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Maximization of Nutrient use Efficiency and Yield through Application of Biofertilizers in Field Pea (*Pisum sativum* L.)

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ABSTRACT

Background: The negative effects of continuous use of chemical fertilizers on soil microbiology and agricultural sustainability are well established. The chemical fertilizers load in environment can be minimized by combined application of fertilizers and biofertilizers in crops like pulses which require less fertilizer-N and respond well to the use of biofertilizers. The objectives of the study were to see the effect of different biofertilizers in reduction of total fertilizer use and the response of field pea to combined application of chemical- and bio-fertilizers in terms of growth, yield and NUE.

Methods: A field experiment was conducted during 2 consecutive *rabi* season of 2017-18 and 2018-19 at KVK, Chhatarpur, Jabalpur (Madhya Pradesh), India to evaluate the application of fertilizers and biofertilizers on growth parameter, nodulation, nutrient content and uptake, nutrient use efficiency, yield and economics of field pea. The experiment was laid out in randomized block design with five treatments in four replications. Treatments comprised of Control, Recommended dose (RD) of NPK (20: 60: 20 kg N, P_2O_5 and K_2O/ha, respectively) (RD_{NPK}), RD_{NPK} + seed inoculation with *Rhizobium* @ 20 g/kg seed (RD_{NPK} +R), RD_{NPK}+ R + phosphate solubilizing bacteria @ 20 g each/kg seed (RD_{NPK} + R+PSB) and 75% of RD_{NPK} + R+ PSB + potash solubilizing bacteria @ 5 kg/ha (75% RD_{NPK}+ R+PSB+KSB). All other practices followed as per recommendation for the region and different observations and indices were recorded by following standard procedures.

Conclusion: The application of 75% RD_{NPK}+R+PSB+KSB was found best treatment among all others which resulted in highest grain yield (1682 kg/ha), protein content (23.1%), protein yield (388.5 kg/ha), net return (Rs. 46 623/ha) and B:C ratio (2.94). The nutrient use efficiency such as partial factor productivity (PFP), agronomic efficiency (AE), physiological efficiency (PE) and economic efficiency (EE) were also higher under combined application of fertilizers and biofertilizers. Thus, 75% RD_{NPK} along with combined application of biofertilizers (R+PSB+KSB) may be applied for higher yield and return from field pea.

Key words: Economics, Nodulation, Nutrient uptake, Nutrient use efficiency, Protein.

INTRODUCTION

Field pea (*Pisum sativum* L. var. *arvens*), derives from the Middle East, is an oldest domesticated crop on earth (Warkentin *et al*., 2015). Field pea is consumed as fresh or dry split as *dal*. Pea seeds, fresh or dry, has high nutritional values due to their high contents of protein (21-25%), carbohydrates, vitamins A and C, calcium and phosphorous (Ravindran *et al*., 2010). India is the largest pulses producer and consumer in the world and contributes about 1/4th world pulses production. The total area occupied by the pulses in the country during 2017-18 is 29.99 m ha with total production of 25.42 m tones and productivity of 853 kg/ha (DES, 2019). Field pea cultivated in 0.82 m ha area with production of 0.99 m tonnes and productivity of 1204 kg/ha (Anonymous, 2019).

However, due to continuous use of chemical fertilizers and pesticides in the modern agricultural practices led to an adverse effect on soil health and population of the native beneficial soil microorganisms. Soil microflora constitutes the biological parameters of soil which are considered to play a vital role in maintaining soil health, productivity and sustainability. Chemical fertilizers not only leave toxic elements, although in trace amounts in soil, but also alter the microbial dynamics thereby interfering with soil fertility levels (Klein *et al*., 1989; Zhao and Wang, 2010). In a soil-plant system, the rhizosphere determines the overall growth of plant, therefore any change in fertility management will strongly influence the soil-plant interactions. There is need to identify and apply crop specific microorganisms that help in development of nodulation in pulses and to make unavailable form of fixed soil nutrients to plants usable available forms. Biofertilizers, organic products of living cells

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of different types of microorganisms, could convert nutritionally important elements from unavailable to available form through biological processes (Itelima *et al*., 2018).

