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Research Article

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USE OF PLANT GROWTH PROMOTING RHIZOBACTERIA CONTAINING ACC-DEAMINASE ACTIVITY FOR ENHANCING GROUNDNUT YIELD UNDER RAINFED SCENARIO

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ABSTRACT

Groundnut (*Arachis hypogea*) is amongst the most valuable leguminous cash crops grown in rainfed areas. The role of plant growth promoting rhizobacteria (PGPR) containing ACC-deaminase is considered vital promoting plant roots under moisture deficit conditions. Under these circumstances a research experiment was conducted at the farm area of Soil and Water Conservation Research Institute, Chakwal in association with PMAS Arid Agriculture University Rawalpindi for 3 years consecutively during 2015-2017. The main objective of the experiment was to exploit and evaluate the impact of PGPR deaminase activity on yield of groundnut crop. The four treatments included farmer practice (no compost & inoculums), with inoculums, with compost and compost + inoculums in 4 replications under RCBD. The improvement recorded in the pod yield of groundnut was 12 %, in the number of pods plant^{-1} by 20 % and the shelling percentage by 2 % by application of the treatment inoculum + compost. Conclusively, it was ascertained that PGPR containing ACC-deaminase application is an effective approach to enhance groundnut crop production and soil characteristics of degraded soils under rainfed scenario.

Key words: Groundnut, rainfed, PGPR, ACC- deaminase

INTRODUCTION

Groundnut is a vital cash crop of Pakistan specifically in sandy and sandy loam soils and approximately 84 % of the total groundnut sowing area lies in the Punjab province. It is considered that by application of appropriate soil bacteria, leguminous groundnut crop after 30-40 days from sowing tends to supply its self-synthesized nitrogen. Hence, it becomes crucial to inoculate the seed prior to planting with collaborating rhizobium strain for getting higher yields. The application of PGPR in agriculture is an updated version of farming to boost crop productivity for adequately feeding the world (Glick 2012). Drought periods are quite unpredictable in rainfed areas, farmers are hesitant to purchase and apply chemical fertilizers in crops. Under these circumstances, PGPR application becomes pivotal for achieving higher groundnut production in rainfed areas. The PGPR are a heterogeneous group of free-living, soil borne bacteria. These microbes support plant growth directly by supplying nutrients to plants or by diminishing the harm from soil-borne plant microorganisms (Kloepper *et al*., 1980). Rhizospheric soil of groundnut has been displayed to have various plant growth promoting rhizobacteria. These valuable plants related microorganisms assume a vital part in supporting and/or expanding plant growth in both man-made and natural habitat (Compant *et al*., 2010). They have been known to animate and improve plant growth as they can improve and activate the nutrients supply, like nitrogen (Ahmad, 2012) and phosphorous (Rashid *et al*., 2004) and make them accessible for plant or by creation of phytohormones and growth regulators (Ahmad and Malik, 2011) as well as by implication by advancing plant advancement by the suppression of pathogens by restraining or adopting different restricting mechanisms of antibiosis (Rajkumar *et al*.,2010), iron sequestration by siderophores (Bar-ness *et al*., 1992), HCN (Keremer and Souissi, 2001), cell wall damaging proteins like chitinase, protease and cellulase and so on. (Ajit *et al*., 2006), and further developing soil structure by enhancing soil and sequestering harmful weighty metal species from contaminated soils and debasing xenobiotic compounds (like pesticides) and stress mitigation like high saltiness (Moreira *et al*., 2014; Ali *et al*., 2014). A vital quality of a few types of PGPR is the capacity to control ethylene development utilizing the ACC (1-aminocyclopropane-1-carboxylate) deaminase protein, consequently PGPR go about as an ACC sink. These PGPR hydrolyse the ACC radiated from the roots in the rhizosphere into smelling salts and α-ketobutyrate, and animate the expulsion of ACC from the roots to the soil

