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Performance of Phosphobacteria on Phosphorus Economy and Net Return in Different Potato Growing Region of India

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Abstract

Field experiments were conducted at eleven centers of All India Coordinated Research Project on Potato located in different agro-climatic zones to investigate the role of phosphobacteria in P economy in potato crop during 2005-06 and 2006-07. Six treatments consisting of combinations of different levels of P as well as phosphobacteria (PSB) used in the study showed significant effect on yield of potato. At Kalyani, Chhindwara, Kota, Patna, Hassan and Ooty, recommended dose of NK + 75% P + PSB was statistically at par with recommended dose of NPK in term of total yield. At Bhubaneshwar, Dholi, Hisar, Deesa and Modipuram, 75% of fertilizer P + PSB either had no significant effect on potato tuber yield or reduced the yield marginally in two years of experimentations. Net returns with recommended NPK or 75% P + PSB showed the best results at most of the centers. The per cent saving of fertilizer P, calculated using quadratic model, was maximum for Hassan (43%). In general, use of PSB saved around 20 to 25% P, depending upon agro-ecological situations and soil conditions. However, at Bhubaneshwar, Kota and Dholi the saving being very meager was not economical. The results clearly indicate the role of PSB in saving fertilizer P across different agro-climatic zones, However, it also came out very clearly that effectiveness of the PSB depends on agro-ecological situations and soil conditions.

Keywords: Phosphobacteria, phosphorus application, potato, agro-climatic zone

Phosphorus is one of the key nutrients required for higher and sustained productivity of potato and its influence on tuber yield is very well established. Phosphatic fertilizers are expensive and in developing countries like India, they are either imported or manufactured using imported raw material. Due to increase in cost in the recent past, there has been a decreasing trend in the amounts of P fertilizer applied in India (Sundara and Natarajan, 10 and Sundara, *et. al.* 9). At the same time, soils contain substantial reserves of total P, most of it remains relatively inert, and only less than 10% of soil P enters the plant–animal cycle (Kucey, *et al.* 1). Upon addition to the soils, soluble phosphates react with the constituents of the soil and form compounds that are less soluble. This conversion depends upon the soil type. In acid soils, the reaction products are aluminium and iron phosphates and in the predominantly calcareous soils, the reaction products are calcium phosphates. As a result most of the P applied (often as much as 90%) is rendered unavailable for crop uptake but is retained in insoluble form. This is the reason that the potato-based cropping systems in different potato growing pockets generally show positive P balance resulting into its build up (Singh *et al.* 4). Thus, soils commonly have large reserves of 'fixed' P that could support long-term crop requirements if it could be mobilized through appropriate soil management including use of P-solubilizing microbes.

The ability of phosphate solubilizing bacteria (PSB) to convert insoluble forms of phosphorus to an accessible form is an important trait in sustainable farming for increasing plant yields (Singh and Kapoor, 3). The beneficial effects of PSB on crop productivity have been widely described. These soil phosphate solubilizing bacteria stay near the roots and make the phosphorus available to plants from soil.

The extent of benefit from these micro-organisms depends on their population and efficiency which, in turn is governed by a soil and environmental factors. Different potato growing agro-ecological zones are likely to very in the environmental factors resulting into differential responses to applied PSB. Keeping this in view, a multilocation experiment was conducted in the major potato growing states of India under the All India Coordinated Research Project on Potato during 2005-06 to 2006-07 to evaluate role of phosphorus solubilizing bacteria on P economy in potato. The exact quantification of Phosphorus fertilizer in presence of PSB from mobilization soil P is important. Therefore, yield obtained at different levels of P in presence of PSB was fitted in quadratic response model.

Materials and Methods

Field experiments were conducted at eleven centers of AICRP (Potato) located in different agro-climatic regions of the country namely Bhubaneshwar (Orissa), Chhindwara (MP), Deesa (Gujarat), Dholi (Bihar), Hassan (Karnataka), Hisar (Haryana), Kalyani (West Bengal), Kota (Rajasthan), Modipuram (UP), Ooty (Tamilnadu) and Patna (Bihar) with popular potato cultivars of the regions during 2005-06 and 2006-07 (Table 1) to investigate the role of phosphobacteria in P economy in potato. At all the centers the crop was grown during *rabi* (winter) season following recommended package of practices except at Hassan and Ooty centers where the trials were conducted in summer/kharif 2006 and 2007.