In context of soil fertility management, biofertilizers is emerging as an economically attractive and ecologically sound means of fertilization (Kaur and Purewal, 2019). Besides improving soil health, biofertilizer also reduce the amount of chemical fertilizer. Being a leguminous crop, field pea responds well to applied biofertilizers (Negi *et al*., 2006). It fixes atmospheric-N in symbiotic association with root nodulating *Rhizobium*. Field pea also responds to the application of phosphate and potassium solubilizing microorganisms which led to increase in nutrient use efficiency as well as yield (Subba-Rao, 1986; Singh *et al*., 2012; Teotia *et al*., 2016). Keeping these things in background, the objective of conducting the present study was to assess the effect of biofertilizers in combination with chemical fertilizers on yield, economics and nutrient use efficiency of field pea.

MATERIALS AND METHODS

The field experiment was conducted at KVK, Chhatarpur Instructional Farm, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur, Madhya Pradesh (25°04′ N latitude and 79°51′ E longitude) during *Rabi* (winter) seasons of 2017-18 and 2018-19. The soil of the experimental site was sandy loam belongs to class *Typic Ustochrept*. The details of soil characteristics were presented in Table 1. The experiment was laid out in randomized block design with five treatments in four replications. Treatments comprised of (i) Control, (ii) Recommended dose (RD) of NPK (20: 60: 20 kg N,P_2O_5 and K_2O/ha, respectively) (RD_{NPK}), (iii) RD_{NPK}+seed inoculation with *Rhizobium* @ 20 g/kg of seed (RD_{NPK} +R), (iv) RD_{NPK} +R+phosphate solubilizing bacteria @ 20 g each/kg seed (RD_{NPK} +R+PSB) and (v) 75% of RD_{NPK} + R + PSB + potash solubilizing bacteria (KSB) @ 5 kg/ha (75% RD_{NPK} +R+PSB+KSB). The all biofertilizers were obtained from the Microbes Research and Production Centre, Department of Soil science and Agriculture Chemistry, JNKVV, Jabalpur. Field pea variety 'IPFD 10-12' (Harith) was selected in the experiment. The seeds of fieldpea crop were treated with *Rhizobium* and PSB @ 20 g/kg seed as per treatment with standard procedure (Shravani *et al*., 2019). Soil application of KSB biofertilizers @ 5 kg/ha and fertilizers (NPK) was done at the time of final seed bed preparation. Field pea was sown in a planting geometry of 45 ×10 cm. All other cultural practices and plant protection measures were followed as per recommendation for this region.

Five representative plant samples were randomly selected and uprooted carefully at three specific crop growth stages *viz*., active growth stage (25 DAS), flowering (50 DAS) and pod filling stage (75 DAS) for counting the nodules number, nodule diameter and fresh weight and dry weight. After washing of root properly under tap water, nodules were carefully detached from the roots and collected in an icebox form the experimental site. In laboratory, nodules were kept over filter paper for soaking of excess adhered moisture. After counting and taking fresh weight, nodules were oven dried for recording dry weight.

At the time of physiological maturity of crop, five plants were selected randomly for recording growth and yield attributes. From each plot, grain and straw samples were collected and dried for 48 hours at 75°C temperature in oven followed by grinding to do chemical analysis. Field pea grain and straw powder were used for chemical analysis. During 2 year of study (2018-19) Plant samples (seed and straw) were analyzed to access total nitrogen, phosphorus and potassium uptake following standard analytical procedures as suggested by Jackson (1967).

The percentage of protein was calculated by multiplying 6.25 with nitrogen content of grain by using Eq. 1 (Jackson, 1962). The N, P and K uptake of grain and straw was calculated by multiplication of concentration of nutrient with their respective dry weight. Nutrient use efficiency indices like Partial Factor Productivity (PFP), Agronomic Efficiency (AF) and Physiological Efficiency (PE) were estimated as suggested by Dobermann (2007) using the following equations (Eq. 2, 3 and 4). The Economic Efficiency (EE) was calculated by dividing net return (Rs/ha) with cost of production (Rs/ha).