(Madhaiyan *et al*., 2006). The lowering of ACC contents in root tissues decreases the development of endogenous ethylene, advancing plant growth and development. Plant protection from dry spell has been accounted for to be upgraded by diminishing ethylene-interceded inhibitory affects for plant growth (Guo *et al*., 2004). Ethylene influences countless cycles engaged with plant growth and development and plays a key part in plant reaction to biotic and abiotic stresses (Abeles *et al*., 1992). Ethylene amalgamation happens in three progressive enzymatic changes. Methionine is first changed over completely to SAM (Sadenosyl methionine) trailed by the formation of ACC. Extended production of ACC in roots brings about higher ethylene biosynthesis by the ACC oxidase catalyst in various plant tissues (Chen *et al*., 2013). This is a typical response to the stimulation of root ethylene biosynthesis by dry spell. Expanded ethylene production negatively affects root growth and ultimately on plant growth and development (Davies *et al*., 2010). Ethylene influences photosynthesis and stomatal conductance, contingent upon ethylene production and stomatal aversion to it (Pierik., 2006). In addition, ethylene interacts with different chemicals, like auxin and abscisic acid, in controlling plant reaction to water deficiency. Dry spell prompts a decrease in stomatal conductance (gs), and low gs lessens the intercellular CO2 concentration (Ci) and brings down photosynthesis (Flexas *et al*., 2013). The pod yield of groundnut enhanced with the use of PGPR in Indian soils (Buddy *et al*., 2000). The growth and development attributes of field crops as maize (Jacoud *et al*., 1999), rice (Preeti *et al*., 2002) and groundnut (Badawi *et al*., 2011) improved with PGPR applications to seed. The better growth, biomass productivity and yield rely upon the enhanced nutrients supply to plans through extended root growth (length and branching), expanded vertical plant growth (plant height) because of additional carbon fixation and extended nodulation in legumes. The utilization of beneficial microorganisms in crop production and soil fertility improvement, for example, PGPR had expanded interest of agrarian researchers globally to achieve sustainability in farming. The ongoing trial was focused on to research the reaction of PGPR application on the growth and yield of groundnut crop under rainfed scenario of Chakwal, Pakistan.

MATERIALS AND METHODS

Isolation of Plant Growth Promoting Rhizobacteria (PGPR): Soil samples from rhizosphere in groundnut crop fields were collected at the stage of 45 days old in polythene bags. Rhizobacteria were isolated from the rhizospheric soil of groundnut ((BARI-2011)) based on the ACC-deaminase activity employing method given by Glick *et al*. (1995). Colonies of various morphologies were selected and purified. A total of 102 rhizobia isolates comprising ACC-deaminase activity were gathered. All those isolates were sub-cultured and maintained as stabs at 4 C in a cooling incubator.

Assessment of ACC deaminase activity: To determine ACC deaminase activity, Rhizobia isolates were cultured in 5 ml of TSB medium at 28 °C till reaching its to stationary phase. For induction of ACC deaminase activity under non-stress and drought stress conditions, the cells were centrifuged for collection, washed with 0.1 M Tris–HCl (pH 7.5), suspended in a 2 ml of modified DF minimal medium either supplemented with 3 mM final concentration of ACC without PEG (nonstress condition) or with PEG 6000 (−0.30 MPa; drought stress condition) and incubated at 28 °C with shaking for another 36–72 hours. Then ACC deaminase activity was determined by measuring the production of α-ketobutyrate and ammonia generated by the cleavage of ACC by ACC deaminase (Glick 2003).

Experimental details: A field experiment was conducted at Soil and Water Conservation Research Institute (SAWCRI) Farm, Chakwal in association with PMAS Arid Agriculture University Rawalpindi to determine the role of PGPR on groundnut yield during Kharif- 2015, 2016 and 2017. The experimental area was located at East longitude 72043 .640 and North latitude 32055 .770 with altitude of 1690 m ASL.

