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Effect of Microbial Inoculants on Leghemoglobin Content in Nodules and Microbial Populations in Rhizosphere of Soybean in a Vertisols

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study was carried out during kharif season 2019-20 at the Research Farm, Department of Soil Science & Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh (INDIA), to assess the effect of microbial inoculants on leghemoglobin content in nodules and microbial populations in rhizosphere of soybean in a Vertisols. The experiment was

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laid out under randomized block design with three replications. The fifteen treatments comprised of different beneficial microbial consortia in possible combinations applied as seed treatments. Besides these, two control plots were maintained as fertilized un-inoculated control (FUI) and unfertilized un-inoculated control (UFUI). The results revealed that the significant improvement were noticed by the application of consortia NPK+EM+PGPR in leghemoglobin content in nodules at 25, 45 & 65 DAS over control. Similarly, the microbial populations of the diazotroph, PSB, KSB, PGPR, phototroph, Lactic bacterium, actinomycetes, fungus and yeast were maximum in NPK+EM+PGPR treatment and followed by PK+EM+PGPR treatments. Thus, it may be concluded that the consortium of NPK + EM + PGPR was superior for maximum nodulation and microbial population in rhizosphere of soybean in a Vertisol.

Keywords: Microbial inoculants; leghemoglobin; microbial population; soybean, Vertisols.

1. INTRODUCTION

"Soybean (*Glycine max* L.) is an important leguminous oil seed crop, which contains 40-45% protein and 18-20% oil. The top two soybean growing states in India are Madhya Pradesh and Maharashtra with 45% and 40% shares, respectively. In Madhya Pradesh the soybean cultivation spreads over 5.2 M ha with total annual production of 6.7 M tones and productivity of 1285 kg ha^{-1}" [1, 2]. "Soybean rhizosphere harbors vast proportions of soil microorganisms, whose activities largely determine the biological condition of the soil and influence the plant growth right from seed germination to maturity" [3]. "Different microbial consortia i.e. *Pseudomonas* as PGPR is the most efficient and effective strain with significant remarks on isolates of *P. fluorescens* and *P. putida* increasing growth and yield of different crops, especially legumes. *Rhizobium* (diazotroph) is a Gram- negative bacterium and symbiotic N_2-fixer with roots of legumes" [4]. "It colonizes the roots of specific legumes to form tumor like growths called root nodules, which acts as the factories of ammonia production. *Bacillus subtilis* a soil Gram positive catalase-positive bacterium is known also as the hay bacillus or grass bacillus. The *Bacillus* sp. produces soluble exudates which is composed of five organic acids; gluconic acids, succinic acids, lactic acetic and propionic acids. The action of organic acids is recognized as a major mechanism responsible for the release of phosphates from the hydroxyl apatites. *Frateuria aurantia* is a potassium solubilizer, which increases the potassium uptake by the plant" [5].

Isolates of constitutional microorganisms of EM culture (Effective Microbial Culture) individually have already been evidenced beneficial but their consortium could be more valuable to augment the supply of nutrients through solubilization, anti-phytopathogenicity, induced phytoresistance and phytostimulator. In view of the above, the present study was conducted to find the effect of different microbial inoculants on leghemoglobin content and microbial populations in rhizosphere of soybean in a Vertisols.

2. MATERIALS AND METHODS

The present investigation was conducted during kharif 2019-20 under All India Network Project on Biofertilizers, to assess the effect of different microbial inoculants on leghemoglobin content in nodules and microbial populations in rhizosphere of soybean in a Vertisol at the Research Farm, Department of Soil Science, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh (INDIA). It is situated at 23°10'N latitude and 79°57" E longitude at 393 meters above the mean sea level.

"The soil of the experimental site is belonging to Kheri series of fine montmorillonitic hyperthermic family of T*ypic Haplusterts* (Vertisol) with pH of 7.15, electrical conductivity 0.24 dS m^{-1} (1 : 2.5 soil : water ratio) and organic carbon 5.2 g kg^{-1}. The soil available N, P and K were 226, 15.8 and 282 kg ha^{-1}, respectively. The experiment comprised 15 treatments with three replications having 45 plots laid out under randomized block design (RBD). The treatments of different liquid biofertilizers either solo and/or consortia were applied on soybean (cv. JS 2069) as seed treatment / basal application as per the appropriate recommendations. The biofertilizers used were diazotroph (*Rhizobium*), PSB - Phosphate Solubilizing Bacteria (*Bacillus* sp.), KSB- Potash Solubilizing Bacteria (*Fraturia aurentia*), PGPR- Plant Growth Promoting Rhizobacteria (*Pseudomonas fluorescens*) and EM- Effective microbial culture/consortium (six bacteria, two fungus and one actinomycetes) culture" [5]. The different treatment combinations are presented in Table 1.