The six manurial treatments involving combination of P through inorganic fertilizer and phosphobacteria *viz.*, recommended dose of N K (T1), recommended dose of NK + 75% P + phosphobacteria (T2), recommended dose of NK + 50% P + phosphobacteria (T3), recommended dose of NK + 25% P + phosphobacteria (T4), recommended dose of NK + phosphobacteria (T5) and recommended dose of NPK (T6) were tried in randomized block design with four replications at all the centers except at Kota, where only three replications were used. Seed tubers were inoculated with phosphobacteria culture purchased from the authentic source and dried in the shade before planting. Nitrogen was applied in two splits as par recommendation *i.e.* half at planting and rest at earthing up at 40 days after planting through calcium ammonium nitrate. Basal application of P and K was done using single super phosphate and muriate of potash respectively, as per treatments at the time of planting. The crop was harvested at maturity and tuber yield and numbers were recorded from all treatments. Data were analyzed separately for each center following standard statistical procedure. For working out net return, price of potato was taken as per respective region. For exact quantification of contribution of PSB in reducing the requirement of fertilizer P, two-year pooled tuber yield of different centers at varying levels of P in presence of PSB were fitted in quadratic response model ($Y = ax^2 + bx + c$) and taking yield obtained at recommended fertilizers was as target (T) and amount of P required (%) to achieved the same in presence of PSB was calculated using the relationship % P of recommended dose required in presence of PSB to obtain a target yield (T) = $\frac{-b \pm \sqrt{b^2 - 4a(c-T)}}{2a}$

Results and Discussion

At Kalyani, in the first year, there was no significant difference in potato tuber yield due to different treatments (Table 2). However, maximum total tuber yield (27.09 t/ha) was observed with recommended NPK followed by recommended NK along with 75% of recommended P + phosphobacteria (26.71 t/ha). Whereas, maximum number of tubers (598.8 thousand/ha) were observed with recommended dose of NK + 25% of P and PSB (Table 3). The recommended dose of NPK gave highest net returns (₹ 46551/ha) followed by recommended dose of NK + 75% P + phosphobacteria (₹ 44639/ha) and recommended dose of NK + 50% P + phosphobacteria (₹ 44526/ha). During second year, the highest tuber yield of 27.19 t/ha was recorded in the treatment where crop was fertilized with recommended doses of NK along with 75% of P + seed tubers inoculation with phosphobacteria followed by recommended NPK (26.61 t/ha). The lowest yield was recorded in the control where only recommended dose of NK was applied.

Similar trend was observed in net return with highest value in recommended NK + 75% P + phosphobacteria (₹ 33300/ha) followed by application of recommended NPK (₹ 29870/ha). Pooled data indicated maximum yield with recommended dose of NK + 75% P + phosphobacteria (26.95 t/ha) which was statistically at par with recommended dose of NPK

Table 1: Experimental details of all the centers during both the year

Center	Year	Date of Planting		Date of Harvesting	
		I	II	I	II
Bhubaneshwar	2005-06 and 2006-07	25.11.05	24.11.06	23.02.06	24.2.07
Chhindwara	2005-06 and 2006-07	29.10.05	11.11.06	26.02.06	08.03.07
Deesa	2005-06 and 2006-07	17.11.05	20.11.06	01.03.06	12.03.07
Dholi	2005-06 and 2006-07	01.12.05	22.11.06	20.03.06	07.03.07
Hisar	2005-06 and 2006-07	16.10.05	26-10-06	6.03.06	7.03.07
Kalyani	2005-06 and 2006-07	05.12.05	05.12.06	09.03.06	15.03.07
Kota	2005-06 and 2006-07	11.11.05	07.11.06	02.03.06	22.02.07
Modipuram	2005-06 and 2006-07	03.11.05	14.11.06	21.02.06	06.03.07
Patna	2005-06 and 2006-07	22.11.05	30.11.06	25.02.06	21.03.07
Hassan	2006 and 2007	06.06.06	12..06.07	26.09.06	22.09.07
Ooty	2006 and 2007	12.05.06	07.05.07	28.09.06	24.09.07

