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Optimization of nitrogen and phosphorus nutrition for improved phenology, root dynamics, resource-use efficiency and profitability of red bean (*Phaseolus vulgaris*) in the semi-arid region of Afghanistan

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Abstract

An experiment was conducted at the experimental farm of Afghanistan National Agricultural Sciences and Technology University, Kandahar during *Kharif* 2020 to optimize nitrogen (N) and phosphorus (P) nutrition in irrigated red bean (*Phaseolus vulgaris*) for improved crop phenology, root dynamics, yield and resource-use efficiency in semi-arid climate. Experimental treatments comprised of 4 different N-doses (0, 40, 80, 120 kg N/ha) and 04 different P-doses (0, 30, 60, 90 kg P_2O_5/ha) using split-plot design replicated thrice. In general, application of 120 kg N ha^{-1} and 90 kg P ha^{-1} had significantly effect on days taken for different phonological stages (maximum flowering stage, pod formation stage & physiological maturity stage) over control. Root length and dry root weight were significantly higher under treatment 120 kg N ha^{-1} and 90 kg P ha^{-1} at maximum flowering stage. Red bean seed yield (2.50; 2.46 t ha^{-1}) was significantly higher under treatment 120 kg N ha^{-1} and 90 kg P ha^{-1}, respectively. Again, the 120 kg N ha^{-1} and 90 kg P ha^{-1} exhibited maximum gross returns (AFN 180340; 177380 ha^{-1}); net returns (AFN 115540; 111180 ha^{-1}), respectively. The resource-use efficiency in terms of production and monetary– efficiency and water-use efficiency followed the similar trend as that of grain yield with highest magnitude under treatment 120 kg N ha^{-1} and 90 kg P ha^{-1}. Partial factor productivity of applied-N (PFP_N) was significantly higher at N @ 40 kg ha^{-1} thereafter it showed a gradual decline till N @ 120 kg ha^{-1}. The PFP_P was significantly higher at P @ 30 kg ha^{-1}. Overall, it was revealed that increase in N and P levels had positive impact on crop phenology with consistent and significant increase in red bean root parameters, productivity, profitability and resource-use efficiency with highest values in treatment 120 kg N ha^{-1} and 90 kg P ha^{-1}. In nutshells, N @ 120 kg ha^{-1} and P @ 90 kg ha^{-1} may be recommended to the farmers for improved phenology, root dynamics, resource-use efficiency and profitability in semi-arid region of Afghanistan.

Key words: Crop phenology, nitrogen, net returns, phosphorus, root parameters, water-use efficiency.