Composite soil sample was taken at 0-15 cm for physical and chemical characteristics and the land was prepared mechanically. The pre-sowing analysis of field soil revealed that its texture was sandy loam with properties as (pH: 7.8, EC: 0.46 dS m^{-1}) with low to medium soil nutrients (O.M 0.54%, available P: 05 $mgkg^{-1,}$ and Ext K: 122 $mgkg^{-1}$). The groundnut variety (BARI-2011) was sown during the month of April @100 kg seed/ha.

Mineral fertilizer was applied @ 30-80-30 kg N-P_2O_5-K_2O per hectare prior to sowing of groundnut. The inoculum effect was studied with and without compost. The seed was treated with the inoculum using method of sugar solution in deionized water for uniform mixing of seed in the inoculum paste while compost was applied @ 4.0 t $acre^{-1}$ prior to sowing of groundnut in respective plots.

The treatments included:

T_1 Control (no inoculum and no compost)
T_2 Inoculum
T_3 Compost
T_4 Inoculum + Compost

The trial was designed under Randomized Complete Block Design (RCBD) in 4 Repeats.

The groundnut variety BARI 2011 was sown during the month of April at the seed rate of 100 kg ha^{-1}. The groundnut was sown with line-to-line distance of 45 cm. During the month of October, the harvesting was completed using tractor operated digger. The data regarding dry pod yield, pods $plant^{-1}$, shelling percentage, plant height, haulm yield, 100 seed mass, root length, nodule number and nodule dry weight were recorded. Moreover, economic data (prices and labor used) for comparison of treatments was also collected. Samples were also taken for the analysis of N and P content in soil, shoot and kernel. A small dried sample (5 kg) of unshelled nuts was taken and shelled weight was recorded to obtain the groundnut shelling percentage. Shelling percentage can be used to get an estimate of yield when farmer has not yet shelled his harvest.

Shelling percentage= 100 x shelled weight (kg)/unshelled weight (kg)

Soil analysis: The collected soil samples were air dried in shade, crushed in wooden mortar and pestle and sieved through 2mm mesh size sieve. The pH and ECe were measured using procedures given by McLean, 1982. Soil organic matter was determined using the method illustrated by Walkley, 1947. While Available-P and exchangeable-K were measured applying methods given by Watanabe and Olsen, 1965 and Rhoades, 1982 respectively. Soil moisture contents were measured by applying the gravimetric method. The soil analysis was conducted in the laboratory of the SAWCRI, Chakwal.

The 3-year month wise meteorological data including rainfall, minimized and maximized temperature and Relative Humidity during crop growth period (April-Oct) was recorded and presented in Table 1

Table 1. Rainfall during crop growth period

Month	2015				2016				2017			
	Rainfall (mm)	**Min. temp (ºC)**	**Max. temp (ºC)**	**Relative Humidity (RH)**	**Rainfall (mm)**	**Min. temp. (ºC)**	**Max. temp. (ºC)**	**Relative Humidity (RH)**	**Rainfall (mm)**	**Min. temp. (ºC)**	**Max. temp. (ºC)**	**Relative Humidity (RH)**
April	120.4	14.9	29.2	73.0	1.3	13.7	32.3	59.0	94.3	15.4	31.5	47.1
May	1.6	18.8	35.8	34.5	33.4	20.5	38.8	41.4	52.1	21.3	37.3	47.1
June	48.5	21.92	36.48	47.0	82.8	23.9	38.8	59.3	50.7	23.2	36.0	54.7
July	151.1	23.24	33.69	75.3	269.2	23.6	35.3	72.4	238.9	24.0	34.0	73.6
Aug.	105.9	22.84	32.19	2.6	101.1	22.5	34.4	71.5	164.1	24.0	34.4	73.6
Sept.	38	20.3	32.7	73.5	61.4	21.3	35.1	67.2	25.3	20.5	34.4	63.2
Oct.	34.4	14.89	29.95	53.9	0	14.5	33.0	56.8	1.2	15.9	33.1	54.0
Total	499.9				549.2				626.6			

Source: SAWCRI Meteorological Station Chakwal

RESULTS

Plant Height: The results (Table 2) indicated that the maximal plant height (28.4 cm) was observed in treatment with inoculum + compost followed by the treatment comprising inoculum (25.5 cm) alone against control (without compost and PGPR) i.e 22.9 cm.

