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Productivity, Profitability and Soil Health of Pigeonpea as Influenced by Phosphorus Levels and Bioinoculants under Eastern Uttar Pradesh

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A B S T R A C T

Field experiments were carried out during *kharif* season of 2008-09 and 2009-10 at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to study the effect of phosphorus levels and bioinoculants on pigeonpea. Results reveal that application of 75 kg P_2O_5/ha recorded the highest soil microorganisms, growth characters, seed yield (2265 and 2124 kg/ha), net return, B: C ratio, production and economic efficiency, being significantly superior over 25 kg P_2O_5/ha and control during both the years. During both the years of study dual seed inoculation with PSB + PGPR produced the maximum nodulation, seed yield (2314 and 2173 kg/ha), net return, B:C ratio, production and economic efficiency, being significantly superior to alone seed inoculation of PGPR, PSB and control. Further results showed that maximum soil nutrient (N, P, K and S) was recorded in the plot where 70 kg P_2O_5/ha applied and this treatment was found significantly superior over 25 kg P_2O_5/ha and control. Dual seed inoculation of PSB + PGPR was recorded higher organic carbon and available soil nutrients, which was significantly superior over alone seed inoculation of PGPR, PSB and control.

Introduction

Pulses are major source of protein in the diets of vegetarian peoples in the developing countries in general and particular in India. Even though India is the largest producer, consumer, processor and importer of pulses in the world, the average productivity is very low and the production is not sufficient to meet the daily requirement of the peoples (Kumawat *et al.*, 2012). Pulses are also an excellent feed and fodder for livestock. India is the shared 24% in the global production of pulses. The major pulses are chickpea (48%), pigeonpea (15%), mungbean (7%), urdbean (7%), lentil (5%) and fieldpea (5%). Among the pulses pigeonpea is the fifth prominent grain legume crop in the world and occupies the second position in India after chickpea (Kumawat *et al.*, 2013). The major pulses producing states are Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, Karnataka and Andhra Pradesh, which together account for about 80% of the total production. India has the largest acreage under pigeonpea 2.66 million hectare with a total production of 2.47 million tonnes, respectively (Ali and Gupta, 2012). The low yield of this crop is not only due to its grown in marginal and sub-marginal land, but also inadequate and imbalanced fertilization as well as continuous use of chemical fertilizers which decrease productivity, sustainability and finally affected soil health. Among the macronutrients phosphorus is major plant nutrient which is referred to as the key element in crop production. It affects seed germination, cell division, flowering, fruiting, synthesis of fat, starch and in fact mostly all bio-chemical activities. It also induces root proliferation and nodulation. P has novel function of special importance in the process of energy storage and transfer. Response of phosphorus in pigeonpea has been reported by many researchers (Kumar and Kushwaha, 2006; Singh and Yadav, 2008; Kumawat *et al.,* 2015).

Phosphorus solubilizing rhizobacteria (PSB) are capable to convert insoluble phosphorus into soluble forms, therefore used to increase the solubility of reprecipitated soil phosphorus for crop production PSB help in the solubilization of native phosphorus from rock phosphate and other readily in soluble forms of soil phosphorus by producing organic acid like citric, gluconic, succinic, lactic, oxalic, glycolic, malic, formic, maleic and α-ketogluconic. PSB can solublize almost 15-20 kg P_2O_5/ha per season (Chandra and Kumar, 2005 and Kumawat *et al.,* 2010a). Positive response of PSM in pulse crops has been reported by many researchers (Kumawat *et al.,* 2009abc; Kumawat *et al.,* 2010b) Plant growth promoting rhizobacteria (PGPR) are a group of free-living rhizobacteria that colonies of rhizosphere and benefited to near growing roots of plants. Microorganisms of various genera were isolated as plant growth promoting rhizobacteria of which *Bacillus* and *Pseudomonas* sp. are predominant. PGPR exert a direct effect on plant growth by production of phytohormones, solubilization of inorganic phosphates, PGPR reduce the populations of root pathogens and other deleterious microorganisms in the rhizosphere, thus benefiting the plant growth reported by Podile and Kishore (2006) and Singh and Singh (2012a). Keeping this in view a field experiment was planned to enhance the yield of pigeonpea and soil health with the bioinoculants and phosphorus.