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Introduction

Red bean (*Phaseolus vulgaris* L.) also known as kidney bean, is an important protein-rich pulse crop in Afghanistan, contributing significantly to food and nutritional security as well as rural household incomes, particularly in the semi-arid regions of the country. Red beans are drought tolerant which offer better adaptability in harsh and water-scarce climate of the nation. In Afghanistan, red bean has been grown in an area of about 31655 ha with production of about 18360 tons and productivity of 580 kg/ha as per an available data of 2012 (http://cso.gov.af/Content/files/Agriculture.pdf), occupying major share among all pulses in the country. The Takhar, Mazar, Kunduz, Baghlan, Samangan, Balkh, Jawzjan, Faryab, Kapisa, Herat, Gor and Badghis are the major red bean growing provinces of Afghanistan. Recently, the Afghanistan government has given great emphasis for red bean promotion keeping in view congenial agro-climatic conditions in some parts of the nation. However, the productivity of red bean in the country is low due to poor soil fertility, poor irrigation infrastructure, low rainfall, poor supply of improved seeds, imbalanced and sub-optimal fertilizer-use specially nitrogen (N) and phosphorus (P), and poor crop management (Ehsan *et al*., 2017a; Ibrahim *et al*., 2017; Noori *et al*., 2019; Hamim and Choudhary, 2019; Kohistani and Choudhary, 2019; Omran *et al*., 2020; Seerat *et al*., 2025). Nitrogen and phosphorus management plays crucial role in enhancing the pulse productivity, thus, in order to promote the red bean cultivation in the country we have to strengthen the agronomic practices of this crop specifically fertilizer N and P management (Noori *et al*., 2019; Choudhary *et al*., 2020). Efficient fertilizer N and P management is a crucial factor that greatly affects the growth and yield of red bean production worldwide being a highly nutrient exhaustive crop (Choudhary *et al*., 2015). However, the optimization of P application dose at varying N levels is not done till date for red bean cultivation in Afghanistan. Nitrogen is one of the major essential plant nutrients and successful crop production depends mainly upon the availability of nitrogen and phosphorus in adequate amounts (Rana *et al*., 2018; Varatharajan *et al*., 2019a, 2019b). One of the probable reasons for low yield of grain legumes in general is the high requirement of N and P for the formation and development of prominent grains (Heba *et al*., 2021; Kumar *et al*., 2018). To produce one unit of seeds, red bean needs as much as three times more N and P than that needed by cereals like rice. Red bean needs much more N and P nutrition at reproductive stage than it does in the vegetative stage. Optimal N nutrition generally stimulates plant growth, root activity and yield components leading to enhanced crop productivity, profitability and resource-use efficiency (Pratap *et al.*, 2022). Similarly, P management plays a crucial role in early root development and nodule formation in legumes especially under P-deficient soils. Better rooting system improves the nutrient and water uptake in semi-arid conditions. The P nutrition also enhances phenological progression, reproductive development and seed yield (Choudhary *et al.*, 2015, 2020). In nutshell, current study on optimization of balanced N and P nutrition in harsh and moisture-limited semi-arid climate of Afghanistan, may lead to enhanced plant and root growth, yield and improved water- and nutrient-use efficiencies. Despite the crop's importance in the nation, there is limited location-specific research on optimal N and P management in red bean. Therefore, evaluating the effects of nitrogen and phosphorus on the crop phenology, root dynamics, profitability and resource-use efficiency is highly essential to develop sustainable and economically viable fertilizer recommendations for semi-arid farming systems of Afghanistan.

Materials and Methods

Experiment details

The experiment was conducted during *kharif* season in the Tarnak Farm of Afghanistan National Agricultural Sciences & Technology University (ANASTU), Kandahar, Afghanistan. The experimental treatments comprised of 4 different N-doses (control, 40, 80, 120 kg N/ha) and 04 different P-doses (control, 30, 60, 90 kg P_2O_5/ha) in a split-plot design replicated thrice. The P_2O_5 was supplied through DAP as basal dose. The remaining N was applied through urea. Based on available literature, a blanket dose of K (40 kg K_2O/ha) as muriate of potash was applied at sowing time in red bean. The size of each plot was 4.5 m × 3 m with gross plot size of 13.5 m^2. The distance between adjacent plots and replications was maintained at 1.0 m and 2.0 m apart, respectively. The plant spacing was 45×10 cm which accommodated 10 rows/plot and 30 plants/row while using 100 kg seed/ha. One border row from both sides of each plot as well as one sample row from one side of the plot was discarded, besides, 20 cm crop rows from other two sides (i.e. one plant each from both sides) as border effect. Thus, net plot size was 3.15 × 2.6 m i.e. 8.19 m^2. Initially, the soil had 152.8 kg available-N ha^{-1}, 10.1 kg available-P ha^{-1} and 189.7 kg available-K ha^{-1} with alkaline soil pH as analyzed using standard methodologies (Rana *et al.*, 2014). Geographically Kandahar is situated in southern part of Afghanistan with semi-arid to subtropical climate with extreme cold and hot situations. The hottest months are June–July with the mean temperature of 31.9^{0}C, whereas the mean minimum temperature of the coldest month, January, falls in the range of 5.1^{0}C. Average normal annual rainfall of Kandahar is about 190.6 mm or 15.9 mm per month. The driest weather is in June with no rainfall. January is the wettest month of the year with an average rainfall of 54 mm. The details of the data are given in Fig. 1.

