Article AR2198c

DOI: HTTPS://DOI.ORG/10.23910/1.2021.2198c

International Journal of Bio-resource and Stress Management

Crossref

October 2021

Print ISSN 0976-3988
Online ISSN 0976-4038

IJBSM 2021, 12(5):441-449

Research Article *Natural Resource Management*

Response of Yield, Water Use Efficiency and Economics of Broad Bean to Irrigation and Phosphorous Level in Lower Indo-Gangetic Plains of Eastern India

S. K. Patra[1], Sanjit Pramanik[2*], R. Ray[2], P. Acharjee[3] and M. K. Modak[4]

[1]Dept. of Agricultural Chemistry and Soil Science, [2]Dept. of Soil and Water Conservation, [3]Dept. of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal (741 252), India
[4]Dept. of Seed Science and Technology, Institute of Agricultural Science, Calcutta University, Kolkata, West Bengal (700 019), India

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Corresponding Author

Sanjit Pramanik
e-mail: sanjit.bckv@gmail.com

Citation: Patra et al., 2021. Response of Yield, Water Use Efficiency and Economics of Broad Bean to Irrigation and Phosphorous Level in Lower Indo-Gangetic Plains of Eastern India. International Journal of Bio-resource and Stress Management 2021, 12(5), 441-449. HTTPS://DOI.ORG/10.23910/1.2021.2198c.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Acknowledgement: Authors are very grateful to the All India Coordinated Project (AICRP) on Irrigation Water Management, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India for providing necessary funds and facilities to conduct the research programme.

Abstract

The field experiment was conducted during the winter seasons of 2009–10, 2010–11 and 2011–12 on a sandy loam soil of lower Indo-Gangetic plains of Eastern India to optimize irrigation schedule and phosphorus level on broad bean. The treatments comprised of three irrigation levels viz. 30, 60 and 90 mm of cumulative pan evaporation (CPE) and four phosphorus levels viz. 0, 30, 60 and 90 kg P_2O_5 ha^{-1} were laid out in a split plot design. The results showed that irrigation at CPE 30 mm and phosphorus at 90 kg P_2O_5 ha^{-1} registered significantly the highest average seed yield of 4.76 and 5.37 t ha^{-1}, respectively. The interaction effects revealed that irrigation at CPE 30 mm with 90 kg P_2O_5 ha^{-1} recorded significantly mean maximum yield (5.69 t ha^{-1}) and gross return (₹ 45520 ha^{-1}), net return (₹ 28870 ha^{-1}) and BCR (1.73). In limited water availability, higher seed yield (5.13 t ha^{-1}), maximum WUE (37.18 kg ha^{-1} mm^{-1}), higher gross return (₹ 41040 ha^{-1}), net return (₹ 25590 ha^{-1}) and BCR (1.66) were found with irrigation at CPE 90 mm with 90 kg P_2O_5 ha^{-1}. Significant linear relationships were detected between yield with applied irrigation water (R^2=0.964) and phosphorus (R^2=0.989). Thus imposition of irrigation at CPE 90 mm coupled with 90 kg P_2O_5 ha^{-1} could be recommended to broad bean growers for deriving higher yield, WUE and income.

Keywords: Broad bean, economics, irrigation, phosphorous, seed yield, water use efficiency

1. Introduction

Broad bean (*Vicia faba* L.) is one of the most important winter season grain legume crop grown in India and other developing countries of the world. It is useful for human nutrition as a good source of carbohydrates (48–54%), protein (20–36%), minerals and vitamins; animal feeding, industry and medicinal purposes (Sharaan et al., 2004). It is one of the best low input crops that can be used as green manure in rotation with cereals. It improves soil fertility due to its capacity to fix atmospheric nitrogen (N_2) symbiotically by nodule bacteria to the tune of 130 to 160 kg N ha^{-1}, when incorporated into soil (Hoffmann et al., 2007; Horst et al., 2007; Jensen et al., 2010; Rajan et al., 2012; Singh et al., 2013). In spite of its versatile and diversified uses in nutrition, biological and medicinal fields, it is still considered as a less privileged crop in India. The productivity of

Article History

RECEIVED on 19th March 2021 RECEIVED in revised form on 28th September 2021 ACCEPTED in final form on 13th October 2021