Number of Pods: The data regarding number of pods per plant of groundnut is given in Table 2. It was observed that maximum number of pods per plants (45.7) were recorded in treatment having inoculum + compost followed by the treatment having inoculum (42.3). According the data lowest pods per plants were recorded in control.

Haulm Yield: According to the data presented in the Table 2, the maximum haulm yield (1,243 kgha^{-1}) was recorded in the treatments with inoculum + compost followed by compost (1,047 kg ha^{-1}). Minimum haulm yield was recorded 825.3 kg ha^{-1} in control practice without the amendment of compost or inoculum.

Dry Pods Yield: The data presented in table 2 indicates that maximum dry pods yield was recorded in the treatment having compost + inoculum (2061kgha^{-1}) followed by PGPR inoculum (1823 kgha^{-1}). Minimum dry pods yield (1608 kgha^{-1}) was recorded in control.

Shelling Percentage: The data is shown in Table 2. The maximum shelling percentage (65%) in the treatment with compost + inoculum followed by the inoculum (63%). Minimum Shelling Percentage (60.3 %) was recorded in control practice without the amendment of compost or inoculum.

100 Seed Weight: According to the data presented in the Table 2, the maximum 100 seed mass (54.2 g) was found in the treatment having Compost + Inoculum followed by the Inoculum (51.3 g). Minimum 100 seed mass (47.7 g) was found in control

Table 2. Impact of Inoculum on Groundnut Pods per plant, Dry Pods yield, Shelling percentage, Plant height, Haulm yield and 100 seed mass

Parameter	**Treatments**	**Years**			**Mean**
		Year 1	**Year 2**	**Year 3**	
Plant height (cm)	Control	21.7 C*	22.1C	24.9 A	22.9 C
	Compost	23.7 BC	24.2 BC	25.4 A	24.4 BC
	Inoculum	24.6 B	25.3 AB	26.7 A	25.5 B
	Inoculum+compost	27.6 A	28.1 A	29.4 A	28.4 A
	LSD$_{0.05}$	2.1	3.2	4.7	1.6
Pods per plant	Control	34.6B	36.0B	37.3B	35.9 C
	Compost	38.0 AB	43.6A	44.6A	42.1 B
	Inoculum	37.3AB	44.0A	46.0A	42.3 B

	Inoculum+ compost	41.6A	47.6A	48.0A	45.7 A
	$LSD_{0.05}$	5.61	7.25	6.56	3.37
haulm yield (kgha-1)	Control	728 C	829.3 C	918.7 D	825.3 D
	Compost	964 B	1002.0 B	1176.3 B	1047.4 B
	Inoculum	948 B	997.0 B	1106.0 C	1017.2 C
	Inoculum+compost	1183 A	1235.3 A	1311.7 A	1243.4 A
	$LSD_{0.05}$	37.063	39.313	28.743	17.284
Dry pods yield (kgha-1)	Control	1571 C	1608 B	1645 C	1608 C
	Compost	1728 B	1720 B	1932 B	1793 B
	Inoculum	1779 B	1751 B	1941 B	1823 B
	Inoculum compost	1938 A	2102 A	2143 A	2061 A
	$LSD_{0.05}$	64.6	165.6	27.3	47.2
Shelling percentage	Control	58.6 A	60.3 A	62.6 A	60.3 A
	Compost	61.3 A	62.3 A	64.6 A	62.7 A
	Inoculum	61.6 A	63.6 A	64.0 A	63.0 A
	Inoculum +compost	62.3 A	64.6 A	69.0 A	65.2 A
	$LSD_{0.05}$	13.7	8.2	16.1	6.4
100 seed weight (g)	Control	46.533 B	47.130 C	49.593 B	47.752 C
	Compost	50.690 A	51.387 B	51.517 AB	51.198 B
	Inoculum	50.580 A	51.390 B	52.010 AB	51.327 B
	Inoculum+compost	53.387 A	54.283 A	55.173 A	54.281 A
	$LSD_{0.05}$	3.5242	2.7112	4.0234	1.5916

*indicates significance among treatment means at 5% level of confidence.