Materials and Methods

The field experiment was conducted at the Agriculture Research Farm of Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, during the *kharif* seasons of 2008-09 and 2009-10. The Farm is located at 25° 18′ north latitude and 83° 03′ east longitude with an elevation of 129 m above mean sea level. The experimental soil was sandy clay loam in texture having pH (7.46, 7.53). It was moderately fertile being low in organic carbon (0.34 and 0.37 %). The available N, P, K, S was 188.7, 18.5, 205.3, 19.3 kg/ha in first year and 194.2, 22.4, 210.6, 21.5 kg/ha in second year, respectively. The experiment was laid out at the same site and same plots during both the years in split plot design replicated thrice keeping phosphorus levels (control, 25, 50 and 75 kg/ha) in main plots and bioinoculants (control, PSB, PGPR and PSB+PGPR) in sub plots. Phosphorus was applied as per treatment through diamonium phosphate (DAP). A uniform dose of N, K_2O and sulphur @ 30, 40 and 30 kg/ha were applied though urea, muraite of potash and elemental sulphur (90 %). Seed of crop was inoculated with phosphate solubilizing bacteria (*Bacillus polymyxa*), PGPR (*Rhizobium* + *Pseudomonas florencenses*) and dual inoculation with PSB+PGPR (*Bacillus polymyxa* + *Rhizobium* + *Pseudomonas fluorescens*) before sowing of crop. Long duration pigeonpea *cv.* Bahar was sown by ridge-furrow method of planting on 14 and 20 July in 2008 and 2009 and the respective crop was harvested on 06 and 12 April in 2009 and 2010, respectively. The required plant population (60 x 20 cm) was obtained after a month of seeding by thinning of the plants. During first year more favorable weather conditions specially rainfall which was comparatively higher (528.60 mm) than second year (420.41 mm). During second year at flowering time (January to February) flower dropping due to frost and resulted affect yield of pigeonpea. Production efficiency and economic efficiency was calculated as following formula suggested by Kumawat *et al.,* (2015).

Results and Discussion

Effect of phosphorus

Phosphorus levels has significant effect on microbial populations, chlorophyll content, effective nodules/plant, nodules dry weight (mg), leaf area index, growth crop rate and plant dry weight at 50 and 100 DAS during both the years (Tables 1 and 2). Data indicated that application of phosphorus @ 75 kg/ha recorded the highest microbial population (1.5 and 1.9 cfu/g of soil), effective nodules/plant (9.93 and 9.16) and nodules dry weight (74.41 and 69.35 mg/plant) and its being at par with 50 kg P_2O_5/ha and significantly superior over 25 kg P_2O_5/ha and control, respectively. Further data showed that highest chlorophyll content (35.50 and 33.75 SPAD), leaf area index (1.57 and 1.25), crop growth rate (0.429 and 0.353 g/day/plant) and dry matter production (21.43 and 17.64) were noted with the application of phosphors @ 75 kg/ha which was significantly superior to control and 25 kg P_2O_5/ha but at par with 50 kg P_2O_5/ha during both the years of experimentation. Similarly, higher yield attributes *viz*. pods/plant, seeds/pod, 1000-seed weight (Figs. 1, 2 and 3) and seed yield (2265 and 2124 kg/ha) was found with the application of 75 kg P_2O_5/ha, being significantly superior to 25 kg P_2O_5/ha and control. This might be due to the fact that plants absorbed plant nutrients relatively in higher quantity because the pool of available phosphorus was already increased doses of applied phosphorus resulting enhancement of growth and yield attributes of crop. The present results agree with those of Singh and Singh (2012a) and Singh and Singh (2012b). The higher yields may be ascribed to the effect of P on root development, energy transformation and metabolic processes of the plant, which in term resulted in greater translocation of photosynthates towards the sink development. These results are in conformity with Singh and Ahlawat (2007) in pigeonpea, Kumawat *et al.,* (2010b) in greengram and Singh and Singh (2012b).