broad bean in India is very low as compared with other major broad bean growing countries due to limitations of irrigation water and available nutrients (Singh et al., 2010). This legume is mainly grown in the unproductive marginal lands with inadequate farm input resources. Irrigation and phosphorous (P) are the most essential components for encouraging growth characters, better root development and yield (El-Gindy et al., 2003; Hamed, 2003; Tayel and Sabreen, 2011; Neenu et al., 2014). Phosphorus plays a vital role in physiological processes and several enzymatic reactions in plant system. It requires adequate amount of P for supporting higher growth character, seed yield and nutrients uptake (Kandil et al., 2019). Increasing application of 18–48 kg N ha^{-1} and 30–45 kg P ha^{-1}enhanced nodule formation, biological N_2 fixation and produced the highest yield (Abdel-Ghaffar, 1988). Water stress has been identified as a major constraint for seed yield production. The effect was found to be more pronounced in reproductive and grain filling stage than in vegetative stage of crop growth (Xia, 1994; Khan et al., 2010). On the other hand, excessive water supply can stimulate the vegetative growth rather than the reproductive one (Rinaldi et al., 2008) and reduce the harvest index and seed yield. The deficit irrigation has deleterious effect on symbiotic N_2 fixation in broad bean (Musallam et al., 2004). Irrigation plays a key role on increased water utilization, yield upscaling and quality improvement (Rabie and Kawthar, 1991; Khan et al., 2010). Irrigation water should be applied in synchrony with crop and local atmosphere demands without placing the plants under water stress that would reduce yield or quality of the harvested crop substantially (Taylor, 1965; Meena et al., 2015). Being a short duration crop, it can be accommodated as a contingent crop in lowland *kharif* paddy (June-October). A well distributed rainfall of 650 to 1000 mm per annum is ideal for broad bean cultivation (Gasim and Link, 2007; Abdel, 2008), so it is well fitted in crop diversification replacing high water consuming summer or boro paddy (February-May) in lowland ecosystem. In the lower Indo-Gangetic alluvial plains of eastern India, the farmers generally raise the crop in residual soil moisture immediately after harvesting *kharif* paddy without supplemental irrigation and judicious P-fertilization resulting in low productivity. It is therefore necessary to develop an efficient, feasible and economically viable irrigation and P management strategy to obtain the potential yield in broad bean. Hence, the present study was executed.

2. Materials and Methods

2.1. Experimental site and soil characteristics

The field experiment was conducted on a sandy loam soil (Aquic Fluvaquept) in the Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya, Gayeshpur, Nadia, West Bengal belonging to the lower Indo-Gangetic plains of Eastern India during three successive winter seasons of 2009-10, 2010-11 and 2011-12 to study the differential effects of irrigation regimes and phosphorus fertilization levels on broad bean. The experimental site is located between $22^0 58'31''$ N latitude and $88^0 26'20''$ E longitude with an average altitude of 9.75 m above mean sea level. The climate in this region is classified as humid subtropical. The physical and hydro-physical properties of the experimental soil are furnished in Table 1. The initial soil had pH 6.83, EC 0.37 dS m^{-1} and organic C 5.6 g kg^{-1} with available N, P and K contents were 153.7, 21.5 and 160.2 kg ha^{-1}, respectively. The mean monthly maximum and minimum temperature and relative humidity ranged from 24.7 to 35.5°C and 11.6 to 27.2°C and 86.5 to 97.1% and 55.3 to 74.8%, respectively during the experimental period (October to March). Average rainfall received during the growing period was 1.03 mm. The depth of water table ranged from 6.2 to 7.6 m below local ground surface.

Table 1: Physical and hydro-physical properties of the experimental soil

Soil depth (cm)	Soil texture (%)			BD (Mg m^{-3})	HC (cm hr^{-1})	Infiltration (cm hr^{-1})	FC (%, w/w)	PWP (%, w/w)
	Sand	Silt	Clay					
0-15	70.17	15.75	14.08	1.49	2.35	1.82	23.64	11.16
15-30	72.41	16.24	11.35	1.53	2.23	1.45	21.38	10.74
30-45	78.92	12.27	8.81	1.58	2.31	1.23	19.52	9.43
45-60	74.56	14.01	11.36	1.47	2.19	1.16	22.53	10.57

BD: bulk density; HC: Hydraulic conductivity; FC: Field capacity; PWP: Permanent wilting point

2.2. Experimental treatments and design

The experiment comprised of twelve treatment combinations having three irrigation levels viz. 30, 60 and 90 mm of cumulative pan evaporation (CPE) with 50 mm water depth assigned in main plots and four levels of phosphorus viz. 0, 30, 60 and 90 kg P_2O_5 ha^{-1} allotted in sub-plots were laid out in a split plot design with three replications.

2.3. Agronomic manipulations

The land was thoroughly pulverized by country ploughing followed by ridging. Broad bean (*Vicia faba* L.) cv. local seeds were sown at 5-6 cm depth on the ridges during the last week of October in each experimental year at a spacing of 60× 15 cm^2 (Tayel and Sabreen, 2011). The net plot size of each treatment was 4×3 m^2 with 1.0 m wide open buffer channel between plots to control intrusion of seepage and irrigation water from adjacent plots. All treatments received a common dose of farmyard manure at the rate of 10 t ha^{-1} during final land preparation and 20 kg N ha^{-1} and 40 kg K_2O ha^{-1} in the form of urea and muriate of potash, respectively as basal dressing. Phosphorus as single superphosphate was applied during sowing as per prescribed schedules. Standard cultural practices and plant protection measures were uniformly adopted in all plots. The plants on maturity were harvested in the second week of March in each year. The growing period of crop was lasted for 135–137 days.

2.4. Irrigation schedules

Irrigations were scheduled based on CPE of 30, 60 and 90 mm in respective plots. Daily evaporation data were recorded from a US Weather Bureau Class A Pan evaporimeter located in the research farm. In all 4, 3 and 2 number of irrigation at an interval of 22–24, 33–35 and 43–45 days were applied at 50 mm depth of water in irrigation scheduling of 30 mm, 60 mm and 90 mm of CPE, respectively. A common irrigation of 20 mm depth was applied to each plot uniformly through bucket sprinkler just after sowing for proper seed germination and broad bean seedling establishment. Irrigations were given as per treatments when CPE reached at respective value and the quantity of water was measured with the help of a Parshall flume.