Table 3. Impact of Inoculation on groundnut root length, number of nodule and nodule dry weight

Parameter	Treatments	Years			Mean
		Year 1	Year 2	Year 3	
root length plant $^{-1}$(cm)	Control	16.56 C*	16.73 C	18.40 C	17.22 D
	Compost	18.40 B	18.73 B	19.50 BC	18.88 C
	Inoculum	19.40 AB	19.56 B	20.80 B	19.91 B
	Inoculum+compost	20.76 A	21.76 A	23.73 A	22.08 A
	$LSD_{0.05}$	1.3918	0.9052	1.4349	0.5749
nodule number plant^{-1}	Control	62.6 B	71.3 B	74.3 B	69.4 C
	Compost	79.6 A	81.3 AB	84.3 AB	81.7 B
	Inoculum	75.3 AB	78.3 AB	85.6 AB	79.7 B
	Inoculum+compost	87.0 A	92.0 A	95.3 A	91.4 A
	$LSD_{0.05}$	13.472	15.400	14.419	6.7837
nodule dry weight plant^{-1} (mg)	Control	70.8 B	72.7 C	75.0 B	72.8 C
	Compost	84.8 A	86.8 AB	89.6 A	87.0 B
	Inoculum	81.4 AB	84.9 B	87.9 A	84.8 B
	Inoculum+compost	90.9 A	93.8 A	98.4 A	94.4 A
	$LSD_{0.05}$	11.311	7.8339	11.759	4.8273

*indicates significance among treatment means at 5% level of confidence.

Root length per plant: According to the data given in Table 3 regarding the effect of PGPR Inoculum and compost on Root length plant $^{-1}$ of groundnut crop, the Maximum Root length plant $^{-1}$ (22.0 cm) was found in the treatment with Compost + Inoculum followed by the Inoculum treatment (19.9 cm). Minimum Root length plant $^{-1}$ (17.2 cm) was recorded in Control practice without the amendment of compost or inoculum.

Number of Nodule per plant: It was observed that highest number of nodules plant^{-1} (91) were found in the treatment comprising Compost + Inoculum followed by the Inoculum treatment (81.7) as given in Table 3. Minimum quantity of Nodules plant^{-1} (69.4) was found in control.

Nodule dry weight plant^{-1}: According to the data presented in the table 3, the maximum Nodule dry weight plant^{-1} (94.4 mg) was found in the treatment having Compost + Inoculum followed by the Inoculum treatment (87 mg). Minimum Nodule dry weight plant^{-1}, 72.8 mg, was found in control.

Nutrients Composition:

Table 4. Impact of inoculum on nitrogen and phosphorus in soil, plant and kernel

Parameter	Treatments	Years			Mean
		Year 1	Year 2	Year 3	
N content in soil (%)	Control	0.044 B*	0.047 B	0.047 B	0.046 C
	Compost	0.048 B	0.052 AB	0.054 A	0.051 B