Table 2: Effect of PSB and graded dose of P on total tuber yield (t/ha) at different centers

Treatments	Center											
	Kalyani			Chhindwara			Kota			Patna		
	I	II	Pooled	I	II	Pooled	I	II	Pooled	I	II	Pooled
T1	22.6	22.17	22.39	25.88	27.15	26.52	14.69	14.22	14.46	30.35	26.68	28.52
T2	26.71	27.19	26.95	31.14	32.54	31.84	27.43	22	24.72	35.86	30.66	33.26
T3	26.39	25.38	25.89	30.2	31.05	30.63	26.38	20.77	23.58	34.73	29.65	32.19
T4	25.64	25.64	25.64	27.39	29.07	28.23	22.41	15.11	18.76	32.83	29.41	31.12
T5	24.15	23.51	23.83	26.5	28.52	27.51	17.24	15.11	16.18	31.11	27.73	29.42
T6	27.09	26.61	26.85	31.63	33.05	32.34	28.56	23.97	26.27	36	30.87	33.44
CD (0.05)	NS	3.7	3.79	1.76	2.74	3.08	1.05	1.52	1.39	1.7	3.05	2.36
	Hassan			Ooty			Bhubaneshwar			Dholi		
	I	II	Pooled	I	II	Pooled	I	II	Pooled	I	II	Pooled
T1	24.65	19.53	22.09	9.49	4.79	7.14	8.32	13.15	10.74	11.39	6.79	9.09
T2	44.15	28.23	36.19	21.3	9.82	15.56	9.47	20.58	15.03	16.02	10.34	13.18
T3	34.71	25.79	30.25	19.15	6.32	12.74	4.99	17.56	11.28	14.09	9.57	11.83
T4	31.94	22.81	27.38	14.38	5.95	10.17	8.41	16.76	12.59	13.12	8.95	11.04
T5	28.38	16.15	22.27	12.32	5.31	8.815	5.15	14.66	9.905	12.16	7.26	9.71
T6	37.71	26.98	32.35	21.78	11.15	16.47	9.27	22.51	15.89	16.41	11.81	14.11
CD (0.05)	4.52	1.46	3.22	6.68	3.38	5.12	NS	1.39	3.22	2.78	0.99	1.99
	Hisar			Deesa			Modipuram					
	I	II	Pooled	I	II	Pooled	I	II	Pooled			
T1	25.92	25.78	25.85	40.67	39.26	39.97	28.01	29.57	28.79			
T2	29.51	28.95	29.23	39.85	37.72	38.79	27.4	28.99	28.2			
T3	28.97	28.45	28.71	41.74	36.17	38.96	26.98	28.47	27.73			
T4	27.7	27.41	27.56	39.16	38.07	38.62	27.74	29.17	28.46			
T5	26.94	26.11	26.53	42.15	38.19	40.17	26.95	28.65	27.8			
T6	30.55	31.65	31.1	40.56	38.09	39.33	29.01	30.16	29.59			
CD (0.05)	2.56	5.82	4.30	NS	NS	NS	NS	2.9	NS			

T1: Recommended dose of N K, **T2:** Recommended dose of NK + 75% P + phosphobacteria, **T3:** Recommended dose of NK + 50% P + phosphobacteria, **T4:** Recommended dose of NK + 25% P + phosphobacteria, **T5:** Recommended dose of NK + phosphobacteria and **T6:** Recommended dose of NPK.