2.5. Soil moisture extraction

For periodic soil moisture studies, soil samples were drawn from 0–15, 15–30, 30–45, 45–60 and 60–75 cm depth with the help of screw auger from net plot area of each treatment just before and 24 hours after irrigation, at 10 days interval and during sowing and final harvest of the crop. The soil moisture content in the sample was determined by gravimetric method. The profile soil moisture depletion was calculated by the following formula:

$$d=\sum_{i=1}^{n}\frac{(M_1^i-M_2^i)}{100}\times D_b\times Z$$

Where, *d*= Soil moisture depletion in the root zone (cm);

M_1^i=Soil moisture in the ith layer of profile 24 hours after irrigation (%, w/w);

M_2^i=Soil moisture in the ith layer of profile just before the next irrigation (%, w/w);

D_b=Bulk density of the ith layer (Mg m^{-3});

z =Depth of the ith layer (cm); and

$\sum_1^n$=Summation 'n' number of soil layers of the root zone

The data obtained on moisture content for each soil layer of respective treatment were used for computing the moisture extraction by crop from that particular soil layer of the profile.

2.6. Computation of seasonal crop water use

Seasonal crop water use (CWU) or, actual crop evapotranspiration (ETa) under the different irrigation treatments during the entire cropping period was computed using the following one dimensional field water balance equation (Garrity et al., 1982):

CWU = I+P± ΔS–R–C-D

Where, CWU is the seasonal crop water use (mm), I is the irrigation water (mm), P is the precipitation (mm), ±ΔS is the change in soil water storage in the profile between sowing and harvest time (mm) up to a depth of 75 cm (mm), R is the surface runoff (mm), C is the capillary rise from groundwater and D is the drainage below the root zone. The amount of precipitation received during the growing period was trace and assumed to be fully utilized by the crop. R was considered negligible as the field plots were bunded at 30 cm height and care was taken to prevent bund overflow. The contribution of capillary flux (C) to crop water use was assumed to be negligible as the groundwater is sufficient deep (6.2-7.6 m) throughout the period of experimentation that the water percolates downward out reach of the plant roots (Yang et al., 2007). D was assumed negligible as controlled irrigation water was applied. Thus, WU =I+P±ΔS.

2.7. Water use efficiency

Water use efficiency (WUE) for each treatment was calculated as seed yield divided by seasonal water use and expressed as, WUE=Y/CWU (kg ha^{-1} mm^{-1})

Where, Y=Marketable seed yield (kg ha^{-1}) and CWU = Seasonal crop water use (mm)

2.8. Benefit-cost ratio analysis

The economic feasibility of different irrigation and P fertilizer levels was worked out through benefit-cost ratio (BCR) analysis. The cost of production including expenses incurred in land preparation, sowing, intercultural operation, manures and fertilizers, crop protection measures, irrigation water, harvesting and threshing with labour charges was calculated as per prevailing market rates during the period of experimentation. The estimates of economic returns and BCR of individual treatment was calculated as,

Gross return (₹ ha^{-1})=Market price of the produce (₹ t^{-1})×seed yield (t ha^{-1})

Net return (₹ ha^{-1}) = Gross return (₹ ha^{-1}) - cost of production (₹ ha^{-1})

BCR=Net return/ cost of production

2.9. Statistical analysis

The year-wise yield data generated for crop was subjected to analysis of variance using software packages of MS Excel and SPSS 12.0 version. Statistical significance between means of individual treatments was assessed using Fisher's Least Significant Difference (LSD) test at $p<0.05$ (Gomez and Gomez, 1984).

3. Results and Discussion

3.1. Seed yield

The effect of different irrigation regimes on seed yield of broad bean was significant in each experimental year (Table 2). Maximum seed yield was obtained when irrigation at high moisture regime (CPE 30 mm) was scheduled and was superior to irrigation at CPE 60 mm and CPE 90 mm. However,

Table 2: Effect of different levels of irrigation and phosphorus application on seed yield (t ha^{-1}) of broad bean

Phosphorus level (P)	Irrigation level (I)															
	2009-2010				2010-2011				2011-2012				Pooled			
	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
P_0	3.63	3.36	3.20	3.39	3.82	3.56	3.41	3.60	3.75	3.45	3.21	3.47	3.73	3.46	3.27	3.49
P_{30}	4.42	3.93	3.66	4.00	4.70	4.27	3.98	4.31	4.56	4.20	3.86	4.20	4.56	4.13	3.83	4.17
P_{60}	4.87	4.32	4.12	4.44	5.22	4.63	4.50	4.78	5.04	4.43	4.29	4.59	5.04	4.46	4.30	4.60
P_{90}	5.76	5.32	4.99	5.36	5.83	5.31	5.23	5.46	5.47	5.28	5.16	5.31	5.69	5.30	5.13	5.37
Mean	4.67	4.23	3.99	-	4.89	4.44	4.28	-	4.70	4.34	4.13	-	4.76	4.34	4.13	-
	I	P	I × P	P × I	I	P	I × P	P × I	I	P	I × P	P × I	I	P	I × P	P × I
SEm±	0.12	0.18	0.16	0.17	0.08	0.17	0.12	0.14	0.08	0.11	0.12	0.13	0.09	0.17	0.15	0.16
LSD (p=0.05)	0.34	0.51	0.45	0.48	0.23	0.49	0.34	0.40	0.22	0.31	0.34	0.36	0.24	0.48	0.43	0.45