Crop phenology and root dynamics

Biometric observations *w.r.t.* different phenological stages like maximum flowering stage, pod formation and physiological maturity stage of red bean crop were recorded in terms of days taken as per standard procedures from 30 DAS onwards at every 30 DAS intervals up to maturity (Rana *et al.*, 2014). To determine the total root dry weight, three plants were selected randomly at 30, 60, 90 DAS in each treatment after field irrigation to saturation point carefully taken away from the ground using a shovel making sure that roots are not damaged. These uprooted plant roots were washed under a tap with clean water. Then their roots from the base of the shoots were cut. These root samples were kept in sampling room for air shade drying for 30-days till constant weight of root was attained and then their root weight was measured with balance and average was worked out and expressed in gram. For root length, three plants already uprooted for root length measurements by using measuring tape. The average length of three uprooted plants was recorded as root length

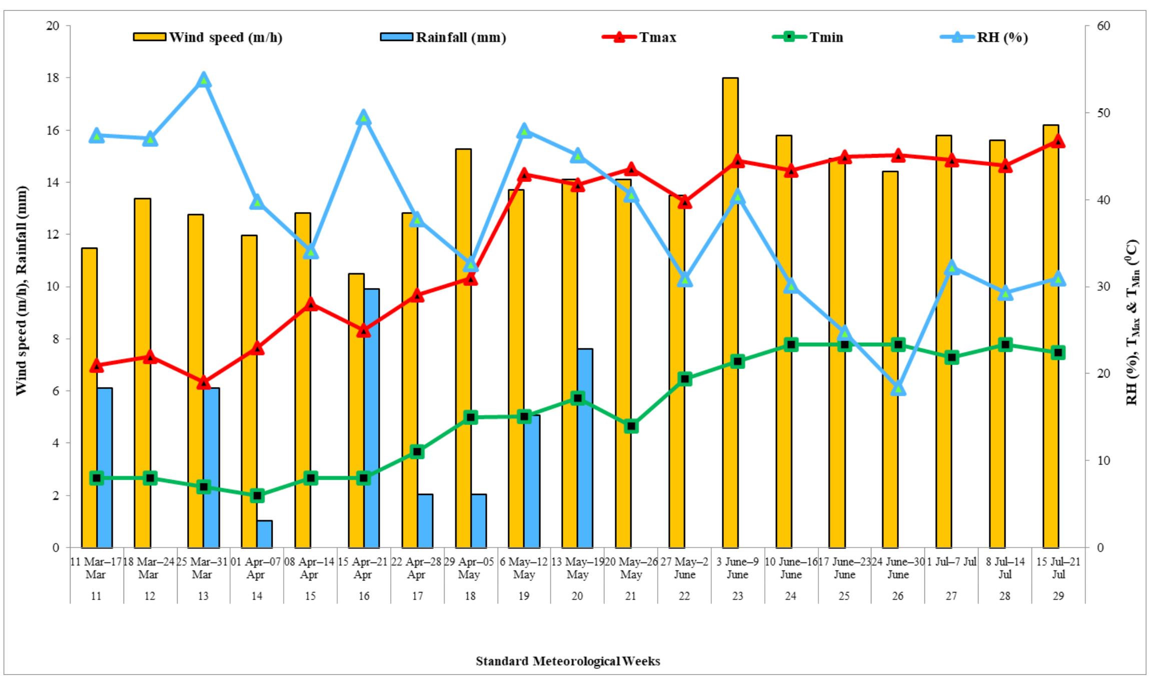

Fig. 1. Mean weekly meteorological observations during crop growth period (March-July, 2020) at experimental site (ANASTU, Kandahar).

and was expressed in cm.

Resource-use efficiencies

After harvesting and threshing of crop, the seeds were sun-dried for several days to reach a constant weight and thereafter the seed yield was computed as t/ha for each plot/treatment (Rana *et al.*, 2014). The seed yield was used for calculating different resource-use efficiencies as follows:

Water-use and water-use efficiency: The seasonal water use (Et) is computed from profile water contribution (CS), effective rainfall (ER) and irrigation water applied (I) using following equation:

Et = CS + ER + I

The profile water contribution (CS) was not taken into consideration in current study. Thus, effective rainfall and irrigation water use was considered as the seasonal total water use in the present study by taking into account the respective crop growth period of by following the procedure as suggested by Choudhary *et al.* (2006). The total water use (TWU) was calculated by taking into consideration the total number of irrigations and depth of water applied and effective rainfall during crop growth. Each irrigation depth was measured by using an ordinary scale meter, which had mm and cm mark. In each plot, the depth of water was measured at 5 selected spots after each irrigation and on the basis of these observations; the mean depth of irrigation water was calculated for each plot. The rainfall data was taken from 'Agro–meteorological Observatory' of Kandahar University, Afghanistan. Water use efficiency (WUE) was computed by using following formula (Choudhary *et al.*, 2006):

$$\text{WUE (kg ha}^{-1}\text{mm}^{-1}) = \frac{\text{Y}}{\text{TWU}}$$

Where, Y is the economic yield (seed yield in kg/ha) and TWU refers to total amount of seasonal water used in ha–mm, respectively.