Maximum net return (`$\times 10^3$ 93.43 and 87.66/ha), benefit: cost ratio (3.19 and 2.99) production efficiency (8.5 and 7.9 kg/ha/day) and economic efficiency (349.9 and 328.3 `/ha/day) was obtained with 75 kg P_2O_5/ha and this treatment, being significantly superior over 25 kg P_2O_5/ha and control (Table 3). Similar findings were also made by Singh and Singh (2012b) and Ahirwar *et al.,* (2016). Further table 3 indicated that protein content was maximum with the application of 75 kg P_2O_5/ha and lowest in control. Similarly highest protein yield was recorded with the highest level of phosphorus i.e. of 75 kg P_2O_5/ha which was statistically similar to 50 kg P_2O_5/ha and significantly superior to 25 kg P_2O_5/ha and control. This could be ascribed due to protein content is essentially the manifestation of N concentration in seed. Hence, increased N concentration might have increased the protein content and finally protein yield. These results corroborated with the finding of Jain *et al.,* (2007) and Singh and Singh (2012b). The maximum available soil organic carbon was recorded under 75 kg

P_2O_5/ha and this treatment has significantly superior to 25 kg P_2O_5/ha and control (Table 5). Similarly, application of 75 kg P_2O_5/ha recorded maximum available soil N, P, K and S but it was statistically at par with 50 kg P_2O_5/ha and significantly superior to 25 kg P_2O_5/ha and control (Table 5).

It might be due to the beneficial effect of phosphorus on root growth and development and nodulation of mungbean which led to more N_2-fixation and thus after harvest of crop N depletion under phosphorus treatment was low as compared to control. The increase in available nutrients in soil with application of phosphorus could be due to utilization of native phosphorus with increasing levels of phosphorus which resulted in building up of higher soil nutrients status. Similar findings were also made by Ahirwar *et al.*, (2016).

Effect of bioinoculants

Among the bioinoculants, dual inoculation with PSB + PGPR was significantly recorded higher microbial population (1.5 and 2.0 cfu/g of soil), effective nodules/plant (10.85 and 9.63) and nodules dry weight (81.87 and 73.00 mg/plant) as compare to PGPR, PSB and control during both the years (Tables 1 and 2). Further data showed that higher chlorophyll content (36.0 and 34.55 SPAD), leaf area index (1.58 and 1.26), crop growth rate (0.436 and 0.359 g/day/plant) and dry matter production (21.78 and 17.93) were recorded in PSB + PGPR in both the years, respectively.

Seed inoculation with PSB + PGPR was recorded significantly higher values of yield attributes like pods/plant, seeds/pod, 1000-seed weight (Figs. 1, 2 and 3) and seed yield (2314 and 2173 kg/ha, respectively) of pigeonpea when compared to PGPR, PSB and control in both the years.

Structural and functional characteristics of roots contribute to rhizosphere processes and both have significant influence on the capacity of roots to acquire nutrients.

Roots also interact extensively with soil microorganisms which further impact on plant nutrition either directly, by influencing nutrient availability and uptake, or indirectly through plant (root) growth promotion. These observations are in agreement with those of Singh and Yadav (2008) and Kumawat *et al.*, (2009a) and Singh and Singh (2012b).