Protein yield (kg/ha) =

$$\frac{\text{Protein content (\%)} \times \text{grain yield (kg/ha)}}{100} \quad \text{- Eq. 1}$$

Applied N partial factor productivity (PFP_N) =

$$\frac{GY_{+N}}{FN} \quad \text{- Eq. 2}$$

Applied N agronomic efficiency (AE_N) =

$$\frac{GY_{+N} - GY_{-N}}{FN} \quad \text{- Eq. 3}$$

Applied N physiological efficiency (PE_N) =

$$\frac{GY_{+N} - GY_{-N}}{TN_{+N} - TN_{-N}} \quad \text{- Eq. 4}$$

Where,

TN_{+N}= Total N uptake by aboveground plants in plot that received N fertilizer.

TN_{-N}= Total N uptake by aboveground plants in plot that received zero-N fertilizer (control).

FN= The amount of N fertilizer (chemical) applied.

GY_{+N}= Grain yield in the plot that received N fertilizer.

GY_{-N}= Grain yield in the plot that received zero-N fertilizer (control).

The significant of treatment effect was determined using F-test (Panse and Sukhatme, 1967). Analysis of variance was performed using online statistical program OPSTAT. Pooled data analysis was also performed using same online statistical program. Comparisons of treatment mean values were performed using least significant difference (LSD, p = 0.05).

RESULTS AND DISCUSSION

Growth attributes

The maximum plant height (75.5 cm), number of branches/plant (3.5) and number of roots/plant (14.0) were recorded from the plants received 75% RD_{NPK} +R +PSB +KSB followed by RD_{NPK} +R+PSB (72.3 cm, 3.2 and 13.2, respectively) whereas, least in control (65.5 cm, 2.5 and 8.3, respectively) (Table 2). The higher values of these plant growth parameters may be due to increase in availability of NPK with the application of chemical fertilizers along with biofertilizers like Rhizobium, PSB and KSB. It has been reported that inoculation of chickpea with Rhizobium, PSB and KSB enhances stem height, root length and number of roots/plant (Gupta and Sahu, 2012; Gangwar and Dubey, 2012; Kumari *et al.,* 2014).

Phenological changes

Significant effects of application of biofertilizers were recorded in days to 50% flowering and physiological maturity. There was 5 days delay in 50% flowering and 10 days delay in physiological maturity recorded in 75% RD_{NPK} +R+PSB+KSB in comparison to control (Table 2). The increase in these phenologies was also observed in case of application of fertilizers (NPK) alone or in combination with Rhizobium or/and PSB over no fertilizers (control). Under abiotic stresses, plants shorten their vegetative growth and flower early. However, under proper nutrients supply, plants try to increase their biomass by delaying flowering and maturity (Ye *et al*., 2019). This phenomenon has been also reported in pulse crops (Namvar and Sharifi, 2011). The increased availability of nutrient in soil through biological processes of biofertilizers like Rhizobium, PSB and KSB is well documented (Tilak *et al*., 2006; Kundu *et al*., 2009; Ghosh *et al.,* 2010; Rajawat *et al*., 2019).

Table 1: Initial soil properties of experimental field (0-15 cm).

Properties	Value
pH (soil: water, 1:2.5)	6.8
EC (dS/m)	0.13
Available N (kg/ha)	205
Available P (kg/ha)	17
Available K (kg/ha)	210
Available S (kg/ha)	9.1
Available Zn (mg/kg)	0.48
Available Fe (mg/kg)	4.9
Texture	Sandy loam
Taxonomic classification	Typic Ustochrept

Yield attributes

The significant positive effect of addition of chemical and biofertilizers were recorded in all yield attributes (Table 2). The significantly higher value of all yield attributes *viz.*, numbers of pods/plant (22.0), number of grains/pod (8.0) and test weight (171.7 g) were recorded with 75% RD_{NPK} +R+PSB+KSB followed by RD_{NPK} +R+PSB (20.3, 7.0 and 169.3g, respectively over control (12.0, 6.0 and 150.3 g, respectively) (Table 2). Increased availability of plant nutrient and production of phytohormones under application of biofertilizers along with chemical fertilizers resulted in higher plant growth which led higher values of all yield attributes. Singh and Sharma (2011) and Selvakumar, *et al.* (2012) have also recorded similar observations in chickpea and urdbean, respectively.