Production–efficiency (PE): Production–efficiency (PE) of each treatment was (kg/ha/day) was computed using the following expression:

$$\text{PE} = \frac{\text{Total economic yield (kg ha}^{-1})}{\text{Duration of the crop}}$$

Monetary–efficiency (ME): Monetary–efficiency (ME) of each treatment (AFN ha^{-1} day^{-1}) was computed using following expression:

$$\text{ME} = \frac{\text{Total net returns (AFN ha}^{-1})}{\text{Duration of the crop}}$$

Partial factor productivity (PFP) of applied nutrients

Partial factor productivity of applied nitrogen (PFP_N): In this experiment, we applied varying doses of nitrogen. The seed yield (kg ha^{-1}) so obtained in each treatments/plot was divided by the total applied–N to estimate partial factor productivity of applied-N (PFP_N) as kg ha^{-1} kg^{-1} of applied-N.

$$\text{PFPn} = \frac{\text{Seed yield (kg ha}^{-1})}{\text{Total applied} - \text{N (kg ha}^{-1})}$$

Partial factor productivity of applied phosphorus (PFP_p): Applied-P through inorganic fertilizers was calculated. The seed yield so obtained in each treatments/plot was divided by the total applied–P to estimate partial factor productivity of applied-P (PFP_p) as kg ha^{-1} kg^{-1} of applied-P.

$$\text{PFPp} = \frac{\text{Seed yield (kg ha}^{-1})}{\text{Total applied} - P_2O_5 \text{ (kg ha}^{-1})}$$

Economic analysis

In order to evaluate the different treatments, total cost of production and gross returns (including by product) as well as net returns were worked out. The benefit: cost ratio was also calculated on the basis of total cost of production. Cost of cultivation (AFN/ha) was worked out by using the prevailing input costs/prices incurred *viz.* seeds, fertilizers, pesticides, herbicides etc. applied to each treatment for red bean production. Gross returns were calculated on the basis of seed and stover yield and their present prices in the market (red bean seed price = 70000 AFN/t, stover price = 2000 AFN/t). Net returns (AFN ha^{-1}) were calculated by using the following formula:

Net returns (AFN ha^{-1}) = Gross returns (AFN ha^{-1}) – Cost of cultivation (AFN ha^{-1})

Benefit: cost ratio (BCR) was determined by using the formula given below:

$$\text{B: C ratio} = \frac{\text{Gross returns (AFN ha}^{-1})}{\text{Cost of cultivation (AFN ha}^{-1})}$$

Statistical analysis

The field experiment data recorded on various parameters during the course of investigation were statistically analyzed duly following the analysis of variance technique for split plot design (Rana *et al*., 2014). The statistical significance was tested with 'F' test at 0.05 level of probability and where ever the 'P' value was found significant, critical CD at P=0.05. All these calculations were carried out with the degree of freedom (df) as difference.

Results and Discussion

Days taken to different phenological stages

Effect of different N and P fertilization levels on days taken to different phenological stages like maximum flowering stage, pod formation and physiological maturity stage of red bean crop is presented in Fig. 2. The nitrogen levels showed significant influence on phenological stages i.e. days taken to maximum flowering stage, pod formation and physiological maturity stage. However, red bean in N_{120} treatment (59, 71 and 105 days) took minimum days to attain maximum flowering stage, pod formation and physiological maturity stage. Different P-levels reduced the minimum days taken to attain maximum flowering stage, pod formation and physiological maturity stage as compared to respective N-levels, where P-fertilization had non-significant influence on minimum days taken to attain maximum flowering stage. These results are in conformity to the findings of Kohistani and Choudhary (2019).