I_1: irrigation at CPE 30 mm; I_2: irrigation at CPE 60 mm; I_3: irrigation at CPE 90 mm; P_0, P_{30}, P_{60}, and P_{90} denotes 0, 30, 60 and 90 kg P_2O_5 ha^{-1}, respectively

there was no statistical variation in yield under irrigation at CPE 60 mm and CPE 90 mm in each year. The 3-year average data showed that dry moisture regime at CPE 60 mm and CPE 90 mm decreased the seed yield by 9.7% and 15.2%, respectively over relatively wet moisture regime at CPE 30 mm. This evidently implies that water stress due to deficit irrigation water application throughout the growth stages was the main limiting factor in reducing the potential yield over the years. The negative or adverse effect of soil water deficit might have resulted in decrease of various physiological and enzymatic processes, reduction of nutrients uptake, low rates of photosynthesis and poor nodulation thus restricted growth characters which ultimately affected the yield of broad bean (Tayel and Sabreen, 2011). Similar findings were also reported by El-Gindy et al. (2003) and Hegab et al. (2014) who observed the highest grain yield of broad bean with increasing irrigation application.

Likewise, seed yield increased consistently and significantly with increasing P application over control (no added P) and attained maximum value at 90 kg P_2O_5 ha^{-1} irrespective of year of study. However, the yield data obtained at 30 and 60 kg P_2O_5 ha^{-1} during 2009–10, 2010–11 and their pooled values was statistically at par. The increase in yield due to addition of 30, 60 and 90 kg P_2O_5 ha^{-1} over unfertilized P plot was 19.5, 31.8 and 53.9%, respectively. This indicates the essentiality of adequate P fertilization for proper nourishment of leguminous crops like broad bean for betterment of root mass development and its proliferation, root nodulation, and translocation of photosynthates towards the sink resulting into higher yield in this coarse textured sandy loam soil which inherently contains moderate plant available P. These results were in consonance with the observations of Said (1998), Ahmed and El-Abagy (2007) and Kubure et al. (2015) who noticed the significant improvement in the productivity of broad bean in response to higher level of P-fertilizer application under field conditions.

The interaction effect between irrigation regime and P fertilization on seed yield was significant in all the experimental years. The results indicated that the incremental dose of P fertilization to soil at a particular irrigation level increased the yield concomitantly; the effect was more so in wet moisture regime than in dry moisture regime. On an average, maximum seed yield of 5.69 t ha^{-1} was recorded with higher irrigation level at CPE 30 mm accompanied with higher dose of P fertilization at 90 kg P_2O_5 ha^{-1} which was on parity with moderate deficit irrigation level at CPE 60 mm with higher dose of P fertilization at 90 kg P_2O_5 ha^{-1} (5.30 t ha^{-1}). On the contrary, lowest irrigation level at CPE 90 mm without P fertilization recorded significantly the minimum yield (3.27 t ha^{-1}). This study clearly pointed out the inevitability of higher dose of P-fertilizer application under moderate to wet soil moisture condition for obtaining the higher seed yield of broad bean. The interaction effects between year×irrigation and year×P fertilization on seed yield were non-significant which indicates that the irrigation and phosphorus treatments under almost similar climatic conditions across the years might have stabilized the yield.

3.2. Soil water balance components and water use efficiency

The components of soil water balance during the cropping period of 2009–10, 2010–11, 2011–12 and their average values under different irrigation regimes and P levels are presented in Tables 3 and 4, respectively. Average depth of irrigation water applied at 30, 60 and 90 mm of CPE was 200, 150 and 100 mm, respectively. No rainfall was received in the crop growing period 2009-10 and 2010–11, but only 3.1 mm during 2011–12. The soil profile moisture contribution irrespective of irrigation and P levels ranged between 13.89 and 16.93 mm. Thus the seasonal crop water use (CWU) at 30, 60 and 90 mm of CPE was 236.42, 187.00 and 137.96 mm, respectively. The overall results indicated that irrespective of P levels maximum WUE (30.12 kg ha^{-1} mm^{-1}) was observed under dry moisture regime i.e. 90 mm CPE. This could be attributed

Table 3: Components of soil water balance and water use of broad bean under different levels of irrigation and phosphorus application during 2009−10, 2010−11 and 2011−12