Table 1. Details of different treatment combinations

Treatment Combinations			
T_1	*Rhizobium*	**T_9**	NPK + PGPR
T_2	NPK consortium	**T_{10}**	PK + EM
T_3	EM culture	**T_{11}**	PK + PGPR
T_4	PGPR	**T_{12}**	NPK+EM+PGPR
T_5	PK Consortium	**T_{13}**	PK + EM + PGPR
T_6	*Rhizobium* +EM	**T_{14}**	FUI
T_7	*Rhizobium* + PGPR	**T_{15}**	UFUI
T_8	NPK + EM		

The recommended NPK dose for soybean, based on initial soil test, was 20:80:20 (N : P_2O_5 : K_2O kg ha^{-1}). The sources of N, P and K used were urea, single super phosphate and muriate of potash. Besides these, two types of control plots were maintained as fertilized uninoculated control (FUI) and unfertilized uninoculated control (UFUI) to measure the comparative effects of different microbial inoculants.

2.1 Leghemoglobin Content in Nodules

In the present study, leghemoglobin content in nodules of soybean crop was estimated by the cyanmethemoglobin method. The principle of this method is the conversion of hemoglobin into cyanmethemoglobin by the addition of potassium cyanide and ferricyanide, whose absorbance is measured at 540 nm in a spectrophotometer against a standard solution. This method is considered as a reference method because it is accurate, cheap, sensitive to small variations [6].

2.2 Estimation of Microbial Populations in Rhizospheric Soil

Samples of rhizospheric soil were used as fresh as possible without grinding, sieving or any modifications. The collected samples were kept in low density polyethylene bags and could be stored in refrigerator at 4ºC. At the start of the experiment, microbial population counts ware analyzed by Serial Dilution Technique [7]. The initial microbial population counts of experimental soils presented in Table 2.

2.3 Statistical Analysis

The data generated on leghemoglobin content in soybean nodules and microbial populations in rhizospheric soil were statistically analyzed to draw suitable inference as per standard method [8].

3. RESULTS AND DISCUSSION

3.1 Leghemoglobin Content in Soybean Nodules

The leghemoglobin content was determined in the soybean root nodules at 25, 45 and 65 DAS and presented in Table 3. At 25 DAS of soybean, the leghemoglobin content in nodules varied from 2.10 to 3.31 mg g^{-1} nodule with a mean value of 2.74 mg g^{-1} nodule. The maximum leghemoglobin content was estimated with the treatment NPK+EM+PGPR of soybean nodules (3.31 mg g^{-1} fresh nodule weight) which was 45.7% more as compared to that of FUI (2.27 mg g^{-1} fresh nodule weight), followed by PK+EM+PGPR, Rhizo+PGPR, Rhizo+EM, NPK+EM, EM culture, NPK+PGPR, NPK consortium and *Rhizobium* for leghemoglobin content of 3.29, 3.26, 3.18, 3.07, 2.89, 2.89, 2.74 and 2.71 mg g^{-1} nodule, respectively corresponding to increment of 44.9, 43.6, 40.2, 35.2, 27.2, 27.2, 20.7 and 19.2%, respectively over that of FUI.

Similarly, the results at 45 DAS and 65 DAS of soybean showed that the application of NPK+EM+PGPR contributed to the maximum leghemoglobin content of 3.76 and 3.11 mg g^{-1} nodule with response of 38 and 50%, respectively over that of FUI. The higher leghemoglobin contents in this treatments due to the better root and nodules development [9, 10].

3.2 Microbial Populations (*Rhizobium*, PSB, KSB and PGPR) in Rhizosphere of Soybean at Harvest

The population counts of *Rhizobium* in rhizosoheric soil of soybean at harvest are presented in Table 4. It is apparent from results that the *Rhizobium* population were maximum of 6.48 log cfu (30.19 x10^5 cfu g^{-1} soil) with the inoculation of consortium NPK+EM+PGPR along with the relative response of 1.85 log fold increase over that of control FUI (3.51 log cfu = 32.35x10^2 cfu g^{-1} soil). The population of soybean rhizobia in rhizospheric soil was also noted more with 80 kg P_2O_5+LRh by 1.69, 1.55 and 1.57 log folds, respectively over to that of control (3.297, 5.499 and 4.619 log cfu g^{-1} soil at 21 DAS, 45 DAS and at harvest, respectively [11, 12].