Root nodulation

Significant variations in all nodulation parameters like nodules per plant, nodule mean diameter and nodule fresh and dry weight were recorded under different treatments. The highest values of nodulation were recorded at 50 DAS and minimum at 75 DAS (Table 3). The significantly maximum values of nodules per plant was recorded in 75% RD_{NPK} +R+PSB+KSB followed by RD_{NPK} +R+PSB and NPK+R and least under control at all the crop growth stages (25, 50 and 75 DAS). The increase in nodules per plant was maximum (84%) under 75% RD_{NPK}+R+PSB+KSB over control at 50 DAS. Mean diameter of nodules, nodules fresh and dry weight is an indicator of effective nodulation and these are directly related to N-fixation. All these parameters were also higher under 75% RD_{NPK}+R+PSB+KSB followed by NPK+R+PSB and least under control (Table 3). The maximum increase in mean diameter of nodules (67 and 37.5%), fresh weight of nodules per plant (96.2 and 47.7%) and dry weight of nodules per plant (96.4 and 36.9%) were recorded under 75% RD_{NPK}+R+PSB+KSB over control and NPK, respectively. The maximum translocation of photosynthate from top to root zone for utilization by root-nodulating bacteria is at the active growth

Table 2: Effect of nutrient management on growth, phenology and yield attributes of field pea (Pooled analysis).

Treatment	Plant height (cm)	Branches /plant	Number of root/ plant	Days to 50% flowering	Days to Maturity	Number of pods /plant	Number of grains /pod	Test weight (g)
Control	65.5	2.5	8.3	42.0	110.0	12.0	6.0	150.3
RD_{NPK}	68.5	2.5	10.3	45.0	114.0	17.3	6.0	158.7
RD_{NPK} + R	69.5	2.8	12.8	45.0	115.0	18.3	6.5	168.3
RD_{NPK} + R + PSB	72.3	3.2	13.2	45.0	117.0	20.3	7.0	169.3
75% RD_{NPK} + R + PSB + KSB	75.5	3.5	14.0	47.0	120.0	22.0	8.0	171.7
SEm±	1.6	0.04	0.2	0.8	0.3	0.3	0.2	0.5
CD (P≤0.05)	5.2	0.1	0.6	2.5	1.0	1.0	0.6	1.6

Table 3: Effect of nutrient management on root nodulation in field pea (Pooled analysis).

Treatment	Number of nodule /plant			Mean diameter of nodules (mm)			Fresh weight of nodules /plant (mg)			Dry weight of nodules /plant(mg)		
	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS
Control	11.8	14.3	8.3	3.2	3.3	2.0	55.3	75.3	42.3	12.2	16.8	9.3
RD_{NPK}	15.0	17.0	11.3	3.5	4.0	2.5	75.7	100.0	53.5	16.9	24.1	10.8
RD_{NPK} + R	15.9	19.3	12.7	3.8	4.3	2.6	82.0	113.7	53.7	17.4	24.2	11.5
RD_{NPK} + R + PSB	16.8	24.0	12.3	4.1	5.1	2.7	90.7	118.7	55.2	18.4	25.6	14.5
75% RD_{NPK} + R + PSB + KSB	20.5	26.3	14.3	4.3	5.5	3.0	102.3	147.7	66.5	22.6	33.0	18.5
SEm±	0.8	0.6	0.1	0.2	0.3	0.1	0.4	1.4	0.3	0.5	1.1	0.4
CD (P≤0.05)	2.6	2.1	1.5	0.7	0.9	0.2	0.9	2.1	1.0	1.5	3.7	1.2

stage (up to 50% flowering). Thus, maximum nodulation parameters were recorded at this stage.