Root dynamics

Effect of different N and P fertilization levels on root parameters like root dry weight (g) and root length (cm) of red bean crop at maximum flowering stage is presented in Fig. 3. Root length was recorded highest in N_{120} (28.6 cm) followed by N_{80}, N_{40} and control. Here, N_{80} and N_{40} were at par with each other and showed significantly higher values over control. Among P fertilization levels, highest root length was observed under P_{90} (27.9 cm). The interaction effect was found significant for root length. It was revealed that under N_{120} root parameter (RDW) was found highest (3.89 g plant^{-1}) followed by N_{80}, N_{40} and control, respectively. These results are in conformity to those obtained by Harish *et al*. (2025). Amongst P fertilization levels, significantly highest RDW was found in P_{90} (3.92 g plant^{-1}) over P_{60}, P_{30} and control. There was no interaction effect between

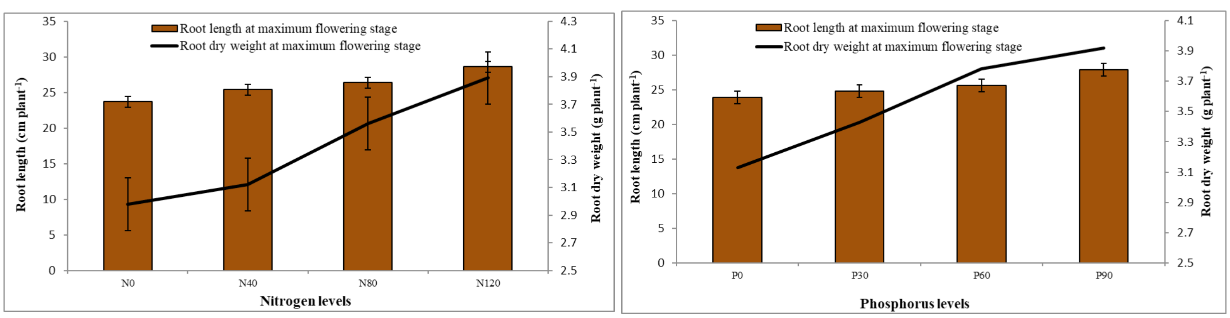

Fig. 3. Effect of n and P levels on root dry weight and root length at maximum flowering stage of red bean.

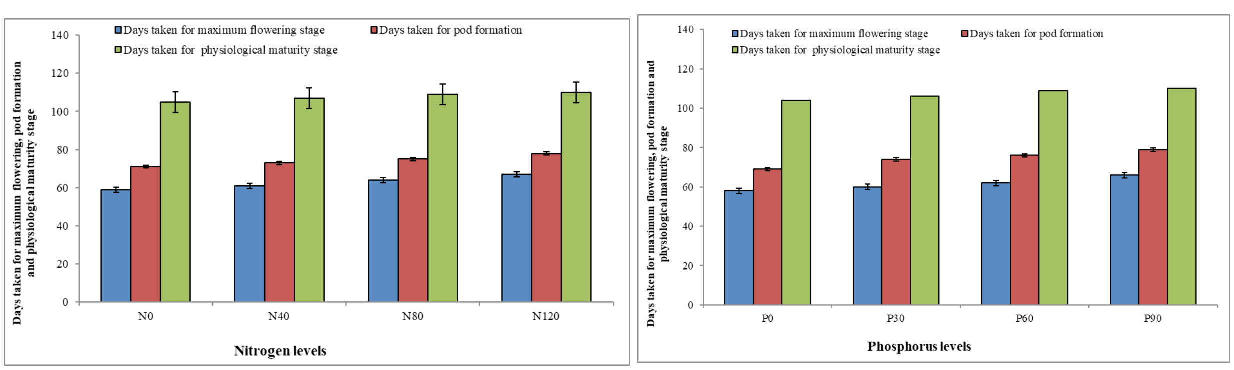

Fig. 2. Effect of N & P levels on days taken for days taken for different phenological stages of red bean.

main-plot and sub-plot treatments both for RDW and root length.