The data on populations of PSB (*Bacillus* sp.) in rhizospheric soil of soybean at harvest are presented in Table 4. The consortium of NPK+EM+PGPR increased the maximum microbial population maximum for the PSB counts of 9.81 log cfu (64.56x10^8 cfu g^{-1} soil) and increment of 1.38 log fold over that of FUI (log cfu7.11 = 12.88x10^6 cfu g^{-1} soil). The findings showed that the seed treatment with *A. awamori*increased fungal (25.25 and 29.06 cfu x 10^3 /g) and actinomycetes population (23.44 and 26.19 cfu x 10^8/g) while *B. polymixa* increased phosphate solubilizing bacterial counts (21.37 and 23.31 cfu x 10^6/g) significantly at 30 and 60 DAS, respectively. The application of FYM (5 t/ha) had significantly increased the fungi (22.21 and 27.25 cfu x 10^3/g), actinomycetes (20.37 and 23.77 cfu x 10^8 /g), bacterial (30.55 and 36.02 cfu x 10^6/g) and PSB population (18.42 and 21.30 cfu x 10^6 /g) in the soybean field at 30 and 60 DAS, respectively [13,14]. Further, the inoculation of NPK+EM+PGPR might have given added advantages over native microbial population [15,16].

The data pertaining to the population of KSB (*F. aurantia*) in soil of soybean at harvest werecounted and listed in Table 4. The

Table 2. Initial microbial population counts of experimental soils

Particulars	Population Counts (cfu g^{-1})
Rhizobium	4.52 X 10^6
Phosphorous Solubilizing Bacteria - PSB	3.67 X 10^5
Potash Solubilizing Bacteria - KSB	3.91 X 10^7
Pseudomonasn sp. (PGPR)	5.43 X 10^7
Rhodopseudomonas sp.	1.27 X 10^3
Sachhromyces sp.	2.19 X 10^3
Streptomyces sp.	1.93 X 10^4
Aspergillus sp.	1.51 X 10^3
Lactobacillus sp.	2.14 X 10^3

Table 3. Effect of microbial inoculants on leghemoglobin content in nodules of soybean at different growth stages

Treatment	Leghemoglobin content in nodules (mg g^{-1} nodule)		
	25 DAS	45 DAS	65 DAS
Rhizobium	2.75	3.19	2.54
NPK consortium	2.74	3.19	2.54
EM culture	2.89	3.34	2.69
PGPR	2.21	2.66	2.01
PK consortium	2.30	2.75	2.10
Rhizobium +EM	3.18	3.63	2.98
Rhizobium +PGPR	3.26	3.71	3.06
NPK +EM	3.07	3.52	2.87
NPK+PGPR	2.89	3.34	2.69
PK+EM	2.63	3.08	2.43
PK+PGPR	2.65	3.10	2.45
NPK+EM+PGPR	3.31	3.76	3.11
PK+EM+PGPR	3.29	3.74	3.09
FUI	2.27	2.72	2.07
UFUI	2.10	2.55	1.90
SE_m ±	**0.16**	**0.16**	**0.16**
CD (*p=0.05*)	**0.46**	**0.46**	**0.46**

consortium of NPK+EM +PGPR was found statistically superior to increase KSB population of 7.42 log cfu (26.30x10^6 cfu g^{-1} soil) along with the relative response of 1.93 log fold increase over that of FUI (3.85 log cfu = 70.79x10^2cfu g^{-1} soil). Similar results were also obtained by Savaliya et al. [17], reported that the application of 45 kg P_2O_5/ha + PSB seed inoculation + PSB soil application (P_3) were recorded significantly highest PSB count at 30 DAS (6.72×10^6), 60 DAS (7.30×10^6) and at harvest (9.48×10^6). Similarly, application of 45 kg K_2O/ha + KSB seed inoculation + KSB soil application (K_3) recorded significantly the highest KSB count at 30 DAS (6.58×10^6), 60 DAS (7.48×10^6) and harvest (9.53×10^6).