Table 3: Effect of PSB and graded dose of P on total tuber number ('000/ha) at different centers

Treat-ments	Center														
	Kalyani			Chhindwara			Kota			Patna			Hassan		
	I	II	Pooled	I	II	Pooled	I	II	Pooled	I	II	Pooled	I	II	Pooled
T1	520.8	505	513.1	578.1	603.4	590.8	755.4	908.2	831.8	692.5	682.3	687.4	257.3	219.4	238.4
T2	580.7	580	580.4	536.5	557.9	547.2	672.3	508.5	590.4	869.3	779.2	824.25	388.5	359.4	374
T3	543.8	521	532.3	567.3	581	574.2	782.4	601.1	691.8	782.5	716.7	749.6	261.7	332.7	297.2
T4	598.8	601	599.9	485	513.1	499.1	776.7	620.6	698.7	748.4	771	759.7	249.3	280.2	264.8
T5	543.8	550	546.8	470.7	500.8	485.8	611.4	656.8	634.1	691.8	717.7	704.75	251.4	183.6	217.5
T6	589.2	613	601.2	552.5	580.2	566.4	568.4	454.7	511.6	783.7	736.6	760.15	255.2	340.3	297.8
CD (0.05)	NS	NS	NS	37.3	44.2	39.2	NS	71.9	120.4	81.7	NS	91.5	62.6	19.8	13.21
	Ooty			Bhu.	Dholi			Hisar			Deesa	Modipuram			
	I	II	Pooled	II	I	II	Pooled	I	II	Pooled	II	I	II	Pooled	
T1	450.5	263	356.8	293.8	275.7	268.1	271.9	356.3	353.4	354.85	644.6	715.9	728.8	722.4	
T2	858.1	412	634.8	453	378.5	345.1	361.8	439	389.5	414.25	652.3	725.7	738.2	732	
T3	668	305	486.4	409	353	317.5	335.3	436	367.3	401.65	216.7	688.5	715.7	702.1	
T4	692.7	292	492.2	379.6	311.3	292.1	301.7	410.1	361.9	386	727.5	715.9	725.9	720.9	
T5	467.4	294	380.9	340	294	280.9	287.5	412.2	349	380.6	583.3	710.6	724.9	717.8	
T6	815.1	490	652.4	500.2	402.4	394.9	398.7	421.7	426.5	424.1	709.2	733.2	742.5	737.9	
CD (0.05)	179.4	132	151.1	21.7	81.5	44.8	63.08	46.5	NS	59.56	NS	NS	NS	NS	

T1: Recommended dose of N K, **T2:** Recommended dose of NK + 75% P + phosphobacteria, **T3:** Recommended dose of NK + 50% P + phosphobacteria, **T4:** Recommended dose of NK + 25% P + phosphobacteria, **T5:** Recommended dose of NK + phosphobacteria and **T6:** Recommended dose of NPK.

Table 4: Effect of PSB and graded dose of P on net return (₹/ha) at different centers

Treat-ments	Centers											
	Kalyani		Chhindwara		Kota		Patna		Hassan		Ooty	
	I	II	I	II	I	II	I	II	I	II	I	II
T1	34901	21569	63599	92839	19835	17963.88	47336	-25620	64980	47700	-25620	NR
T2	44639	33300	80784	115757	69129	47138.88	62673	25513	107925	87725	25513	*NR*
T3	44526	28723	77870	109429	65458	42823.90	59636	17459	94540	72550	17459	*NR*
T4	41614	29079	68452	100901	49629	20855.90	54147	-4267	88975	57575	-4267	*NR*
T5	38701	25057	65884	98520	29993	21481.88	49383	-12884	54940	30000	-12884	*NR*
T6	46551	29870	82103	115571	731610	54103.88	63022	26997	99840	85000	26997	*NR*
	Bhubaneshwar		Dholi		Hisar		Deesa		Modipuram			
	I	II	I	II	I	II	I	II	I	II		
T1	NR	- 6432	20800	4365	47943	47399	139141	164071	33348	37516		
T2	*NR*	21850	36250	20270	60920	58680	133342	153122	30293	34435		
T3	*NR*	10238	33850	16275	59081	56997	143255	144325	29463	33742		
T4	*NR*	7499	27600	14205	54310	53154	130695	156225	32143	35899		
T5	*NR*	- 424	24250	8180	51631	48311	146336	157451	30143	34761		
T6	*NR*	29142	40950	29655	65159	69635	136589	155039	34723	37498		

T1: Recommended dose of N K, **T2:** Recommended dose of NK + 75% P + phosphobacteria, **T3:** Recommended dose of NK + 50% P + phosphobacteria, **T4:** Recommended dose of NK + 25% P + phosphobacteria, **T5:** Recommended dose of NK + phosphobacteria and **T6:** Recommended dose of NPK.