Treatment	2009-2010				2010-2011				2011-2012			
	PC (mm)	Irrigation (mm)	Rainfall (mm)	Crop water use* (mm)	PC (mm)	Irrigation (mm)	Rainfall (mm)	Crop water use* (mm)	PC (mm)	Irrigation (mm)	Rainfall (mm)	Crop water use* (mm)
I_1P_0	13.28	200	0	233.28	14.12	200	0	234.12	14.26	200	3.10	237.36
I_1P_{30}	14.03	200	0	234.03	14.28	200	0	234.28	15.18	200	3.10	238.28
I_1P_{60}	14.82	200	0	234.82	14.51	200	0	234.51	15.63	200	3.10	238.73
I_1P_{90}	15.16	200	0	235.16	14.96	200	0	234.96	16.04	200	3.10	239.14
I_2P_0	13.82	150	0	183.82	14.82	150	0	184.82	14.66	150	3.10	187.76
I_2P_{30}	14.46	150	0	184.46	15.52	150	0	185.52	15.42	150	3.10	188.52
I_2P_{60}	14.98	150	0	184.98	15.85	150	0	185.85	16.15	150	3.10	189.25
I_2P_{90}	15.42	150	0	185.42	16.12	150	0	186.12	16.38	150	3.10	189.48
I_3P_0	14.36	100	0	134.36	14.94	100	0	134.94	15.33	100	3.10	138.43
I_3P_{30}	15.18	100	0	135.18	16.12	100	0	136.12	16.34	100	3.10	139.44
I_3P_{60}	15.62	100	0	135.62	16.92	100	0	136.92	17.12	100	3.10	140.22
I_3P_{90}	15.96	100	0	135.96	17.22	100	0	137.22	17.60	100	3.10	140.70

I_1: irrigation at CPE 30 mm; I_2: irrigation at CPE 60 mm; I_3: irrigation at CPE 90 mm; P_0, P_{30}, P_{60}, and P_{90} denotes 0, 30, 60 and 90 kg P_2O_5 ha^{-1}, respectively; *Including an initial common irrigation of 20 mm depth for seedling emergence and crop establishment; PC: soil profile water contribution

Table 4: Components of soil water balance, crop water use (CWU) and water use efficiency (WUE) of broad bean under different levels of irrigation and phosphorous application (average data of 3 years)

Treatment	PC (mm)	Irrigation (mm)	Rainfall (mm)	CWU* (mm)	Seed yield (t ha^{-1})	WUE (kg ha^{-1} mm^{-1})
I_1P_0	13.89	200	1.03	234.92	3.73	15.88
I_1P_{30}	14.50	200	1.03	235.53	4.56	19.36
I_1P_{60}	14.99	200	1.03	236.02	5.04	21.35
I_1P_{90}	15.39	200	1.03	236.42	5.69	24.07
I_2P_0	14.43	150	1.03	185.46	3.46	18.66
I_2P_{30}	15.13	150	1.03	186.16	4.13	22.19
I_2P_{60}	15.66	150	1.03	186.69	4.46	23.89
I_2P_{90}	15.97	150	1.03	187.00	5.30	28.34
I_3P_0	14.88	100	1.03	135.91	3.27	24.06
I_3P_{30}	15.88	100	1.03	136.91	3.83	27.97
I_3P_{60}	16.55	100	1.03	137.58	4.30	31.25
I_3P_{90}	16.93	100	1.03	137.96	5.13	37.18

I_1: irrigation at CPE 30 mm; I_2: irrigation at CPE 60 mm; I_3: irrigation at CPE 90 mm; P_0, P_{30}, P_{60}, and P_{90} denotes 0, 30, 60 and 90 kg P_2O_5 ha^{-1}, respectively; *: Including an initial common irrigation of 20 mm depth for seedling emergence and crop establishment; PC: Soil profile water contribution

to the full utilization of applied irrigation water for promoting seed yield. The lower WUE under increasing wet moisture regime was probably due to water loss through evaporation and drainage, which in turn resulted in decrease in yield. These observations are in accordance with the findings of Hegab et al. (2014) and Paolo et al. (2015) who reported the decreasing

WUE with increasing irrigation water supply in broad bean. Rifaat (2002) also demonstrated that magnitude of seed yield of broad bean was highly dependent on the amount of water availability and its use efficiency. Likewise, increasing P application regardless of irrigation regimes improved the WUE consistently and accomplished maximum value (29.86 kg ha^{-1} mm^{-1}) at higher level of P (90 kg P_2O_5 ha^{-1}) application. This might be due to the fact that increasing P-fertilizer doses enhanced the water requirement for crop leading to higher seed yield. The interaction effects between irrigation and P-fertilizer combinations showed that WUE increased with decrease in soil moisture and increase in P fertilization level. Maximum WUE (37.18 kg ha^{-1} mm^{-1}) was obtained with dry soil moisture regime at CPE 90 mm coupling with higher level of P application at 90 kg P_2O_5 ha^{-1}. On the other hand, minimum WUE (15.88 kg ha^{-1} mm^{-1}) was obtained with wet soil moisture regime at CPE 30 mm with zero P application. The results also indicated that when availability of irrigation water is limited or scarce, imposition of deficit irrigation scheduling at CPE 90 mm throughout the entire growing season in combination with high level of P at 90 kg P_2O_5 ha^{-1} administration could be a viable alternative for increased seed yield and maximum WUE.

