Schreven *et al.* 1953; Singleton *et al.* 2002). Rhizobium is highly

Table 1: Response of some commonly experimented PGPR on different crops

Sl. No.	PGPR	Plant	Pot / field experiment	Effect on plants	References
1	*Pseudomonas putida* (GAP-P45)	Maize	Pot	Performed best with respect to growth and development in moisture stress conditions	Sandhya *et al.* 2010
2	*Azospirillum* (45 L1)	Foxtail millet	Pot	Showed higher panicle and seed weight	Rafi *et al.* (2012)
3	*Azotobacter*	Wheat	Pot	Increased grainyield 16.5%–19.42% over control	Mahato and Kafle (2018)
4	*Rhizobium* (USDA 3456)	Groundnut	Field	Significantly higher haulm yield than un-inoculated treatment	Michael Asante *et al.* 2020
5	*Bradyrhizobim yuanmingense* (BR 3267)	Groundnut	Field	Significantly increased 13 to 40% pod yield than un-inoculated treatment	Michael Asante *et al.* (2020)
6	*Azospirillum*	Finger millet	Field	Enhanced growth characters like plant height, dry matter, leaf area index and grain yield	Ramya *et al.* (2020)

host specific and suitable species should be chosen for different crops (Table 2). Earlier it was found that in groundnut crop the slow growing *Bradyrhizobium* Zhang *et al.* 1999; Chen *et al.* 2003; Yang *et al.* 2005) acted more efficiently for establishment of root nodules, whereas in recent past,it was observed that fast growing rhizobium efficiently acted for effective root nodulation (Khalid *et al.* 2015; Akhal *et al.* 2008; Rosália *et al.* 2005). NC 92, IGR 6, IGR 40, TAL 1000 and TNAU 14 are some superior stains of *Bradyrhizobium* that work efficiently and recommended for groundnut (ICAR 2009). It has been observed that Rhizobium activity, population and its effect on groundnut differs according to different agroecological conditions (Table 3).

Table 2: Rhizobium species suitable for different crops

Species of *Rhizobium*	Associated crops
R. leguminosarum	*Lathyrus*, lentil, Peas (*Pisum*), *Vicia*
R. trifoli	*Trifolium*
R. phaseoli	*Phaseolus*
R. lupini	*Lupinus*
R. japonicum	*Glycine max*
R. meliloti	Fenugreek (*Trigonella*), Lucerne (*Medicago*), *Melilotus*
Cowpea miscellany	*Acacia, Albizzia, Atylosia,* blackgram, clusterbean, cowpea, *Dalbergia, Glyricidia,* greengram, groundnut, *Indigofera,* moth bean, *Prosopis,* redgram, *Sesbania, Stylosanthes,* sunnhemp, *Tephrosia*
Separate group	Bengalgram (gram)

Source: *Hirsch et al. 2001; Datta et al. 2015; Reddy and Reddy, 2015.*

Groundnut, a Legume Oilseed

Groundnut (*Arachis hypogaea* L.) is a self-fertilized annual leguminous oilseed crop and it is widely cultivated in the arid and semi-arid regions in the world (40°N and 40°S) from equatorial region to warm temperate region. Semiarid tropics are the major growing zone of groundnut crop (Fletcher *et al.* 1992; Tarimo 1997). In the world, after soybean, rapeseed and mustard and sunflower, it is the fourth most common source of edible oil and third most important source of vegetable protein (Ojiewo *et al.* 2020). Groundnut is one of the most vital cash crops of India (Madhusudhana 2013). On an average, groundnut kernels contain 45-51% oil, 25% protein and 24.2% carbohydrates (Rajgopal *et al.* 2000). Groundnut is also rich in vitamins like B group and E and rich in all the 20 essential amino acids among which arginine content is maximum. The calorific value of groundnut seed is 567 Kcal/100g of seed (Arya *et al.* 2016). Globally major amount (53%) of groundnut kernels is used for edible oil, 32% is consumed in confectionary and remaining quantity is used for food and seed production (Rajgopal *et al.* 2000). After oil extraction, the byproduct, i.e., oil cake, is used as cattle feed and concentrated organic manure (Rajgopal *et al.* 2000). Groundnut oil is rich in unsaturated fatty acids, such as poly unsaturated fatty acid (PUFA) (linoleic acid 25-35%) and mono unsaturated fatty acid (MUFA) (oleic acid 40-50%), moreover, it is very much suitable for deep frying because of its higher iodine value (ICAR-DGR, 2015). Worldwide groundnut area, production and productivity are 296 lakh ha, 488 lakh tone