Crop productivity

Crop productivity: Increasing levels of N and P showed a consistent and significant increase in seed yield at each level of P and N, respectively with highest values at N @ 120 kg ha^{-1} alongwith P_2O_5 @ 90 kg ha^{-1} (Table 1). Among P-levels, P_{90} treatment was the highest yielder (2.46 t ha^{-1}) and lowest yield was recorded for control P_0 (1.96 t ha^{-1}). Trend in seed yield for N-levels was N_{120}>N_{80}>N_{40}>control, respectively. Trend in seed yield for P-levels was P_{90}>P_{60}>P_{30}> P_0, respectively. In present study, the growth and yield attributing characters have shown positive and significant association with seed yield. The N and P are essential nutrients for pulses, being major component of protein and, their balanced supply plays a vital role in enhancing growth, yield and overall pulse productivity in Afghanistan (Ehsan *et al*., 2017a, 2017b; Ibrahimi *et al*., 2017; Jahish *et al*., 2017; Noorzai and Choudhary, 2017; Omran *et al*., 2017, 2020; Noori *et al*., 2019; Choudhary *et al*., 2015, 2020).

Crop profitability

Cost of cultivation (AFN ha^{-1}): An increase in N and P levels (N_0, N_{40}, N_{80}, N_{120} and P_0, P_{30}, P_{60}, P_{90}) increased the cost of cultivation because of varying amounts of nitrogen and phosphorous fertilizer used (Table 1). Cost of cultivation (AFN ha^{-1}) ranged between AFN 49,500–64,800 ha^{-1} for N levels and between AFN 48,500–66,200 ha^{-1} under different P levels, due to varying inputs and agronomic operations like tillage, fertilizer doses, water management, weed management, pest and disease management etc. in all the N and P levels (Pradhan *et al*., 2025).

Gross returns (AFN ha^{-1}): The results revealed that considerably higher gross returns were observed in N_{120} (AFN 180340 ha^{-1}) which was followed by N_{80} and N_{40} (Table 1); while control resulted in lowest gross returns (AFN 146620 ha^{-1}). Among P fertilization levels, P_{90} exhibited highest gross returns (AFN 177380 ha^{-1}) followed by P_{60} (AFN 166520 ha^{-1}), P_{30} (AFN 153780 ha^{-1}) and lowest gross returns in P_0 (AFN 141440 ha^{-1}). These results are similar to the findings of Rana *et al*. (2018); Varatharajan *et al*. (2019a, 2019b). For higher yields in grain legumes, we need to supply adequate amount of N for the growth and development and final higher productivity, profitability and resource-use efficiency (Heba *et al*., 2021; Kumar *et al*., 2019; Choudhary *et al*., 2015, 2020).

Net returns (AFN ha^{-1}): The results revealed that considerably higher net returns were observed in N_{120} (AFN 115540 ha^{-1}) which was followed by N_{80} and N_{40}; while control treatment resulted in lowest net returns (AFN 97120 ha^{-1}) (Table 1). Among P fertilization levels, P_{90} exhib-

Table 1. Effect of varying nitrogen and phosphorous levels on profitability of red bean.

Treatments	Seed yield (t/ha)	Cost of cultivation (×10^{3}AFN/ha)	Gross returns (×10^{3}AFN/ha)	Net returns (×10^{3}AFN/ha)	B: C ratio
Nitrogen levels					
N_0	2.03	49.5	146.62	97.12	2.96
N_{40}	2.12	54.6	153.24	98.64	2.80
N_{80}	2.34	59.7	168.96	109.26	2.83
N_{120}	2.50	64.8	180.34	115.54	2.78
SE(m) ±	0.08	-	3.77	2.37	0.02
CD (*P*=0.05)	0.27	-	11.33	5.98	0.67
Phosphorus levels					
P_0	1.96	48.5	141.44	92.94	2.91
P_{30}	2.13	54.9	153.78	98.88	2.80
P_{60}	2.31	61.1	166.52	105.42	2.72
P_{90}	2.46	66.2	177.38	111.18	2.67
SE(m) ±	0.12	-	1.65	2.39	0.05
CD (P=0.05)	0.35	-	4.91	5.57	0.73

ited highest gross returns (AFN 111180 ha^{-1}) followed by P_{60} (AFN 105540 ha^{-1}), P_{30} (AFN 98880 ha^{-1}) and lowest net returns in P_0 (AFN 92940 ha^{-1}). This result is similar to the finding of Paul *et al.* (2016) and Rajpoot *et al*. (2021) who found that cotton supplied with 100% RDF led to highest gross and net returns and B: C ratio over control.