3.3. Relationships of yield with irrigation water and phosphorus

The relationship between seasonal irrigation water applied and seed yield of broad bean was assessed for 3-year pooled data (Figure 1). A linear regression equation was best fitted between the average seed yield with seasonal irrigation water applied with highly significant coefficient of regression (R^2) value of 0.9643. This indicated that regardless of phosphorus levels the marketable yield responded linearly to increasing seasonal water application and reached peak value of 4.76 t ha^{-1} with 200 mm irrigation water application (CPE 30 mm).

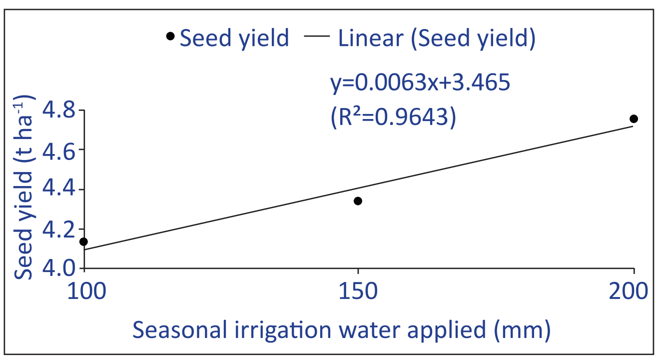

Figure 1: Relationship between seasonal irrigation water applied (x) and seed yield (y) of broad bean for different irrigation schedules (average data of 3 years)

The linearity between corn grain yield and seasonal irrigation water amount was reported by Payero et al. (2006b). Similarly, a highly significant linear relationship was detected between P administration and seed yield (R^2=0.9896) from the pooled data over the three years (Figure 2). This implied that irrespective of irrigation levels, the increasing level of P application progressively increased the seed yield and attained maximum of 5.37 t ha^{-1} with 90 kg P_2O_5 ha^{-1}. These observations are interesting from irrigation and P management points of view. The increasing amounts of P application at a certain level of irrigation resulted enhanced seed yield and WUE and the effects were more conspicuous in lower water regimes than in higher water regime. These equations have given a lot of opportunities in increasing the seed yield and WUE of broad bean under limited, moderate and abundant water supply conditions supplemented with high level of P (90 kg P_2O_5 ha^{-1}) fertilization.

3.4. Moisture extraction pattern

The percentage of soil moisture extraction under different irrigation regimes and P-fertilization levels was relatively higher in surface layer (0–15 cm), thereafter decreased consistently with increase in soil depth (Table 5). Higher extraction was found in 0–15 cm and 30–45 cm layer with irrigation at CPE 30 mm than that of CPE 60 mm and CPE 90 mm; whereas the soil moisture extracted from 45-60 cm soil layer was found maximum with irrigation at CPE 60 mm, closely followed by that of CPE 90 mm. Maximum soil moisture extraction from

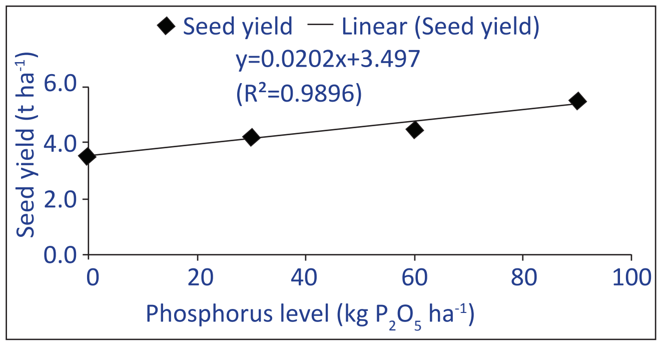

Figure 2: Relationship between dose of P application (x) and seed yield (y) of broad bean (average data of 3 years)

Table 5: Moisture extraction pattern (%) at different soil depths as influenced by different levels of irrigation and phosphorus application (average data of 3 years)

Treatment	Soil moisture extraction at different soil depth (cm)				
	0-15	15-30	30-45	45-60	60-75
Irrigation level (I)					
I_1 (CPE 30 mm)	30.85	24.01	18.74	14.74	11.66
I_2 (CPE 60 mm)	30.17	24.55	18.33	15.21	11.75
I_3 (CPE 90 mm)	29.51	25.44	17.89	15.13	12.03
Phosphorus level (P)					
P_0 (0 kg P_2O_5 ha^{-1})	31.54	25.69	17.97	13.92	10.87
P_{30} (30 kg P_2O_5 ha^{-1})	30.58	25.18	18.17	14.28	11.40
P_{60} (60 kg P2O5 ha^{-1})	30.35	24.67	18.66	15.15	11.57
P_{90} (90 kg P_2O_5 ha^{-1})	28.23	23.12	18.48	17.26	12.91

the sub-surface (15–30 cm) and deeper layer (60–75 cm) was observed with irrigation at CPE 90 mm and minimum at CPE 30 mm. On an average, upper soil layer (0–30 cm) contributed about 54.8% while the deeper layer (30–75 cm) accounted for 45.2% of the total moisture extraction. This might be due to more availability of soil moisture depleted by higher density of roots accumulated in upper soil layer and more soil evaporation from this layer (Goswami, 2011). The moisture stress condition in the surface layer as a result of irrigation at 60 and 90 mm of CPE might have stimulated the plant roots penetrate to deeper layers of the soil profile to meet their water requirement. Higher soil moisture was extracted from surface (0–15 cm) and sub-surface soil layer (15-30 cm) with control treatment (zero P) as compared with incremental P fertilization. Relative contribution of moisture extraction with different P-fertilizer doses was found more in deeper layers (30–75 cm) in comparison with control. Moisture extraction in bottom-most layer (60–75 cm) was found maximum at 90 kg P_2O_5 ha^{-1} in comparison with other P-treatment plots. This indicates that under water stress higher P fertilization might have improved the elongation and proliferation of root which likely enable the plant to absorb more moisture from the deeper layers of soil profile.