Table 3: Effect of *Rhizobium* on groundnut under different agroecology

Sl. No.	Agroecology	Effect on groundnut	*Rhizobium* strain	References
	Salt stress	Unable for nodulating	*Bradyrhizobium sp.* ATCC10317	Dardanelli *et al.* (2009)
		Capable of nodulating	*Bradyrhizobium sp* TALl 371	
2	Soil acidity	Better performance in acidic soil	*Bradyrhizobium sp.* MAR 1510	Rossum *et al.* (1994)
		Better performance in neutral soil	*Bradyrhizobium sp.* MAR 411	
3	Nutrient solution containing high carbonate	Nodulation inhibited	*Rhizobium*	Tang *et al.* (1998)
4	Soil moisture deficiency	Little or no effect on N2-fixation	*Rhizobium sp.*	Venkateswarlu *et al.* (1989)
5	Waterlogged condition	Reduced *Rhizobium* population in groundnut after rice cultivation	*Rhizobium sp.*	Dey and Pal (2014)

and 1647 kg/ha respectively in 2019 (FAOSTAT, 2021). Globally, China is the largest producer of groundnut and India ranks second in groundnut production. Groundnut can be produced in diverse soil inclusive of light to heavy textured soil and the most suitable soil is light sandy-loam soil. Moreover, it requires warm climatic conditions with a nicely distributed rainfall ranging from 500 to 1000 mm (ICAR-DGR, 2015). In India, groundnut is grown in an area of 4.89 million hectare, with an yield of 1893 kg/ha and production of 9.25 Million tons. In India, Gujarat is the highest producer of groundnut and its contribution is 42.55% of total production in the country. In 2013-14, India imported 0.11 thousand tons of groundnut by spending rupees 0.36 crore, whereas, in the same year it exported 509.75 thousand tons of groundnut and earned 3187.66 crore revenue (Agricultural statistics at a glance 2019, GOI).

According to Singh *et al.* (1997) biological criteria for lesser yield in oilseeds is due to conversion of one gram glucose produced from photosynthesis into 0.83 g starch, 0.4 g protein and only 0.32 g of lipids. Therefore, it needs additional inputs for higher yield. Nutrients required for groundnut to produce 2000-2500 kg/ha of pod yield are 160-180 kg of N, 20-25 kg of P, 80-100kg of K, 60-80 kg of Ca, 15-20 kg S, 30-45 kg Mg, 3-4 kg Fe, 300-400 g Mn, 150-200 g Zn, 140-180 g B, 30-40 g Cu and 8-10 g Mo (Singh, 1999). Both primary and secondary macronutrients have distinct role in kernel filling and oil synthesis, whereas, sulphur (Tandon 1991) and calcium are most essential of oil synthesis and pod formation respectively. Biofertilizers are prepared by using microorganisms which can reduce cost of cultivation and make it environment friendly (Gupta *et al.* 2003). Gradually, use of biofertilizer is getting more importance as it includes microbial culture either for seed inoculation or soil application which results in higher crop yield (Mahdi 1992). As the biofertilizers consists of living microbial culture, so it has beneficial influence on plant performances both directly and indirectly (Fuentes-Ramirez and Caballero-Mellado 2005). Rhizobium forms nodule and fixes nitrogen biologically and thus, improve crop yield and soil quality (Fig. 2). (Chetti *et al.* 1995) found that highest growth parameters obtained from use of both *Rhizobium* and *Phosphobacterium* and that ultimately showed maximum dry matter accumulation in groundnut. Beneficial microorganisms present in the soil facilitate to increase nutrient availability. That's why plant growth promoting microorganisms (PGPM) has a distinct role in agriculture. Generally, PGPM includes both bacterial and fungal species. Use of plant growth promoting rhizobacteria (PGPR) is increasing steadily in all over world and showing positive influence on crop growth and productivity in most of the field crops which is a path towards sustainable agriculture (Sharma *et al.* 2016).