However, the reduction in nodulation parameters at 75 DAS was mainly due to increased demand of photosynthate to reproductive parts *i.e.*, flowering and fruiting; therefore the availability of photosynthate to roots decreases and degeneration of nodulation starts (Ayala and Rao, 2002). In the treatment of 75% RD_{NPK} +R+PSB+KSB, the activities of biofertilizers significantly increased the availability of NPK to the crop plants and thus resulted in higher values of nodulation. These findings are in line with Mohammadi and Sohrabi (2012). The nitrogen-fixing capability in legume can judge by the accumulation of fresh and dry matter in the nodule. The results are in agreement with the finding of Nagy and Pinter (2015).

Yield and economics

The significant increase in grain and straw yield of field pea was recorded due to combined application of chemical and bio-fertilizers. Significantly highest grain yield during 2017-18 (1642 kg/ha) and 2018-19 (1721 kg/ha) were recorded in 75% RD_{NPK}+R+PSB+KSB over control (951 and 1013 kg/ha during 2017-18 and 2018-19, respectively). The analysis of pooled grain yield data revealed significantly highest yield under 75% RD_{NPK} +R+PSB+KSB (1682 kg/ha) followed by RD_{NPK} +R+PSB (1443 kg/ha) and least under control (981 kg/ha). Further, the grain yield of field pea under application of rhizobium was 22.3%, rhizobium +PSB 26.3% and R+PSB+KSB 47.2% higher over recommended NPK (Table 4). The cumulative effect of fertilizers and biofertilizers *i.e.*, 75% RD_{NPK}+R+PSB+KSB in increasing grain yield over control was 71.5%. The similar results were also observed in straw yield with the significantly highest value under 75% RD_{NPK}+R+PSB+KSB (2402 and 2480 kg/ha during 2017-18 and 2018-19, respectively) over control. The pooled data showed 69.5% higher straw yield in 75% RD_{NPK} +R+PSB+KSB over control, whereas 49.2% higher due to application of biofertilizers (Rhizobium+PSB+KSB) over recommended NPK. The grain yield is directly related to growth and yield attributes parameters. The increased availability of plant nutrients under application of chemical fertilizers + biofertilizers (Rhizobium+PSB+KSB) resulted in increase in plant growth parameters. The healthy plants bear more numbers of flowers, pods and 100 seed weight which finally resulted in higher grain and straw yield of field pea. Kumari *et al*. (2012) and Bhat *et al*. (2013) have also reported similar findings in field pea.

Economics was calculated using pooled yield data. The significantly highest values of gross return (INR 70 623/ha), net return (INR 46 623/ha) and B:C ratio (2.94) were recorded in 75% RD_{NPK} +R+PSB+KSB followed by RD_{NPK} +R+PSB and least under control. The application of biofertilizers (R+PSB+KSB) has recorded 85% increment in net return over application of NPK alone (Table 4). The higher yield and low investment under biofertlizers have resulted in higher net return and B: C ratio under integrated use of fertilizers and

Table 4: Effect of nutrient management on grain and straw yield and economics of field pea.

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)			Gross return	Net return	B:C
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	(INR /ha)	(INR /ha)	ratio
Control	951	1 013	981	1 386	1 475	1 455	41 234	18 734	1.83
RD_{NPK}	1 104	1 182	1 143	1 604	1 696	1 653	47 985	25 185	2.10
RD_{NPK} + R	1 361	1 434	1 398	2 003	2 048	1 939	58 695	35 695	2.55
RD_{NPK} + R + PSB	1 403	1 483	1 443	2 081	2 101	2 102	60 590	37 390	2.61
75% RD_{NPK} + R + PSB + KSB	1 642	1 721	1 682	2 402	2 480	2 466	70 623	46 623	2.94
SEm±	46	42	29	74	138	158	1 212	1 211	0.05
CD (P≤0.05)	144	129	90	230	431	347	3 775	3 775	0.16

biofertilizers. These results are in close conformity with findings of Kumar (2011) and Singh *et al.* (2018).