Table 5: Effect of PSB and graded dose of P on net return (₹/ha) at different centers (mean of two years)

	Kalyani	Chhindwara	Kota	Hassan	Dholi	Hisar	Deesa	Modipuram
T1	28235	78219	18899	56340	12583	47671	151606	35432
T2	38970	98271	58134	97825	28260	59800	143232	32364
T3	36625	93650	54141	83545	25063	58039	143790	31603
T4	35347	84677	35242	73275	20903	53732	143460	34021
T5	31879	82202	25737	42470	16215	49971	151894	32452
T6	38211	98837	63632	92420	35303	67397	145814	36111

T1: Recommended dose of N K, **T2:** Recommended dose of NK + 75% P + phosphobacteria, **T3:** Recommended dose of NK + 50% P + phosphobacteria, **T4:** Recommended dose of NK + 25% P + phosphobacteria, **T5:** Recommended dose of NK + phosphobacteria and **T6:** Recommended dose of NPK.

Table 6: Contribution of PSB in phosphorus nutrition of potato crop as derived from quadratic ($y= ax^2+bx+c$) model

Quadratic co-efficients	Kalyani	Chhindwara	Kota	Patna	Hassan	Ooty	Bhubaneshwar	Dholi
a	-0.30	0.196	-0.576	-0.252	0.332	0.586	0.426	0.008
b	60.94	46.86	164.9	69.26	153.6	47.27	24.31	44.2
c	23949	27367	15884	29452	22536	8766	10357.75	9765
R^2	0.944	0.966	0.963	0.997	0.986	0.998	0.713	0.990
Target Yield* (kg/ha)	26850	32340	26270	33440	32350	16470	15890	14110
Dose of P required in presence of PSB (%)	76	80	94	82	57	81	89	97
Contribution of PSB (%)	24	20	6	18	43	19	11	3

*Yield obtained at recommended dose of fertilizer.