3.5. Economics

The benefit-cost ratio (BCR) analysis was worked out to determine the economic feasibility of different irrigation and P management practices on broad bean (Table 6). The total cost of production increased with incremental irrigation and phosphorus levels. The gross return and net return also increased progressively due to increase in seed yield as a result of increasing levels of irrigation and phosphorus application. BCR followed almost the same trend except in the treatment combinations of I_2P_{60} and I_2P_{90} where the seed yield did not increase proportionately and gross returns obtained were impractical as compared with the increased cost of production. The overall results showed that maximum gross return (₹ 45520 ha^{-1}), net return (₹ 28870 ha^{-1}) and BCR (1.73) were achieved from irrigation at CPE 30 mm with 90 kg P_2O_5 ha^{-1}. Under limited water supply, irrigating the crop at CPE 90 mm with 90 kg P_2O_5 ha^{-1} could be remunerative to obtain more gross return (₹ 41040 ha^{-1}), net return(₹ 25590 ha^{-1}) and BCR (1.66). Conversely, minimum gross return (₹ 26160 ha^{-1}), net return (₹ 14160 ha^{-1}) and BCR (1.18) were realized from irrigation at CPE 90 mm with no-P application (I_3P_0). The seasonal irrigation water had strong quadratic relationships with net return and BCR where both R^2 values were found to be unity (Figure 3). The crop attained the maximum net return and BCR values with 200 mm of seasonal irrigation water application (CPE 30 mm). The corresponding values thereafter declined with reduction in water supply. The higher economic benefit was ascribed to the increase in seed yield as a result of maintenance of wet moisture regime across the growth stages.

Table 6: Economic analysis of broad bean under different levels of irrigation and phosphorus application (average data of 3 years)

Treatment	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Benefit-cost ratio
I_1P_0	13200	29840	16640	1.26
I_1P_{30}	14350	36480	22130	1.54
I_1P_{60}	15500	40320	24820	1.60
I_1P_{90}	16650	45520	28870	1.73
I_2P_0	12600	27680	15080	1.20
I_2P_{30}	13750	33040	19290	1.40
I_2P_{60}	14900	35680	20780	1.39
I_2P_{90}	16050	42400	26350	1.64
I_3P_0	12000	26160	14160	1.18
I_3P_{30}	13150	30640	17490	1.33
I_3P_{60}	14300	34400	20100	1.41
I_3P_{90}	15450	41040	25590	1.66

I_1: irrigation at CPE 30 mm; I_2: irrigation at CPE 60 mm; I_3: irrigation at CPE 90 mm; P_0, P_{30}, P_{60}, and P_{90} denotes 0, 30, 60 and 90 kg P_2O_5 ha^{-1}, respectively; Cost of cultivation without fertilization and irrigation: ₹ 10800 ha^{-1}; Cost of applied irrigation water (₹ ha^{-1}): I_1: 2400, I_2: 1800, I_3: 1200; Cost of P-fertilization (₹ ha^{-1}): P_{30}: 1150, P_{60}: 2300, P_{90}: 3450; Sale price of produce (₹ t-1): 8000

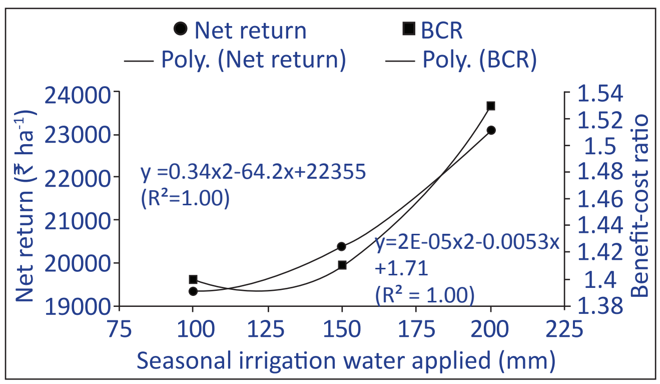

Figure 3: Relationships of seasonal irrigation water applied (x) with net return and benefit-cost ratio (y) of broad bean for different irrigation schedules (average data of 3 years)

4. Conclusion

Broad bean is responsive to both irrigation and phosphorouws application. Under copious water availability, maximum seed yield, moderate WUE and highest profits were obtained with irrigation at CPE 30 mm along with 90 kg P_2O_5 ha^{-1}. In water scarce situation, irrigation at CPE 90 mm coupling with 90 kg P_2O_5 ha^{-1} was found most suitable for increased yield, maximum WUE and higher profits and may thus be recommended in the lower Indo-Gangetic plains of eastern India and similar agro-climatic regions.