Nutrients concentration and protein yield

Significant improvement in NPK concentration in grain and straw of field pea was recorded due to different nutrient management treatments (Table 5). The significantly higher NPK concentrations were recorded in 75% RD_{NPK} +R+PSB+KSB followed by RD_{NPK} +R+PSB and least under control. The NPK concentrations in field pea grain and straw were also increased due to the inclusion of biofertilizers over chemical fertilizers. The increase in NPK concentration due to combined application of fertilizers and biofertilizers varied between 15.6 to 57.1% in grain and in straw 27.2-90% over control. The increased availability of phosphorus, potash and nitrogen through fixation of atmospheric N, solubilization of insoluble phosphorus and potash under application of biofertilizers (Rhizobium, PSB and KSB) might have resulted in increased concentration of NPK in grains and straw of field pea.

Significantly increase in protein content and protein yield was also observed under application of NPK fertilizers and biofertilizers (Rhizobium, PSB and KSB). The highest value of protein content (23.1%) and protein yield (288.5 kg/ha) was recorded under 75% RD_{NPK} +R+PSB+KSB, which are significantly higher over control and NPK (Table 5). The combined application of NPK fertilizers and biofertilizers (Rhizobium, PSB and KSB) has improved the protein content by 15.5% and protein yield by 98%. The increased N content in grain and higher yield resulted in higher protein content and protein yield under 75% RD_{NPK} +R+PSB+KSB over the rest of the treatment. Similar findings under integrated nutrient management (chemical fertilizers + biofertilizers) were also reported by Bhat *et al.* (2013).

Nutrient uptake

Nutrient uptake is the product of yield and nutrient concentration in the grains and straw. The increased yield and nutrient concentration under use of fertilizers and biofertilizers has resulted in higher nutrient uptake under these treatments.

Table 5: Effect of nutrient management on NPK content in grain and straw of field pea.

Treatment	N content (%)		P content (%)		K content (%)		Protein	Protein yield
	Grain	Straw	Grain	Straw	Grain	Straw	(%)	(kg/ha)
Control	3.2	1.2	0.42	0.20	0.68	1.11	20	196.2
RD_{NPK}	3.4	1.4	0.56	0.26	0.73	1.30	21.3	242.3
RD_{NPK} + R	3.5	1.5	0.61	0.29	0.76	1.33	21.9	304.1
RD_{NPK} + R + PSB	3.6	1.5	0.63	0.31	0.80	1.38	22.5	324.0
75% RD_{NPK} + R + PSB + KSB	3.7	1.7	0.66	0.38	0.82	1.41	23.1	388.5
SEm±	0.06	0.03	0.006	0.002	0.01	0.03	0.13	1.6
CD (P≤0.05)	0.20	0.10	0.02	0.008	0.03	0.11	0.45	5.21

Table 6: Effect of nutrient management on NPK uptake in field pea.

Treatment	N uptake (kg/ha)			P uptake (kg/ha)			K uptake (kg/ha)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Control	31.42	17.46	48.88	4.12	2.91	7.03	6.68	16.15	22.83
RD_{NPK}	38.85	23.15	61.99	6.40	4.30	10.70	8.34	21.49	29.83
RD_{NPK} + R	48.91	29.09	78.00	8.52	5.62	14.15	10.62	25.79	36.41
RD_{NPK} + R + PSB	51.93	31.53	83.47	9.09	6.52	15.61	11.54	29.01	40.55
75% RD_{NPK} + R + PSB + KSB	62.22	41.92	104.14	11.10	9.37	20.47	13.79	34.77	48.56
SEm±	1.10	1.75	2.13	0.22	0.38	0.46	0.25	1.53	1.58
CD (P≤0.05)	3.41	5.45	6.64	0.67	1.17	1.43	0.78	4.77	4.91

Therefore, significantly higher uptake of NPK was recorded in 75% RD_{NPK} +R+PSB+KSB followed by RD_{NPK} +R+PSB and least under control (Table 6). The increase in N-uptake by grain under 75% RD_{NPK} +R+PSB+KSB was 98.0% and by straw 140.0%, whereas total uptake was 113.1% over control. The use of biofertilizers (R+PSB+KSB) also increased the total N-uptake by 68.0% over NPK. The P-take by grains increased by 291.2% and by straw 112.7% due to application of RD_{NPK}+R+PSB+KSB over control. Similar trend was also observed in K-uptake by grains and straw of field pea. These results are in line with Mohammadi and Sohrabi (2012) and Singh *et al*. (2018).