Benefit: cost ratio: The outcome revealed that considerably higher B: C ratio were observed in control (2.96) which was followed by N_{40} and N_{80} treatment, respectively while N_{120} resulted in lowest B: C ratio (2.78) (Table 1). The P_0 treatment exhibited highest B: C ratio (2.91) followed by P_{30} (2.80), P_{60} (2.72) and lowest in P_{90} (2.67). This result is similar to the finding of Paul *et al.* (2016) and Rajpoot *et al*. (2021) who found that cotton supplied with 100% RDF led to highest net returns and B: C ratio over control.

Water-use efficiency of red bean

Water-use was same in all treatments i.e. 600 mm/ha as red bean was given 10 irrigations each of 60 mm. The results indicated that the N_{120} has reported highest WUE (4.17 kg ha^{-1} mm^{-1}) followed by N_{80} and N_{40}, respectively all of which were significantly superior over control which recorded lowest WUE (Table 2). Among P levels, WUE was significantly highest in P_{90} (4.10 kg ha^{-1} mm^{-1}) followed by P_{60}, P_{30} and lowest in P_0 treatment. Since, plant nutrition played a great role in yield enhancement in red bean (Table 1), hence, resulting into higher WUE (Choudhary *et al.*, 2006; Kaur *et al.*, 2024).

Production–efficiency and monetary–efficiency of red bean

Increasing levels of N and P showed a consistent and significant increase in PE at each level of P and N, respectively with highest values at N @ 120 kg ha^{-1} alongwith P_2O_5 @ 90 kg ha^{-1} (Table 2). Trend in production–efficiency for different nitrogen levels was N_{120}>N_{80}>N_{40}>control, respectively. The trend for P levels was P_{90}>P_{60}>P_{30}>P_0, respectively. Significant interaction effect was found for production–efficiency between different N and P levels (Table 3). Significantly maximum production-efficiency was obtained where we applied 120 kg N ha^{-1} and 90 kg P ha^{-1} after that it decreased, following the same trend as that of net returns (Table 1). Maximum production-efficiency (22.3

Table 2. Effect of varying N and P levels on resource-use efficiency of red bean.

Treatments	Resource-use efficiency		
	Water-use efficiency (kg ha^{-1} mm^{-1})	Production-efficiency (kg ha^{-1} day^{-1})	Monetary-efficiency (AFN ha^{-1} day^{-1})
Nitrogen levels			
N_0	3.39	18.1	867.1
N_{40}	3.54	18.9	880.7
N_{80}	3.65	19.3	975.5
N_{120}	4.17	22.3	1031.6
SE(m) ±	0.13	0.69	34.0
CD (P=0.05)	0.45	2.41	120.1
Phosphorus levels			
P_0	3.27	17.5	829.8
P_{30}	3.55	19.0	882.8
P_{60}	3.85	19.4	941.2
P_{90}	4.10	21.9	992.6
SE(m) ±	0.20	1.06	16.3
CD (P=0.05)	0.58	3.11	48.1
Interactions			
SE(m)±	0.25	1.37	68.0
Sub-plot at same main-plot			
CD (P=0.05)	1.19	6.38	107.7
SE(m) ±	0.36	1.96	44.3
Main-plots at same/diff. sub-plot			
CD (P=0.05)	1.10	5.9	145.5

kg ha^{-1} day^{-1}) was recorded in applied N @ 120 kg ha^{-1} and minimum (18.1 kg ha^{-1} day^{-1}) in control treatment and maximum (21.9 kg ha^{-1} day^{-1}) was recorded when we applied P @ 90 kg ha^{-1} and minimum (17.5 kg ha^{-1} day^{-1}) in control treatment, respectively. These results were similar to the findings of Kumar *et al.* (2015) where high fertilization led to better crop yields and net returns, thus resulting in better resource-use efficiency indices like production-efficiency and monetary-efficiency. Maximum monetary-efficiency was obtained when 120 kg N ha^{-1} and 90 kg P ha^{-1} were applied after that it decreased (Table 4.14), following the same trend as that of red bean seed yield (Table 4). Maximum monetary-efficiency was recorded when applied with N @ 120 kg ha^{-1} and 90 kg P ha^{-1} and minimum monetary-efficiency was obtained in control treatment. These results are similar to the findings of Kikuti *et al*. (2005) who studied the effect of N (0, 70,140 and 210 kg ha^{-1}) and P_2O_5 (0, 100, 200 and 300 kg ha^{-1}) on the bean.