Fig.1 Effect of phosphorus and bioinoculants on pods/plant

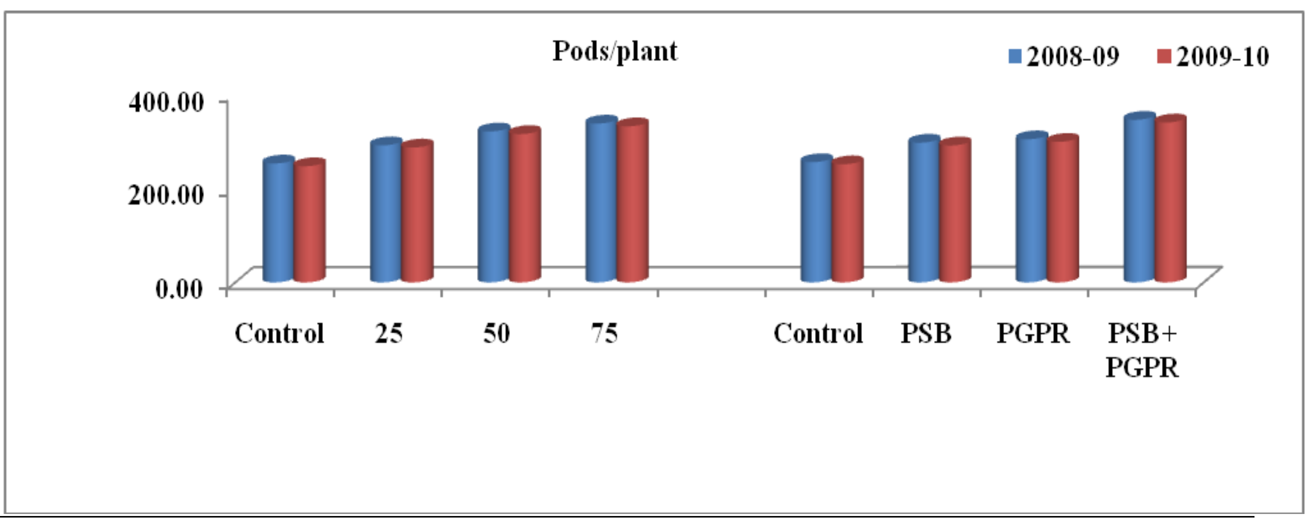


Table.1 Effect of phosphorus levels and bioinoculants on growth attributes of pigeonpea at 50 DAS

Treatment	Microbial population (x 10^4 cfu/g of soil)		Chlorophyll content (SPAD)		Effective nodules/plant		Nodules dry weight (mg/plant)		Leaf area index (LAI)		Crop growth rate (g/day/plant)		Plant dry weight (g)	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Phosphorus (kg/ha)														
Control	1.1	1.5	26.63	24.48	5.95	5.43	45.08	41.10	1.31	0.99	0.323	0.249	16.13	12.43
25	1.3	1.7	30.45	28.83	7.33	7.01	55.52	52.96	1.44	1.11	0.362	0.286	18.09	14.29
50	1.4	1.9	34.28	32.33	9.45	8.69	71.63	65.78	1.57	1.24	0.415	0.341	20.75	17.03
75	1.5	2.0	35.50	33.75	9.93	9.16	74.41	69.35	1.57	1.25	0.429	0.353	21.43	17.64
SEm ±	0.03	0.04	0.62	0.58	0.16	0.14	1.22	1.08	0.03	0.02	0.007	0.006	0.37	0.30
CD (P=0.05)	0.09	0.12	2.13	2.00	0.56	0.50	4.20	3.75	0.10	0.08	0.026	0.021	1.29	1.03
Bioinoculants														
Control	1.1	1.5	28.03	25.90	6.15	5.53	46.57	41.92	1.36	1.04	0.328	0.257	16.40	12.83
PSB	1.3	1.8	31.08	29.15	7.68	7.41	58.00	56.14	1.44	1.12	0.377	0.301	18.84	15.05
PGPR	1.4	1.9	31.75	29.78	7.98	7.71	60.21	58.13	1.50	1.18	0.388	0.312	19.38	15.58
PSB + PGPR	1.5	2.0	36.00	34.55	10.85	9.63	81.87	73.00	1.58	1.26	0.436	0.359	21.78	17.93
SEm ±	0.02	0.03	0.46	0.44	0.13	0.12	0.96	0.88	0.02	0.02	0.006	0.004	0.28	0.22
CD (P=0.05)	0.06	0.08	1.35	1.28	0.37	0.34	2.79	2.57	0.06	0.05	0.016	0.013	0.81	0.66

Table.2 Effect of phosphorus levels and bioinoculants on growth attributes of pigeonpea at 100 DAS

Treatment	Microbial population (x 10^4 cfu/g of soil)		Chlorophyll content (SPAD)		Effective nodules/plant		Nodules dry weight (mg/plant)		Leaf area index (LAI)		Crop growth rate (g/day/plant)		Plant dry weight (g)	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Phosphorus (kg/ha)														
Control	1.3	1.7	29.2	27.4	21.7	17.8	166.0	138.0	2.1	1.9	0.215	0.208	37.6	33.2
25	1.4	2.0	33.1	31.4	26.9	22.0	207.0	170.4	2.3	2.1	0.241	0.237	42.1	38.0
50	1.6	2.2	37.7	35.5	33.2	27.8	254.2	214.8	2.5	2.3	0.271	0.268	47.8	43.8
75	1.6	2.2	38.2	36.8	34.5	29.2	264.6	224.2	2.5	2.3	0.279	0.280	49.4	45.6
SEm ±	0.03	0.04	0.7	0.6	0.6	0.5	4.3	3.7	0.05	0.04	0.005	0.005	0.9	0.8
CD (P=0.05)	0.10	0.14	2.3	2.2	1.9	1.7	14.8	12.7	0.16	0.14	0.017	0.017	3.0	2.7
Bioinoculants														
Control	1.3	1.7	30.3	28.5	23.0	18.4	178.0	142.7	2.1	1.9	0.218	0.210	38.2	33.8
PSB	1.5	2.0	34.1	32.0	28.3	22.7	218.7	176.2	2.3	2.1	0.249	0.246	43.7	39.63
PGPR	1.6	2.1	35.4	33.1	29.9	23.6	223.5	181.9	2.4	2.2	0.255	0.253	44.9	40.8
PSB + PGPR	1.7	2.3	38.4	37.5	35.1	32.2	271.6	246.7	2.5	2.3	0.283	0.284	50.1	46.3
SEm ±	0.02	0.03	0.5	0.4	0.5	0.4	3.3	2.9	0.03	0.03	0.004	0.004	0.6	0.6
CD (P=0.05)	0.06	0.08	1.4	1.3	1.3	1.1	9.8	8.4	0.10	0.09	0.011	0.011	1.9	1.7