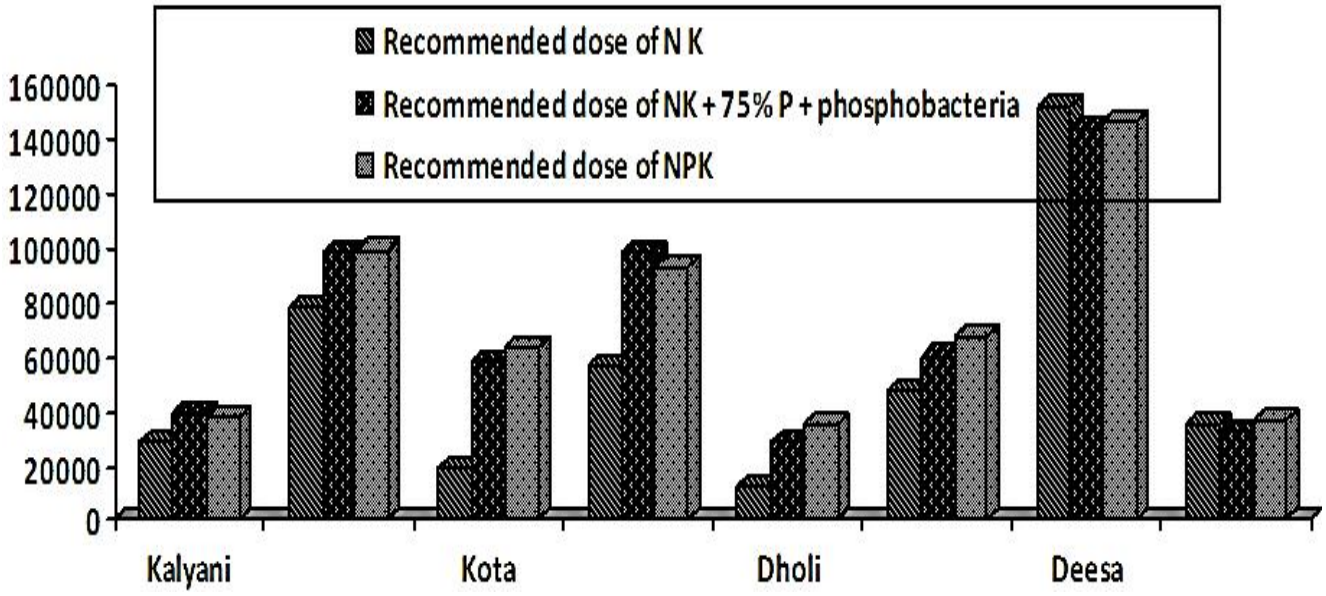

Fig. 1: Effect of PSB and graded dose of P on average net return (₹/ha) of two year at different centers

(26.85 t/ha). Both the treatments were significantly better than control.

At Chhindwara, the recommended dose of NPK recorded significantly higher tuber yield (31.6 and 33.05 t/ha) during both the year which was at par with recommended dose of NK + 75% P + phosphobacteria (30.2 and 31.05 t/ha). Trend of yield in both year was also reflected in pooled yield and maximum tuber yield (32.34 t/ha) was observed in recommended dose of NPK followed by recommended dose of NK + 75% P + phosphobacteria (31.84 t/ha) which was significantly better than control. Recommended dose of NK (without recommended dose of P) produced significantly higher number of total tubers both the year as well as in the pooled analysis. The highest net return was observed in recommended dose of NPK (₹ 82103 and 115571/ha) which was closely followed by recommended NK along with 75% P and PSB (Rs. 80784 and 115757/ha) and recommended NK + 50% P + PSB (₹ 77870 and 109429/ ha) during both the year.

At Kota, recommended dose of NPK during both the year recorded highest tuber yield and net returns (28.55 and 23.97 t/ha and ₹ 73161 and 54103/ha, respectively) which was followed by recommended dose of NK along with 75% P and phosphobacteria (27.43 and 22.0 t/ha and ₹ 69129 and 47139/ha). Pooled analysis also showed that maximum yield (26.27 t/ha) with recommended NPK followed by recommended NK + 75% P + phosphobacteria (24.72 t/ha).

At Patna, the highest total tuber yield was recorded with recommended NPK (36.02 and 30.87 t/ha) which was statistically at par with use of PSB and 75% P with recommended NK (35.89 and 30.66 t/ha) during both the year. Tuber production with recommended dose of NK + 75% P + phosphobacteria (33.26 t/ha) was statistically at par with recommended dose of NPK (33.44) in pooled analysis also. However, number of tubers was maximum with recommended dose of NK + 75% P + phosphobacteria (824.25 thousand/ha) and was at par with recommended NPK. Similar trend was observed in net returns from these two treatments (₹ 63022/ha and ₹ 62673/ha and ₹ 26997/ha and ₹ 25513/ha, respectively during 2005-06 and 2006-07.

At Hassan, potato tuber yield as well as tuber numbers were also significantly higher in the treatment receiving recommended doses of N and K along with 75% of P and PSB (44.15 and 28.22 t/ha and 388.4 and 359.4 thousand/ha, respectively) followed by the treatment receiving recommended doses of N, P and K (37.71 and 216.98 t/ha and 255.2 and 340.3 thousand/ ha). Pooled data also reflected trends observed for tuber yield and number during both the years of experiment. Maximum net return of ₹ 1, 07,925 and 87,725/ha was also obtained with the same treatment followed by recommended doses of NPK (₹ 99840 and 85000/ha). Similarly, at Ooty also, results reveal that phosphobacteria treatment could compensate 25% of P recommended dose as the yield and tuber numbers obtained with 100% recommended dose of P and 75% recommended P + phosphobacteria (21.78, 11.15 and 21.30, 9.82 t/ha) were at per during both year as well as in pooled result. Other treatments showed significantly less number of tubers. Net return (₹ 26,997/ha) was higher when recommended doses of NPK was applied to potato closely followed by the treatment in which 25% of phosphorus dose was substituted by phosphobacteria (₹ 25,513/ha) in the first year.