	Inoculum	0.048 B	0.051 AB	0.055 A	0.051 B
	Inoculum+compost	0.059 A	0.056 A	0.057 A	0.057 A
	LSD	6.274 E -03	7.056 E-03	5.369E-03	2.893E-03
N content in shoot (%)	Control	1.81 B	1.83B	1.85 C	1.83 C
	Compost	1.83 B	1.91 AB	1.94 B	1.88 B
	Inoculum	1.86 B	1.88 B	1.91 B	1.89 B
	Inoculum+compost	1.97 A	2.02 A	2.04 A	2.01 A
	LSD	0.073	0.1159	0.0622	0.0393
N content in Kernal (%)	Control	3.84 A	3.91 B	4.01 B	3.92 C
	Compost	3.91 A	3.94 B	4.02 AB	3.96 B
	Inoculum	3.86 A	3.92 B	4.04 AB	3.94 BC
	Inoculum+compost	3.91 A	4.03 A	4.09 A	4.01 A
	LSD	0.07	0.06	0.0698	0.03
P content in soil (ppm)	Control	8.73 C	9.04 C	9.56 C	9.11 D
	Compost	9.06 B	9.77 B	10.04 B	9.62 B
	Inoculum	8.85 C	9.72 B	10.03 B	9.53 C
	Inoculum+compost	9.73 A	10.02 A	10.16 A	9.97 A
	LSD	0.14	0.04	0.06	0.05
P content in shoot (%)	Control	0.183 C	0.204 A	0.209 B	0.198 C
	Compost	0.192 BC	0.208 A	0.212 AB	0.204 BC
	Inoculum	0.195 B	0.212 A	0.214 AB	0.207 AB
	Inoculum+compost	0.204 A	0.206 A	0.221 A	0.210 A
	LSD	9.083E-03	0.015	9.034E-03	5.825E-03
P content in kernal (%)	Control	0.278 C	0.294B	0.305 C	0.292 C
	Compost	0.288 B	0.298 B	0.315 B	0.300 B
	Inoculum	0.276 C	0.296 B	0.314 B	0.295 C
	Inoculum+compost	0.302 A	0.315 A	0.324 A	0.314 A
	LSD	6.344E-03	7.630 E-03	6.824 E-03	3.183E-03

*indicates significance among treatment means at 5% level of confidence.

Nitrogen content in soil: According to the data presented in the Table 4, the maximum N content in soil (0.058 %) was found in the treatment having Compost + Inoculum followed by N content in soil (0.051 %) in the treatment comprising Inoculum. Minimum N content in soil (0.046 %) was recorded in control.

Nitrogen content in plant: The data presented in Table 4 indicated that the compost +inoculum resulted in maximum N contents in plant shoot (2.01 %) of groundnut crop followed by the treatment having compost (1.89 %) against control (1.83%).

Nitrogen content in Kernel: The data is predicted in Table 4. The maximum N content in kernel (4.01 %) was found in the treatment having Compost + Inoculum followed by the N content in kernel (3.96 %) in the treatment with compost against control (3.92%).

Available P in soil: The data is predicted in Table 4. The maximum concentration of available P in soil (9.97 mg kg^{-1}) was found in the treatment having Compost + Inoculum followed by plant available P in soil (9.62 mg kg^{-1}) in the treatment with compost against control (9.11 mg kg^{-1}).

Total phosphorus in shoot: According to the data presented in the table 4, the Maximum phosphorus contents in plant shoot (0.210 %) was found in the treatment having Compost + Inoculum followed by the P content in shoot (0.207 %) in the treatment having compost. Minimum phosphorus contents in plant shoot (0.198 %) was found in control.

Total P content in Kernel: The data presented in Table 4 depicted that the Maximum phosphorus contents in plant kernel (0.314 %) was found in the treatment having Compost + Inoculum followed by the phosphorus contents in plant kernel (0.300 %) in the treatment having compost. Minimum total P in kernel (0.292%) was observed in control.

DISCUSSION

Moisture stress is a significant requirement for the farming harvests. It likewise adversely affects the crop physiology as well as it impacts plant productivity (Ghorbanpour *et al*., 2013). Around 40% of the worldwide land utilized for agriculture lies in arid and semi-arid areas. Moisture stress at last impacts the morphological and physiological qualities of the yield as well as it adversely affects fresh weight, relative water content of the plant as well as it diminishes nutrient diffusion. Plant growth promoting rhizobacteria (PGPR) and other plant growth regulators (PGR) could assume a critical part in easing of moisture stress in plants (Erturk *et al*., 2010)

In the current study, root area and crop yield were significantly increased in plants applied with PGPR and compost. It may be because of the reason that PGPR animated root development of the plant since it can deliver indole acetic acid (IAA) and IAA had for long been known for its stimulatory impact on root attributes (Barazani *et al*., 1999).