Table.3 Effect of phosphorus levels and bioinoculants on protein content (%), yield (kg/ha) and economics of pigeonpea

Treatment	Protein				Seed yield (kg/ha)		Net return (` ×10^3/ha)		B: C ratio		Efficiency			
	Content (%)		Yield (kg/ha)								Production (kg/ha/day)		Economic (`/ha/day)	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Phosphorus (kg/ha)														
Control	19.15	18.36	321.4	277.7	1673	1508	64.27	56.87	2.30	2.03	6.3	5.6	240.7	212.9
25	19.55	19.01	380.9	342.1	1945	1795	78.23	71.25	2.75	2.51	7.3	6.7	292.9	266.8
50	19.70	19.26	437.4	399.2	2218	2068	91.76	85.50	3.18	2.96	8.3	7.7	343.7	320.2
75	19.97	19.52	452.5	415.3	2265	2124	93.43	87.66	3.19	2.99	8.5	7.9	349.9	328.3
SEm ±	0.39	0.38	7.6	6.7	39	36	1.55	1.41	0.05	0.05	0.14	0.13	5.8	5.3
CD (P=0.05)	NS	NS	26.4	23.4	134	123	5.36	4.89	0.19	0.17	0.50	0.46	20.1	18.3
Bioinoculants														
Control	19.15	18.47	325.2	283.7	1693	1530	65.37	57.57	2.29	2.02	6.3	5.7	244.8	215.6
PSB	19.54	18.94	391.1	350.5	1999	1846	80.46	74.31	2.81	2.59	7.5	6.9	301.4	278.3
PGPR	19.64	19.21	412.2	374.6	2095	1945	85.17	79.09	2.97	2.76	7.8	7.3	318.9	296.2
PSB + PGPR	20.04	19.53	463.8	425.6	2314	2173	96.70	90.30	3.34	3.12	8.7	8.1	362.2	338.2
SEm ±	0.27	0.26	5.8	5.3	29	27	1.21	1.12	0.04	0.04	0.11	0.10	4.5	4.2
CD (P=0.05)	NS	NS	17.0	15.5	86	80	3.53	3.27	0.12	0.11	0.32	0.30	13.2	12.3

Table.4 Correlation coefficients showing relationship between independent variables (yield attributes) And dependent variable (seed yield) of pigeonpea

Character	Pod length (cm)		Pods/plant (Number)		Pods weight/plant (g)		Seeds/pod (Number)		1000-seed weight (g)		Seed yield (kg/ha)	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Pod length (cm)	1.00	1.00										
Pods/plant	0.988**	0.993**	1.00	1.00								
Pods weight/plant (g)	0.993**	0.992**	0.985**	0.987**	1.00	1.00						
Seeds/pod	0.992**	0.985**	0.988**	0.990**	0.991**	0.992**	1.00	1.00				
1000-seed weight (g)	0.988**	0.985**	0.980**	0.981**	0.992**	0.994**	0.984**	0.982**	1.00	1.00		
Seed yield (kg/ha)	0.984**	0.985**	0.979**	0.983**	0.990**	0.991**	0.993**	0.992**	0.985**	0.985**	1.00	1.00

** Significant at 1 % level of significance

Table.5 Effect of phosphorus levels and bioinoculants on organic carbon (%) and available soil nutrient (kg/ha)