Partial factor productivity (PFP) of applied nutrients in red bean

Data pertaining to the effect of different N and P levels on partial factor productivity of applied-N (PFP_N) in red bean indicated that there was a significant difference between different N levels for PFP_N (Fig. 4). N_{40} had highest PFP_N (52.6 kg ha^{-1} kg^{-1}) followed by N_{80}, respectively while N_{120} recorded lowest PFP_N (21.5 kg ha^{-1} kg^{-1}). Among P levels, PFP_N was highest in P_{30} (46.5 kg ha^{-1} kg^{-1}) followed by P_{90} and lowest in P_{60} (27.1 kg ha^{-1} kg^{-1}). Data pertaining to the effect of different N and P levels on partial factor productivity of applied-P (PFP_P) indicated that there was no significant difference between different nitrogen levels for PFP_P (Fig. 4). Among P fertilization levels, PFP_P was highest in P_{30} (68.4 kg ha^{-1} kg^{-1}) followed by P_{60} and lowest in P_{90} (24.9 kg ha^{-1} kg^{-1}). In general, maximum PFP_N was obtained when we applied N @ 40 kg ha^{-1} and P @ 30 kg ha^{-1} thereafter it decreased with increasing N levels till N_{120} and P_{90}. Maximum PFP_P was obtained when we applied N @ 40 kg ha^{-1} and P @ 30 kg ha^{-1} and minimum in control. These results are in accordance with the findings of Kumar *et al.* (2015), and Yadav *et al.* (2018) where high fertilization led to better crop yields but with reduced PFP_N and PFP_P due to lesser incremental increase in the yield over the lower N and P levels.

Conclusion

Present study concluded that application of N @ 120 kg ha^{-1} and P_2O_5 @ 90 kg ha^{-1} proved to be most effective for exhibiting significantly higher root parameters, crop productivity and profitability. Increasing levels of N and P showed a consistent and significant increase in profitability and resource-use efficiency indices *viz*., water-use efficiency, production-efficiency and monetary-efficiency at each level of N and P, respectively with highest values at N @ 120 kg ha^{-1} alongwith P_2O_5 @ 90 kg ha^{-1}. Overall, it can be summarized that the application of N @ 120 kg ha^{-1} alongwith P_2O_5 @ 90 kg ha^{-1} can be used as a technology recommendation for obtaining higher growth, productivity and profitability as well as enhanced resource-use efficiency in red bean in semi-arid region of Afghanistan. Hence, the adoption of this recommendation provides ample opportunities in enhancing the productivity and profitability of red bean (*Phaseolus vulgaris* L.) under semi-arid conditions of Kandahar, Afghanistan.

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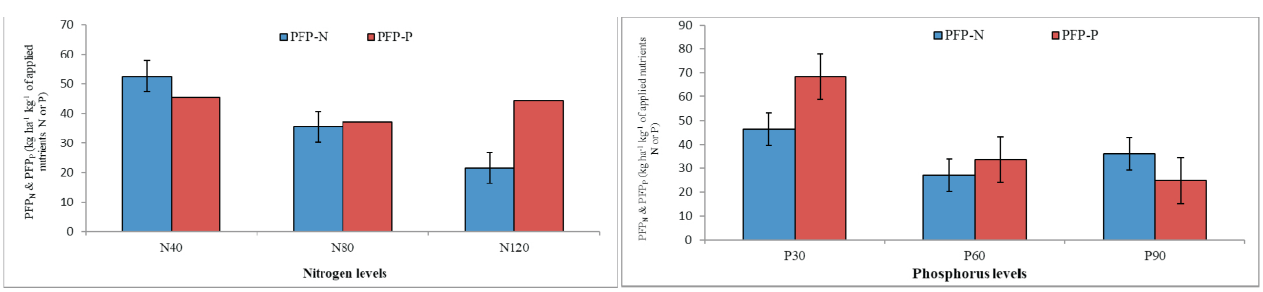

Fig. 4. Effect of different N and P levels partial factor productivity of applied-N (PFP_N) and applied-P (PFP_P) in red bean.

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