The data on population of PGPR (*P. fluorescens*) in soil (0-15 cm) of soybean revealed that the consortium of NPK+EM+PGPR were recorded (Table 4) maximum population of PGPR for 9.66 log cfu (45.70x10^8 cfu g^{-1} soil) with the relative response of 1.57 log fold increase than that of control FUI (6.16 log cfu = 14.45x10^5 cfu g^{-1} soil), followed by the PK+EM+PGPR1.56 log fold increase over that of FUI [18,19]. *Pseudomonas* population in soil ranged from 6.5 to 8.02x10^4 cfu g^{-1} of soil, maximum was influenced by seed inoculation with *Pseudomonas* at 3 g kg^{-1} [20]. "It might be attributed to the synergistic effect of the microorganism's present consortium NPK+EM+PGPR contributing to higher PGPR population at harvest. *Pseudomonas* are the most efficient and effective strain that can act as PGPR. *P. fluorescens* has simple nutritional requirements and grows well in mineral salts media supplemented with any of a large number of carbon sources" [21, 22].

3.3 Microbial Populations of EM Culture (*Rhodopseudomonas* sp., *Lactobacillus* sp., *Streptomyces* sp., *Aspergillus* sp. and *Saccharomyces*) in Soil at Harvest of Soybean

The data on population of phototroph *Rhodopseudomonas* sp. (one of EM organism) in soil at harvest of soybean crop are listed in Table 5. It was noticed that the population of the phototrophic bacteria was enumerated maximum of 5.79 log cfu (61.65x10^4 cfu g^{-1} soil) with the relative response of 1.85 log fold increase with inoculation of consortium of PK+EM+PGPR over that of FUI (log cfu 3.13 = 1.34x10^3 cfu g^{-1} soil). The inoculation of PPB (Phototrophic Purple Bacteria: *Rhodopseudomonas palustris*) increased populations of PPB in the plots, significantly increased by the inoculation. This might be attributed due to the ability of *R. palustris* to degrade aromatic compounds has been researched extensively. *R. palustris* utilizes a reductive coenzyme to convert, *via* reduction and dehalogentation, 3-chlorobenzoate into acetyl CoA and carbon dioxide [22, 23].

Table 4. Effect of microbial inoculants on microbial populations of *Rhizobium,* PSB, KSB and PGPR in rhizosphere of soybean at harvest

Treatment	Population of microorganism [log cfu and in parenthesis cfu g^{-1} soil]			
	Diazotroph (*Rhizobium* sp.)	PSB (*Bacillus* sp.)	KSB (*Fraturia* sp.)	PGPR (*Pseudomonas* sp.)
Rhizobium	5.71 (51.28x10^4)	7.17 (14.79x10^6)	4.92 (83.17x10^3)	7.04 (10.9x10^6)
NPK consortium	5.86 (72.44x10^4)	7.75 (56.23x10^6)	6.31 (20.41x10^5)	6.96 (91.20x10^6)
EM culture	4.62 (41.68x10^3)	7.51 (32.35x10^6)	5.25 (17.78x10^4)	7.93 (85.11x10^6)
PGPR	4.61 (40.73x10^2)	7.37 (23.44x10^6)	4.80 (63.09x10^3)	9.57 (37.15x10^8)
PK consortium	5.61 (40.73x10^4)	8.79 (61.65x10^7)	6.73 (53.70x10^5)	8.73 (53.70x10^7)
Rhizobium+EM	5.14 (13.80x10^4)	8.20 (15.84x10^7)	4.66 (45.70x10^3)	8.20 (15.84x10^7)
Rhizobium+PGPR	5.42 (26.30x10^4)	8.31 (20.41x10^7)	6.44 (27.54x10^5)	8.87 (74.13x10^7)
NPK +EM	5.69 (48.97x10^4)	8.95 (89.12x10^7)	5.93 (85.11x10^4)	8.11 (12.88x10^7)
NPK+PGPR	5.13 (13.37x10^4)	8.86 (72.44x10^7)	6.53 (33.88x10^5)	8.96 (91.20x10^7)
PK+EM	5.93 (85.11x10^4)	9.04 (10.96x10^8)	6.74 (54.95x10^5)	8.99 (97.72x10^7)
PK+PGPR	5.69 (48.97x10^4)	9.51 (35.48x10^8)	6.80 (63.09x10^5)	9.27 (18.62x10^8)
NPK+EM+PGPR	6.48 (30.19x10^5)	9.81 (64.56x10^8)	7.42 (26.30x10^6)	9.66 (45.70x10^8)
PK+EM+PGPR	6.44 (27.54x10^5)	9.32 (20.89x10^8)	7.24 (17.37x10^6)	9.61 (40.73x10^8)
FUI	3.51 (32.35x10^2)	7.11 (12.88x10^6)	3.85 (70.79x10^2)	6.16 (14.45x10^5)
UFUI	3.08 (12.02x10^2)	6.51 (32.35x10^5)	2.62 (41.60x10^1)	5.79 (61.65x10^4)
SE_m ±	**0.41**	**0.39**	**0.60**	**0.38**
CD (*p=0.05*)	**1.14**	**1.13**	**1.20**	**1.10**