Treatment	Organic carbon (%)		Available soil nutrient (kg/ha)							
			Nitrogen		Phosphorus		Potassium		Sulphur	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Phosphorus (kg/ha)										
Control	0.24	0.26	188.3	183.5	15.5	14.3	206.7	204.5	14.2	13.2
25	0.31	0.33	202.9	213.3	17.7	21.4	215.2	222.5	16.6	18.7
50	0.39	0.41	217.0	227.3	19.8	23.5	226.5	233.2	18.5	21.0
75	0.41	0.43	217.7	228.0	20.3	24.0	227.1	234.2	19.2	21.9
SEm ±	0.006	0.007	4.0	4.1	0.4	0.4	4.4	4.4	0.3	0.3
CD (P=0.05)	0.022	0.023	14.0	14.1	1.2	1.3	15.0	15.3	1.1	1.2
Bioinoculants										
Control	0.27	0.29	194.2	200.7	15.5	17.8	210.3	214.3	14.2	15.2
PSB	0.32	0.35	205.4	211.9	17.7	20.4	218.0	219.6	16.6	17.9
PGPR	0.34	0.36	208.5	215.0	19.3	21.8	219.8	225.3	18.2	20.0
PSB + PGPR	0.42	0.44	217.8	224.4	20.7	23.2	227.2	235.2	19.6	21.7
SEm ±	0.004	0.005	2.9	3.0	0.3	0.3	3.1	3.2	0.3	0.3
CD (P=0.05)	0.015	0.016	8.4	8.8	0.8	0.9	8.9	9.2	0.7	0.8

Table.6 Linear regression coefficients equations showing relationship between independent variables (Pods/plant, seeds/pod and 1000-seed weight) and dependent variable (seed yield) of pigeonpea

Dependent variables (Y)	Independent variables (X)	Regression equations $Y = a + b_{yx} X$	
		2008-09	2009-10
Seed yield (kg/ha)	X_1 Pods/plant	$Y = -0.867 + 0.070 X_1$	$Y = -2.922 + 0.073 X_1$
	X_2 Seeds/pod	$Y = -1.302 + 5.409 X_2$	$Y = -2.311 + 5.415 X_2$
	X_3 1000-seed weight (g)	$Y = 0.605 + 0.180 X_3$	$Y = -0.067 + 0.183 X_3$

Fig.2 Effect of phosphorus and bioinoculants on seeds/pod

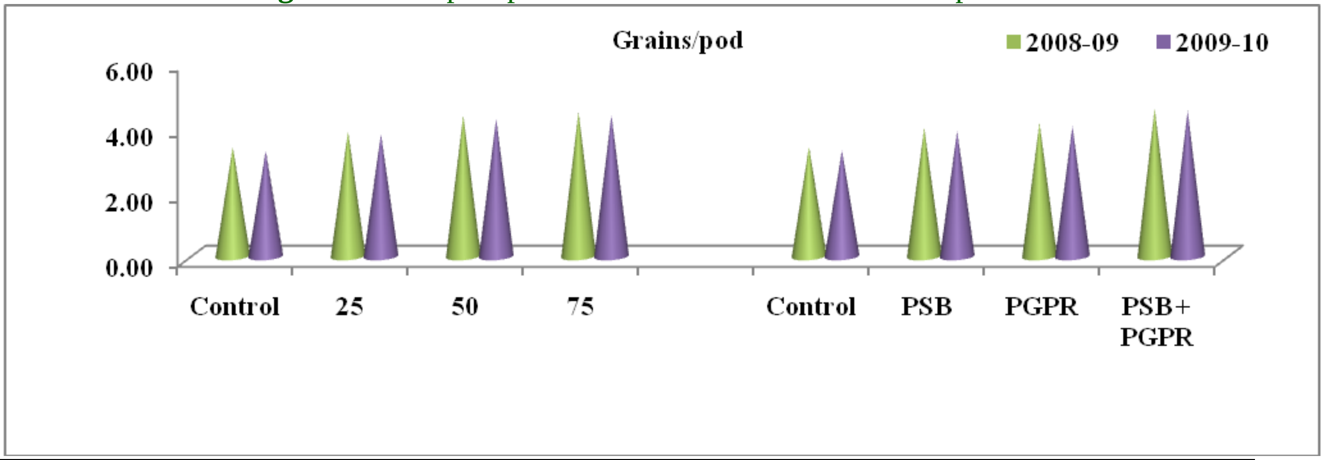
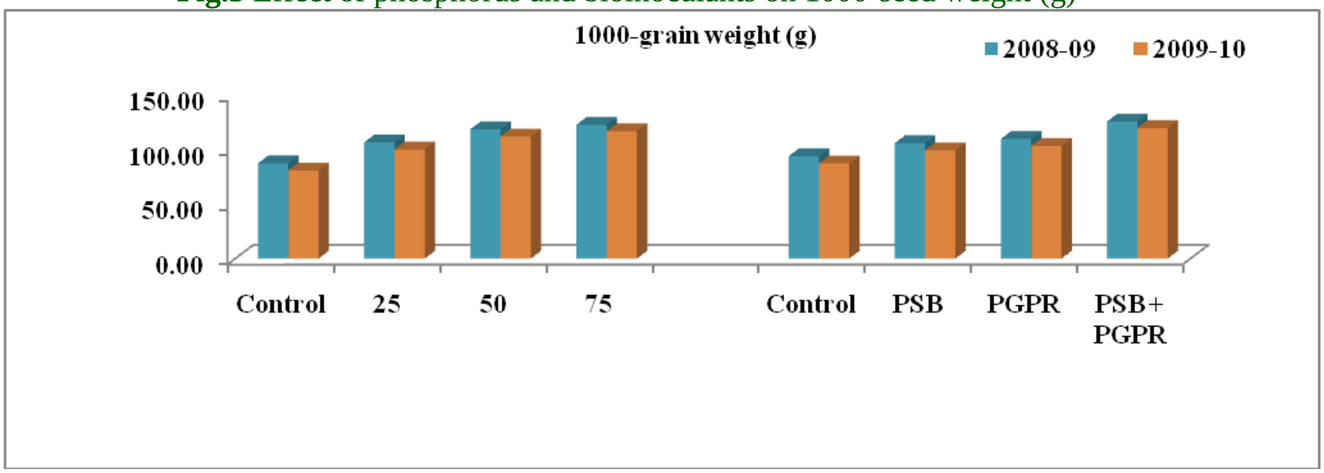