Influence of *Rhizobium* on growth and yield parameter of groundnut

Badawi *et al.* (2011) reported that Bradyrhizobium treated peanut crop resulted dry matter accumulation higher pod and straw yield than control. Basu *et al.* (2006) observed thatgrowth parameters of groundnut like plant height, number of branches per plant, leaf area index, number of nodules per plant were significantly higher with *Rhizobium* inoculation than the untreated treatments. Similarly,pod yield and haulm yield were also more with biofertilizer inoculation. Gunri *et al.* (2014) conducted an experiment on Red and Lataritic Zone of West Bengal and reported that groundnut seed inoculation with *Rhizobium* I (NRCG9) and *Rhizobium* II (IGR6) resulted significantly higher pod yield, haulm yield and number of pods per plant over control. Didagbé *et al.* (2014) studied on different strains of rhizobium in groundnut and noted that compared to control plant height was increased by 23% and 25% in case of WSM 4412 and STM5945 strain. They also reported that there were 38% and 33% increase in leaf number per plant by the application of STM 5894 and WSM 4412 strains of *Rhizobium* respectively. Laxminarayana and Patsram (2005) observed that groundnut seed inoculation with only *Rhizobium* without any organic manure or fertilizer application resulted higher pod yield than untreated control, but both were statistically at par with each other. But the same treatment resulted in significantly higher haulm yieldthan control. In another study, groundnut seed inoculated with NC-92 strain gave significantly higher nodules / plant, nodule dry weight/ plant than that of strain TAL-1371 and strain TAL-1000 (Ashraf *et al.* 2006). However, pods/plant, pod yield and haulm yield from the strain NC-92 also resulted in significantly higher values other two strains of *Rhizobium*. Gomoung *et al.* (2017) reported that different Rhizobium strains collected from different crops improved seed yield of groundnut. A study clearly indicated that seed inoculation with *Rhizobium* in groundnut significantly increased the number of nodules, shoot and root dry matter yields than un-inoculated treatment (Yusif *et al.* (2016). Kumar and Suganya (2017) concluded that among five strains of *Rhizobium* (namely, RS1, RS2, RS3, RS4 and RS5) inoculated in groundnut seed, RS3 resulted in higher shoot length and root length, number of nodules and pod yield. Influence of *Rhizobium* inoculation on growth and yield of groundnut was also noted by Sajid *et al.* (2011) and they found that there was significantly higher growth parameters like plant height, number of shoots, number of leaves, number of nodules, number of pods and pod yield than un-inoculated treatment.

Fig. 2: Root nodule from *Rhizobium* inoculated groundnut plant (Picture taken by Jnana Bharati Palai)

Interaction of *Rhizobium* with other PGPMS

The interaction between *Bradyrhizobium* (strain LMG9283) and *Arbuscular mycorrhizal* fungus (*Glomus intraradices*) showed synergistic effect on yield of groundnut Sene *et al.* (2010). Combined application of *Rhizobium* and phosphorus solubilizing micro-organism (PSM) enhanced germination percentage and root and shoot length of seedlings and 100 kernel weight than single inoculation with either *Rhizobium* or PSM (Singh *et al.* 2013).

In other leguminous crops also the combination of chemical fertilizer and different biofertilizers enhanced growth and productivity. Kumawat *et al.* (2017) reported that combined application of 75% recommended dose of fertilizer (RDF), *Rhizobium* and phosphate solubilizing bacteria (PSB) produced significantly higher seed and stover yields of fenugreek than 75% RDF and *Rhizobium* inoculation as seed treatment. Another prominent result indicated that yields of *Vicia faba* cv. Alborea co-inoculated with *Rhizobium leguminosarum* bv. *viceae* Z25c + *Azotobacter vinelandii* Dv42, *R. leguminosarum* bv. *viceae* Z25c + *Azotobacter vinelandii* ATCC 12837, *R. leguminosarum* bv. *viceae* Z25c + *Azotobacter chroococcum* H23 and *R. leguminosarum* bv. *viceae* Z25c + *Azospirillum brasilense* Sp7 were respectively more by 140.6%, 147.2%, 151.5% and 136.4%than inoculation of *R. leguminosarum* bv. *viceae* Z25 alone (Rodelas *et al.* 1999). Effect of co-inoculation with *Rhizobium* and *Bacillus cereus* in pigeon pea in pot culture resulted in 382% increase in nodule number, 196% increase in nodule dry weight and 116% increase in N fixation and 54% increase in grain yield (Tilak *et al.* 2006). In the same crop, they also tested co-inoculation of *Rhizobium* and *Pseudomonas fluorescens* and observed that 388% increase in nodule number, 267% increase in nodule dry weight and 134% increase in N fixation and 66% increase in grain yield.