At Bhubaneshwar, there was no significant difference among various treatments in the first year of experiment but in second year, the highest total tuber yield and numbers of (22.5 t/ha and 500.2 thousand/ ha) were recorded in recommended dose of NPK followed by use of phosphobacteria with 75% P along with recommended NK doses (20.58 t/ha) (Table 2 and 4).

Pooled data repeated the trend having yield of recommended dose of NPK and recommended dose of NK + 75% P + phosphobacteria at par and better than other treatments. Similar trend was observed for net returns for these two treatments (₹ 29142/ha and 21850/ ha for recommended dose of NPK and recommended dose of NK + 75% P + phosphobacteria, respectively). At Dholi, application of recommended dose of NPK produced highest yield (16.41 and 11.81 t/ha) as well as number of total tubers (402.4 and 394.9 thousand/ha) during both the year as well as pooled yield of two years. However, in tuber numbers during second year, recommended dose of NPK was significantly better than recommended dose of NK + 75% P + phosphobacteria, Similar trend was observe in net return, the highest net returns (₹ 40950 and 29655/ha) was obtained for the recommended dose of NPK followed by recommended dose of NK along with 75% P and phosphobacteria (₹ 36250 and 20270/ha) during both the years of experimentations.

At Hisar, during both the year, total tuber yield was highest in the treatment with recommended dose of NPK (30.55 and 31.65 t/ha) followed by recommended dose of NK + 75% P + phosphobacteria (29.51 and 28.95t/ ha). Similar trend for tuber yield of both the year was also reflected in pooled analysis. Similarly, the highest net return was obtained with recommended dose of NPK (₹ 65159 and 69635/ha) followed by recommended dose

of NK + 75 % P + PSB (₹ 60920 and 58680/ha). Total tuber number during first year was higher with recommended dose of NK + 75% P + phosphobacteria (439.0 thousand/ha) followed by recommended doses of NK + 50% P + PSB (436.0 thousand/ha). Whereas, in 2006-07, total tuber number were higher in the treatment with recommended dose of NPK (427.0 thousand/ha) followed by recommended doses of NK + 75% P + PSB (389.5 thousand/ha).

At Deesa, there was no significant difference among various treatments during both the years. However, in comparison to other treatments, recommended dose of N K + PSB gave highest total tuber yield (42.15 and 39.29t/ha). Highest net returns of ₹ 146336 and 164071/ha were obtained with the use of recommended dose of NK + PSB followed by recommended NK + 50% P + PSB and only PSB (₹ 143255 and 157451/ha).

At Modipuram, there was no significant difference among various treatments during both the years. Results showed that the effect of treatments was non-significant for total yield and numbers of tubers (Table 2, 3 and 4). However, the maximum tuber yield (29.0 and 30.16 t/ha) and number (733.2 and 742.5 thousand/ha) were obtained with recommended NPK. Highest net gain (Rs. 34723 and 37498/ha) was also obtained in the same treatment followed by recommended dose of N K (₹ 33348 and 37516/ha).

On the basis of mean value of two years amongst all the treatments, Maximum net returns (₹ 98837 63632, 35303, 67397 and 36111/ha) *were obtained with* recommended dose of NPK closely followed by recommended dose of NK + 75% P + phosphobacteria (₹ 98271, 58134, 28260, 59800 and 32364/ha) at Chhindwara, Kota, Dholi, Hisar and Modipuram, respectively (Table 5 and Fig.1). Whereas, at Kalyani and Hassan, application of recommended dose of NK + 75% P + phosphobacteria gave maximum net return followed by recommended dose of NPK. However, at Deesa, recommended dose of NK + phosphobacteria gave maximum net return (₹ 151894/ha) followed by recommended dose of NPK (₹ 145814/ha). Therefore, the net return indicated that 25 to 50% dose of P can be saved by the PSB treatment.