Fig.3 Effect of phosphorus and bioinoculants on 1000-seed weight (g)



Further table 3 shows that dual inoculation of PSB + PGPR gave maximum net returns of 96.70 and 90.30 (`×$10^3$ /ha), benefit: cost ratio of 3.34 and 3.12, production efficiency of 8.7 and 8.1 (kg/ha/day) and economic efficiency of 362.2 and 338.2 (`/ha/day), it being significantly superior to seed inoculation alone with PGPR, PSB and control, respectively (Table 3). Among the bioinoculants, dual seed inoculation with PSB + PGPR was recorded higher protein content which was significantly superior to rest of the bioinoculants during both the years (Table 3). Similarly, the highest protein yield was noted with seed inoculation with PSB + PGPR, being significantly superior to PGPR, PSB alone and control. This might be due to direct enhancement of nutrient uptake (N) due to increases in specific ion fluxes at the root surface in the presence of PGPR. Similar results were also reported by Singh and Yadav (2008), Gupta *et al.,* (2009) and Singh *et al.,* (2012). The higher amount of available organic carbon was recorded with seed inoculation of PSB + PGPR and this treatment was significantly superior to seed inoculation with PSB and control. Seed inoculation of PSB + PGPR gave maximum available soil N, P, K and sulphur in soil after harvest of crop but it was statistically similar with seed inoculation of PGPR and significantly superior to seed inoculation of PSB and control (Table 5). It might be due to release of the native P from the soil and increased concentration of phosphorus in soil solution which helped in early root growth and nodules formation. As a result, symbiotic N_2-fixation increased legumes. Due to increase in symbiotic N_2-fixation, available soil nutrients in soil also increased. These observations are in agreement with those of Singh and Singh (2012b).

Correlation and regression coefficient

Correlation between yield attributes (pod length, pods/plant, pod weight/plant, seeds/pod and 1000-seed weight) and seed yield was observed (Table 4). The correlation coefficient between yields attributes and seed yield showed that it was highly correlated with each other. From the regression equation of pods/plant, seeds/pod and 1000-seed weight (Table 6).

It was concluded that to maximize the productivity, profitability; quality of pigeonpea along with sustained soil fertility, the crop pigeonpea may be fertilized with 75 kg P_2O_5/ha along with seed inoculation of PSB + PGPR under irrigated ecosystem of Varanasi in Eastern Uttar Pradesh.

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