Table 5. Effect of microbial inoculants on population of microorganisms of EM culture in soil of soybean at harvest

Treatment	**Population of microorganism [log cfu and in parenthesis cfu g^{-1} soil]**				
	Phtotroph *R. palustris*	**Lactic bacterium *L. lactis***	**Actinomycetes *S. badius***	**Fungus *A. niger***	**Yeast *S. cerevicae***
Rhizobium	3.26 ($1.81x10^3$)	2.62 ($4.16x10^2$)	2.83 ($6.76x10^2$)	2.66 ($4.57x10^2$)	3.88 ($7.58x10^3$)
NPK consortium	3.14 ($1.38x10^3$)	2.91 ($8.12x10^2$)	3.01 ($1.04x10^3$)	2.77 ($5.88x10^2$)	4.07 ($11.74x10^3$)
EM culture	3.58 ($3.80x10^3$)	4.34 ($21.87x10^3$)	4.18 ($15.13x10^3$)	3.83 ($6.76x10^3$)	5.96 ($91.20x10^4$)
PGPR	3.05 ($1.12x10^3$)	2.88 ($7.58x10^2$)	3.29 ($1.94x10^3$)	2.97 ($9.33x10^2$)	3.78 ($6.02x10^3$)
PK consortium	3.24 ($1.73x10^3$)	2.96 ($9.12x10^2$)	3.35 ($2.23x10^3$)	3.46 ($2.88x10^3$)	4.17($14.79x10^3$)
Rhizobium +EM	4.43 ($26.91x10^3$)	4.12 ($13.18x10^3$)	4.19 ($15.48x10^3$)	3.65 ($4.46x10^3$)	5.80 ($63.09x10^4$)
Rhizobium +PGPR	4.08 ($12.02x10^3$)	4.03 ($10.71x10^3$)	3.70 ($5.01x10^3$)	3.18 ($1.51x10^3$)	4.60 ($39.81x10^3$)
NPK +EM	3.99 ($9.77x10^3$)	4.04 ($10.96x10^3$)	4.31 ($20.41x10^3$)	3.93 ($8.51x10^3$)	5.47 ($29.51x10^4$)
NPK+PGPR	4.08 ($12.02x10^3$)	4.23 ($16.98x10^3$)	3.23 ($1.69x10^3$)	3.59 ($3.89x10^3$)	4.67 ($46.77x10^3$)
PK+EM	5.44 ($27.54x10^4$)	5.08 ($12.02x10^4$)	4.25 ($17.78x10^3$)	4.10 ($12.58x10^3$)	5.78 ($60.25x10^4$)
PK+PGPR	5.14 ($13.80x10^4$)	4.59 ($38.90x10^3$)	4.16 ($14.45x10^3$)	3.99 ($9.77x10^3$)	4.94 ($87.09x10^3$)
NPK+EM+PGPR	5.58 ($38.01x10^4$)	5.53 ($33.88x10^4$)	4.64 ($43.65x10^3$)	4.28 ($19.05x10^3$)	6.16 ($14.45x10^5$)
PK+EM+PGPR	5.79 ($61.65x10^4$)	4.94 ($87.06x10^3$)	4.63 ($42.65x10^3$	4.15 ($14.12x10^3$)	6.03 ($10.71x10^5$)
FUI	3.13 ($1.34x10^3$)	2.67 ($4.67x10^2$)	2.76 ($6.16x10^2$)	2.58 ($3.80x10^2$)	3.85 ($7.07x10^3$)
UFUI	2.61 ($4.07x10^2$)	2.29 ($1.94x10^2$)	2.55 ($3.54x10^2$)	2.45 ($2.81x10^2$)	3.12 ($1.31x10^3$)
SE_m ±	**0.23**	**0.25**	**0.23**	**0.23**	**0.29**
CD (*p=0.05*)	**0.67**	**0.72**	**0.66**	**0.66**	**0.84**