Impact of Soil Nutrients on Activities of Rhizobium

Efficiency of a BNF microorganisms is known in a nutrient deficient soil and it was found that root nodulation is less in soils rich in readily available nitrogen (Pitumpe *et al.* 2020; Zahran 1999). Soil treated with 100% RDN through inorganic fertilizers showed comparatively a smaller number of root nodule than soil treated with 100% RDN through FYM and this indicated poor rhizobial activity in rich available nutrient (Baishya *et al.* 2014). Basically, phosphorus is a primary macronutrient, which helps in root development and nodule formation in legumes and plant growth Israel, (1987). Swarnalakshmi *et al.* (2020) mentioned that the bacteria which play major role efficiently in phosphorus solubilization are *Bacillus, Pseudomonas* and *Rhizobium.* As compared to fast multiplying rhizobia, slow multiplying rhizobia shows higher phosphorus deficiency tolerance (Beck and Munns 1985). There is also involvement of potassium (K) in nitrogen fixation. Sufficiency in potassium supply to plants increases carbohydrate accumulation due to higher photosynthesis and that allows better development of root nodules that ultimately results in higher nitrogen accumulation (Premaratne and Oertli, 1994).

Thomas and Hungria (1988) also suggested that potassium helps in transportation of nitrogenous compound from the N-fixing site (nodule) to other parts of the plants which promotes *Rhizobium* for further N reduction. Not only macronutrients, but also there are influence of soil micronutrients on activities of *Rhizobium*. Adissie *et al.* (2020) did not find any significant grain yield enhancement in *faba* bean due to combined application of *Rhizobium* strain EAL 1035 and zinc (2 kg/ ha) compared to the separate application of both. But combined application of *Rhizobium* strain EAL 1035 and boron (1.5 kg/ ha) resulted in higher grain yield by 13.9% and 65.9% over second highest recorded treatment (*Rhizobium* strain EAL 1018 alone) and control treatment, respectively.

Influence of Rhizobium on Soil Quality

Khaitov *et al.* (2016) revealed that there was increase in soil fertility status such as carbon, nitrogen and phosphorus in their experiment on chickpea. According to them, there was increase in total nitrogen (0.022 to 0.033 g kg^{-1}), carbon (0.054 to 0.084 033 g kg^{-1}) and phosphorus (0.007 to 0.015033 g kg^{-1}) content in *Rhizobium* inoculated chickpea field soil than control. Application of biofertilizer (*Rhizobium* and PSM) increased fertility status of post-harvest soil of summer groundnut such as N, P_2O_5, K_2O and S by 14.79%, 8.34%, 2.96%, 30.29% respectively than untreated control (Vala *et al.* 2018). Effect of *Rhizobium* inoculation in groundnut improved residual soil fertility status higher than control in terms of enrichment of N, P and K status of the post-harvest soil (Laxminarayana and Patsram 2005). Yusif *et al.* (2016) also observed similar result such as *Rhizobium* inoculated treatment in groundnut showed higher organic carbon, available N, P, K, Ca and Mg than *Rhizobium* un-inoculated treatment in post-harvest soil. Further, legumes are well known for symbiotic association with micro-organisms. Other than symbiotic *Rhizobium*, other free-living soil bacteria like *Arthrobacter simplex*, *Bacillus laevolacticus*, *B. amyloliquefaciens*, *Pseudomonas denitrificans*, and *P. rathonis*, and all aerobic or facultative anaerobic heterotrophic soil species, have been found to propagate more in presence of *Rhizobium* to promote plant growth (Maitra and Ray 2019; Qiao *et al.* 2012; Spehn *et al.* 2000).

CONCLUSION

From the beginning of crop cultivation importance of legumes with respect to soil health and sustainability is very well known. Use of chemical fertilizers in the post Green revolution era undoubtedly enhanced agricultural productivity, but it happened at a cost of agricultural sustainability. After realizing the adverse impacts of chemical inputs in agriculture, focus has been shifted to integrated management of nutrients and pests to reduce use of chemicals. Further, organic agriculture has created a huge potential for enhancing profitability in agriculture through export of organic produces. Both the approaches have created an enormous opportunity of using microbial inputs in ecofriendly agriculture. Earlier researches evidenced that inclusion of PGPR and as specially *Rhizobium* in groundnut improved crop yield, nutrient uptake and facilitated maintenance of soil fertility along with multiple environmental benefits. The review article concludes that targeting a higher productivity of groundnut and improving soil quality, *Rhizobium* inoculation can be preferred. Further, beneficial roles of *Rhizobium* and other PGPRs may lead towards agricultural sustainability.

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