Nutrient use efficiency

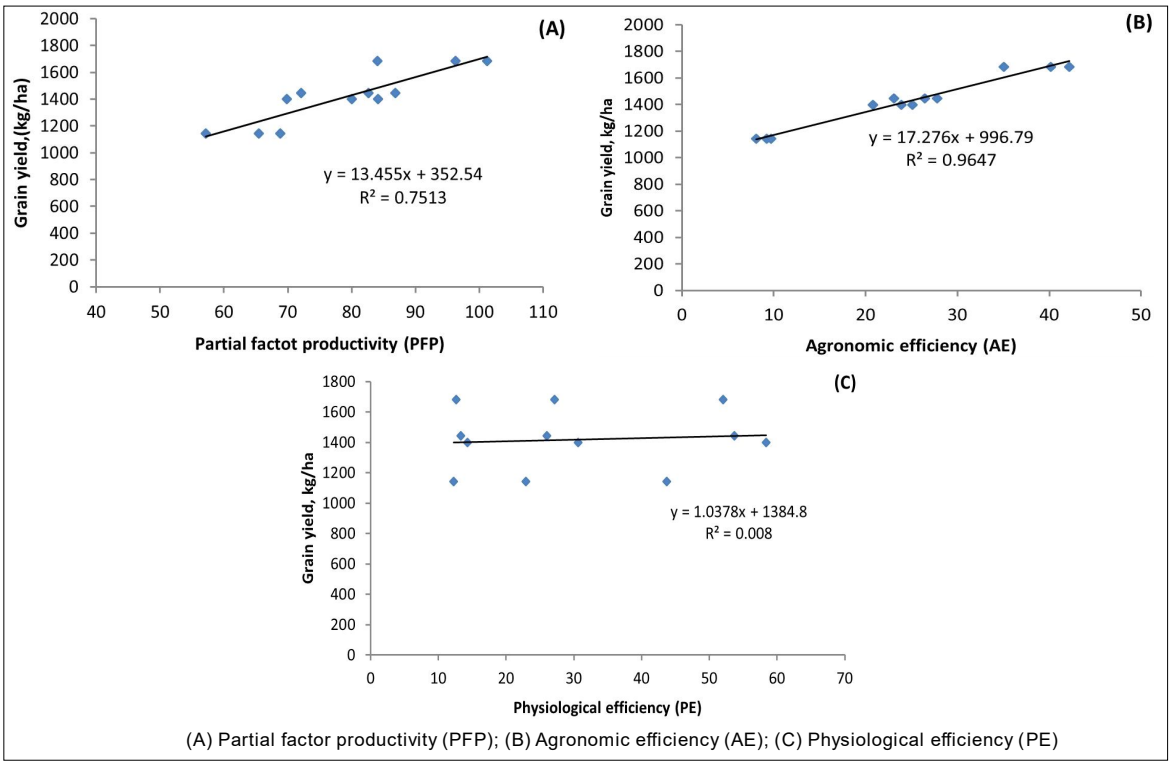
The partial factor productivity (PFP) relates output performance (crop or cropping system productivity) with respect to applied inputs. The gradual increase in PFP was observed due to the addition of biofertilizers along with fertilizers NPK (Table 7). PFP of nitrogen (PFP_N) was highest in 75% RD_{NPK} +R+PSB+KSB (84.08 kg/kg) followed by RD_{NPK} +R+PSB (72.13 kg/kg) and least in NPK (57.13 kg/kg). Similar trend was also observed case of P and K. The maximum value of PFP_P (96.33 kg/kg) and PFP_K (101.28 kg/kg) was recorded under 75% RD_{NPK} +R+PSB+KSB and least under NPK (65.45 and 68.82 kg/kg of PFP_P and PFP_K, respectively).

Agronomic efficiency (AE) indicates yield gain with per unit of applied input. It is a short-term indicator of the impact of applied nutrients on productivity and can be used for recommendation of nutrients in the crop or cropping system. The trend of AE was similar to PFP and thus the highest values were recorded under 75% RD_{NPK} +R+PSB+KSB. The highest value of AE of nitrogen (AE_N) was 35.03 kg/kg, AE_P 40.13 kg/kg and AE_K 42.19 kg/kg was recorded in 75% RD_{NPK} +R+PSB+KSB and minimum under control (8.08, 9.25 and 9.73 kg/kg of AE_N, AE_P and AE_K, respectively).