The outcomes showed 47% increment in rooting ratios when PGPR strains were applied in plants (Erturk *et al*.,2010). Gamalero *et al*. (2004) narrated in detail that the effect of two fluorescent pseudomonads and an arbuscular mycorrhizal fungus on the development and root structure of tomato plant and noticed improved root development in inoculated treatments. The extended root attributes play a significant part in creating resilience to abiotic stresses on particularly to moisture stress in light of the fact that improved root length advances plant development during stress condition. Zhu *et al*. (2016) called attention to the synergistic impacts of PGPR on the shoot and root development of chickpea and soybean under stress condition. It may be because of improved development of plants because of improved plant accessibility of nitrogen and phosphorus (Mamta *et al*., 2010; Qureshi *et al*., 2012).

Inoculation of PGPR significantly increases number of nodules per plant. Nonetheless, Inoculation alone was very impactful in enhancing number of nodules per plant. it might be due to the reason that PGPR affects positively on rhizobia symbiosis. Nodulation is vital for N-fixation, assume a significant part in plant development and efficiency and improve resistance to unfavorable environmental effects (Gresshoff *et al*., 2010). Inoculation of PGPR had been displayed to increment legume nodulation and nitrogen-fixation in alfalfa, soybean and common bean (Korit *et al*., 2017).

Also, legume development and yield have been displayed to increment in inoculated plants. The study is in accordance with Bai *et al*. (2003) who detailed that the co-immunization of Bacillus strains in soybean plants with Bradyrhizobium japonicum showed the most elevated levels in nodule number, nodule weight, shoot and root weights, total biomass, total N and grain yield. It caused increment in nodules (Vassileva *et al*., 1999)

It is evident from the findings that there was an increased number and weight of pods in PGPR inoculated plants. It was found that Pseudomonas fluorescens and *Azospirillum lipoferum* did increase significantly pods plant^{-1}, weight of pod and total dry mass in Phaseolus vulgaris (Yadegari *et al*., 2010). Dey *et al*. (2004) observed significant increment in number of pods and pod weight in peanuts primed with PGPR. It increased pod bearing branches, pod plant^{-1} and mass of pod in chickpea (Dasgupta *et al*., 2015).

The PGPR treatment in combination s of was more effective in increasing yield and yield related components (yield /5-plants, total biomass and harvest index) of chickpea grown in sandy soil. Several studies have currently exposed that inoculation with PGPR, increased leaf area, growth and yield in many plants including legumes (Pirlak *et al*., 2009; Tilak *et al*., 2006). It is evident from various studies that PGPR can improve plant growth, yield either by enhancing leaf area, nitrogen availability to plants, phytohormone productivity, minerals solubilization or by Fe- chelation (Egamberdieva *et al*., 2010). It was reported that PGPR induced increment in yield of a lot of plants including sweet potato, apple, tomato, maize and peanut (Yasmin *et al*., 2007; Karlidag *et al*., 2007).

The growth and yield of field crops i.e. maize (Jacoud *et al*., 1999), rice (Preeti *et al*., 2002) and groundnut (Badawi *et al*., 2011) enhanced with PGPR priming to seed. The enhanced growth, total biomass production and yield may be attributed to increased nutrient availability to plants by extended root proliferation (length and branching), increased vertical growth (plant height and extended branching of shoots), due to enhanced carbon-fixation and increased nodulation in leguminous crops. The improved yields of crops worldwide attract farmers for its application. The present study demonstrated that PGPR application can improve physic-o-chemical properties of degraded soils under rain-fed condition and also can enhance growth and yield of groundnut crop.

CONCLUSION

It was concluded that PGPR in conjunction with compost can increment growth and yield of groundnut, and also improve physic-o-chemical properties of degraded soils under rain-fed scenario as evident from 12% increase in pod yield of groundnut in present study. Further research is needed on isolation of the most effective strains for increasing crop productivity on sustainable basis under rain-fed conditions.

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