The tuber yield obtained in presence of phosphobacteria with respect to varying P levels from 0-75% fitted well in quadratic model with R^2 value ranging from 0.713 for Bhubaneshwar to 0.998 for Ooty. Taking tuber yield at recommended NPK as target yield when % of recommended P required in presence of PSB was calculated, Hassan Center showed maximum saving. At this center only 57% of recommended P application in presence of PSB, achieved the yield what recommended NPK gave and therefore, PSB treatment saved about 43% of P fertilizer. In the per cent saving of P fertilizer due to PSB use Hassan was followed by Kalyani (24%), Chhindwara (20%), Ooty (19%), Patna (16%), and Bhubaneshwar (11%). At Kota and Dholi, PSB treatment could save only a meager amount (*i.e.* 6 and 3%, respectively) of recommended P (Table 6). Therefore, it may be inferred that effectiveness of PSB was dependent on the agro-ecological situation and soil conditions of the field where it is being used.

The results of this study indicated the beneficial effects of PSB inoculation to potato at most of the centers. It was evident that at most places PSB inoculation was capable of saving at least 25% of recommended phosphatic fertilizers as the yield obtained from PSB inoculation replacing 25% of recommended P was superior or at par with recommended NPK at centers Kalyani, Chhindwara, Kota, Patna, Hassan and Ooty. Centers like Bhubaneshwar, Dholi, Hisar, Deesa and Modipuram did not show consistency in P saving with the use of PSB. At Dholi and Hisar, soils were low in organic matter (< 0.5%) and high in pH (> 8.0) which was not very favourable for the PSB group of microbes. However, some response was due to P solubilised possibly from inorganic insoluble calcium compounds.

The poor response at Modipuram was possibly resulting from high available P in soil and at Deesa the very low organic carbon (<0.2 %) might not have allowed PSB to proliferate and solubilise the unavailable P. The beneficial effect and saving of P fertilizer using PSB was reported by Singh (5) and Singh, (6) in north-eastern hills and under East Khasi hill conditions of Meghalaya, Sood, and Sharma (7) at Shimla hills and Sud, and Jatav (8) in brown hill soils of Shimla (HP)). Phosphate solubilizing Bacteria (PSB) are capable of hydrolyzing organic and inorganic phosphorus from insoluble compounds. It is generally accepted that the mechanism of mineral phosphate solubilization by PSB strains is associated with the release of low molecular weight organic acids, through which their hydroxyl and carboxyl groups chelate the cations bound to phosphate, thereby, converting it into soluble forms.

In addition, some PSB produce phosphatase like phytase that hydrolyse organic forms of phosphate compounds efficiently (Zehra, 11; Rodriguez and Fraga, 2). At Chhindwara replacing of 25% of inorganic P with PSB without compromising on yield despite low available soil P was possibly due to the capability of these microbes to mobilize this nutrient from organic sources as soil of the experimental field was having around 0.7% organic carbon.

Similarly, 0.6 % organic carbon in the experimental soils at Kota might have helped the microbes. In addition, pH above 7.5 indicates that P solubilization in these soils might have come from Ca-bound compounds. Even at very low pH (4.0-4.2) good response of PSB at Ooty was possible only due to high content of organic carbon (1.60-1.64 %) in soil. It is most likely that major fraction of P solubilised by PSB had come from organic sources.

The results showed that phosphate solubilizing bacteria (PSB) is of great importance in reducing fertilizer doses and practicing integrated plant nutrients supply. It may be concluded that combined application of P along with tuber inoculation with PSB can be effective in reducing the inorganic P dose by approximately 20 to 25%. Besides saving fertilizer, this treatment also showed increased efficiency, net return and B: C ratio. These information have special importance in the light of wide spread finding that many of the potato growing pockets are showing build up of P in soil creating imbalances of nutrients particularly making some micronutrient unavailable.

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