Data pertaining to the population of lactic bacteria *Lactobacillus* sp. (one of EM culture) in rhizosphere of soybean revealed that the consortium of NPK+EM+PGPR recorded (Table 5) maximum microbial population of 5.53 log cfu (33.88×10^4 cfu g^{-1} soil) with the relative response of 2.07 log fold increase as compare to that of FUI (2.67 log cfu = 4.67×10^2cfu g^{-1} soil). This was followed by the response from PK+EM and PK+EM+PGPR for 5.08 log cfu (12.02×10^4 cfu g^{-1} soil) and 4.94 log cfu (87.06×10^3 cfu g^{-1} soil), respectively along with the response of 1.90 and 1.85log fold increase over that of FUI. "The numbers of bacteria, fungi and actinomycetes has increased after the soil was treated with EM cultures. EM cultures markedly increased the numbers of *Enterobacter* sp. and starch digesting bacteria over that of unfertilized" [24].

The populations of actinomycetes *S. badius* (one of EM culture) in soil of soybean at harvest are exhibited in Table 5. The consortium of NPK+EM+PGPR achieved maximum population of the actinomycetes for 4.64 log cfu (43.65×10^3 cfu g^{-1} soil) with the relative response of 1.66 log fold increase over that of control FUI (2.76 log cfu = 6.16×10^2 cfu g^{-1} soil). Similarly, the actinomycetes population in soil from most of the plots sampled was about 5×10^5cfu g^{-1} of dry [25, 26]. The seed inoculation with *Pseudomonas* at 3 g kg^{-1} showed the maximum number of actinomycetes counts 11.4×10^5 cfu g^{-1} soil that was 13.9% more actinomycetes population over that of control. All the treatments showed numerical increase in actinomycetes population in comparison to that of control.

The population of fungus *Aspergillus* sp. (one of EM culture) in rhizosphere of soybean at harvest are shown in Table 5. It is apparent from the results that the consortium of NPK+EM+PGPR recorded the maximum population of *A. Niger* by 4.28 log cfu (19.05×10^3 cfu g^{-1} soil) with the relative response of 1.66 log fold increase over the control FUI 2.58 log cfu (3.80×10^2cfu g^{-1} soil).The fungus *A. niger* grows aerobically on organic matter as a common contaminant. It is known to remove the heavy metals like lead, cadmium and copper from the water [27. 28].

The results clearly showed that the population of yeast *S. cerevisiae* (one of EM culture) in soil of soybean at harvest was increased from 3.12 log cfu (1.31 $\times 10^3$cfu g^{-1} soil) to 6.16 log cfu (14.45×10^5cfu g^{-1} soil) with mean value of 4.82 log cfu ($66.06 \times 10^3 g^{-1}$ soil). The consortium of NPK+EM+PGPR boosted the population of yeast to maximum by 6.16 log cfu (14.45×10^5 cfu g^{-1} soil) with the relative response of 1.60 log fold increase over that of control FUI (3.85 log cfu = 7.07×10^3 cfu g^{-1} soil), followed by the performance of PK+EM+PGPR and EM culture for 6.03 log cfu (10.71×10^5 cfu g^{-1} soil) and 5.96 log cfu (91.20×10^4 cfu g^{-1} soil), respectively corresponding to the increment of 1.27 and 1.55 log fold over that of FUI.

"Soil yeast and yeast-like fungi produce a variety of biologically active compounds (phytohormones, vitamins, amino acids, enzymes etc.) that have active stimulating effect on the plant growth and development and help to increase their productivity. In addition, yeasts produce antimicrobial substances helping to reduce phytopathogenic infection. *Rhizobium*, *Pseudomonas* spp., *Bacillus subtilis*, *Frateuria aurantia* and effective microorganisms (EM culture) isolates individually are found beneficial but their consortium could be more valuable resource to augment the supply of nutrients through solubilization or mobilization of nutrients" [29,30].

4. CONCLUSION

It was concluded that the microbial populations of the diazotroph, PSB, KSB, PGPR, phototroph, Lactic bacterium, actinomycetes, fungus and yeast were maximum in NPK+EM+PGPR treatment and followed by PK+EM+PGPR treatments. Microbes of EM culture enhance plant growth and productivity by fixing atmospheric nitrogen and supplementing the plants with the fixed nitrogen as ammonia. Additionally, the release of trace elements, secreted antioxidants, exo-polysaccharides, bioactive compounds (vitamins, hormones and enzymes) by the EMs stimulated plant growth and productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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