The physiological efficiency (PE) tells us about what is the ability of the plant to transform nutrients acquired from the source applied to economic yield. The highest values of

Table 7: Effect of nutrient management on nutrient use efficiency in field pea.

Treatment	Partial factor productivity (PFP), kg/kg			Agronomic efficiency (AE), kg/kg			Physiological efficiency (PE)			Economic efficiency
	PFP_N	PFP_P	PFP_K	AE_N	AE_P	AE_K	PE_N	PE_P	PE_K	(%)
Control	-	-	-	-	-	-	-	-	-	83.3
RD_{NPK}	57.13	65.45	68.82	8.08	9.25	9.73	12.24	43.73	22.93	110.5
RD_{NPK} + R	69.88	80.06	84.18	20.83	23.86	25.09	14.27	58.36	30.60	155.2
RD_{NPK} + R+ PSB	72.13	82.64	86.89	23.08	26.45	27.81	13.32	53.69	25.99	161.2
75% RD_{NPK} + R+ PSB + KSB	84.08	96.33	101.28	35.03	40.13	42.19	12.66	52.05	27.19	194.3



(A) Partial factor productivity (PFP); (B) Agronomic efficiency (AE); (C) Physiological efficiency (PE)

Fig 1: Correlation between nutrient use efficiency and grain yield of field pea.

PE were recorded under NPK+R over the rest of the treatments. The maximum PE of nitrogen (PE_N) was 14.27 kg/kg followed by in RD_{NPK} +R+PSB (13.32 kg/kg) and least under RD_{NPK} (12.24 kg/kg). Similarly, maximum value of PE_P was recorded in NPK+R (58.36 kg/kg) followed by RD_{NPK} +R+PSB (53.69 kg/kg) and least under RD_{NPK} (43.73 kg/kg). The PE_K was highest in RD_{NPK} +R (30.60 kg/kg) followed by 75% RD_{NPK} +R+PSB+KSB (27.19 kg/kg) and least in RD_{NPK} (22.93 kg/kg). The increased availability of NPK in soil with the application of fertilizers and biofertilizers resulted in increased yield and uptake of NPK. These have resulted in enhanced nutrients use efficiency (Singh and Sharma, 2011; Mishra *et al*., 2010).

The economic efficiency (EE) indicates the net income per rupees investment in percentage (%). Significantly highest EE was recorded in 75% NPK+R+PSB+KSB (194.3%) followed by RD_{NPK} +R+PSB (161.2%) and minimum in control (83.3%). The highest EE under 75% RD_{NPK} +R+PSB+KSB was mainly due to higher yield of field pea and low input cost of biofertilizers.

Correlation between nutrient use efficiency and grain yield

A strong positive correlation exists between nutrient use efficiency and grain yield of field pea (Fig 1). Among 3 nutrient use efficiencies indices estimated in the study as given in Fig 1, agronomic efficiency (AE) showed strongest positive correlation (R^2=0.964) with grain yield followed by partial factor productivity (R^2=0.75) and least with physiological efficiency (R^2=0.008). Therefore, agronomic efficiency (AE) and partial factor productivity (PFP) are more relevant in this type of study. Similar kind of positive correlation between AE and crop yield was also reported by Zemichael *et al*. (2017)

CONCLUSION

The above results showed that the integration of biofertilizers along with chemicals fertilizers has a positive effect on the plant growth, yield attributes, yield, nutrient content and nutrient use efficiency in field pea. Increased yield and low investment in biofertilizers has led to higher income and B:C ratio under combined application of fertilizers and biofertilizers. The maximum values of all the above parameters were recorded under 75% RD_{NPK} +R+PSB+KSB followed by RD_{NPK} +R+PSB. Thus, it can be concluded from the present investigation that 75% NPK along with combined application of biofertlizers (R+PSB+KSB) may be applied for higher yield and return from field pea.

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