5. Acknowledgement

Authors are very grateful to the All India Coordinated Project (AICRP) on Irrigation Water Management, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India for providing necessary funds and facilities to conduct the research programme.

6. References

Abdel-Ghaffar, A.S., 1988. Factor affecting nitrogen fixation and yield of faba bean (*Vicia faba*) under Egyptian field conditions: A review. Arid Land Research and Management 1(2), 65–75.

Abdel, L.Y.I., 2008. Effect of seed size and plant spacing on yield and yield components of faba bean (*Vicia faba* L.). Research Journal of Agriculture and Biological Sciences 4, 146–148.

Ahmed, M.A., El-Abagy, H.M.H., 2007. Effect of bio-and mineral phosphorus fertilizer on the growth, productivity and nutritional value of some faba bean (*Vicia faba* L.) cultivars in newly cultivated land. Journal of Applied Sciences Research 3(6), 408–420.

El-Gindy, A.M., Abdel, A.A., Aziz, E.L., Sabar, E.A., Abdelghany, A.M., 2003. Engineering and biological properties of faba bean seeds under different irrigation systems. Journal of Agricultural Science, Mansoura University 28(6), 4325–4337.

Garrity, P.D., Watts, D.G., Sullivan, C.Y., Gilley, J.R., 1982. Moisture deficits and grain sorghum performance, evapotranspiration yield relationships. Agronomy Journal 74, 815–820.

Gasim, S., Link, W., 2007. Agronomic performance and the effect of soil fertilization on German winter faba bean. Journal of Central European Agriculture 8, 121–127.

Gomez, K.A., Gomez, A.A., 1984. Statistical procedures for agricultural research. 2nd Ed., International Rice Research Institute, Los Banos, Philippines.

Goswami, S.B., 2011. Effect of irrigation and nitrogen on growth, yield and water use efficiency of black cumin (*Nigella sativa*) in lower indo-gangetic plains. Indian Journal of Agricultural Sciences 81(6), 524–552.

Hamed, M.F., 2003. Faba bean productivity as affected by zinc, phosphorus fertilizer and phosphorein. Annals of Agricultural Science Moshtohor Journal 41(3), 1109–1119.

Hegab, A.S.A., Fayed, M.T.B., Hamada, M.M.A., Abdrabbo, M.A.A., 2014. Productivity and irrigation requirements of faba bean in North Delta of Egypt in relation to planting dates. Annals of Agricultural Sciences 59(2), 185–193.

Hoffmann, D., Jiang, Q., Men, A., Kinkema, M., Gresshoff, P.M., 2007. Nodulation deficiency caused by fast neutron mutagenesis of the model legume Lotus japonicus. Journal of Plant Physiology 164, 460–469.

Horst, I., Welham, T., Kelly, S., Kaneko, T., Sato, S., Tabata, S., Parniske, M., Wang, T.L., 2007. Tilling mutants of Lotus japonicus reveal that nitrogen assimilation and fixation can occur in the absence of nodule enhanced sucrose synthase. Plant Physiology 144, 806–820.

Jensen, E.S., Peoples, M.B., Hauggaard-Nielsen, H., 2010. Faba bean in cropping systems. Field Crops Research 115, 203–216.

Kandil, A.A., Sharief, A.E., Mahmoud, A.S.A., 2019. Influence of phosphorus fertilization levels on productivity of some broad bean cultivars. International Journal of Advanced Research in Biological Sciences 6(7), 124–131.

Khan, H.R., Paull, J.G., Siddique, K.H.M., Stoddard, F.L., 2010. Faba bean breeding for drought-affected environments: A physiological and agronomic perspective. Field Crops Research 115, 279–286.

Kubure, T.E., Cherukuri, V.R., Arvind, C., Hamza, I., 2015. Effect of faba bean (*Vicia faba* L.) genotypes, plant densities and phosphorus on productivity, nutrients uptake, soil fertility changes and economics in Central high lands of Ethiopia. International Journal of Life Sciences 3(4), 287–305.

Meena, R.P., Sharma, R.K., Chhokar, R.S., Chander, S., Tripathi, S.C., Kumar, R., Sharma, I., 2015. Improving water use efficiency of rice-wheat cropping system by adopting micro-irrigation systems. International Journal of Bio-resource and Stress Management 6(3), 341–345.

Musallam, I.W., Al-Karaki, G.N., Ereifej, K.I., Tawaha Abdel-Rahman, M., 2004. Chemical composition of faba bean genotypes under rainfed and irrigation conditions. International Journal of Agriculture and Biology 6, 359–362.

Neenu, S., Ramesh, K., Ramana, S., Biswas, A.K., Subba Rao, A., 2014. Growth and yield of different varieties of chickpea (*Cicer arietinum* L.) as influenced by the phosphorus nutrition under rainfed conditions on Vertisols. International Journal of Bio-resource and Stress Management 5(1), 053–057.

Paolo, E.D., Garofalo, P., Rinaldi, M., 2015. Irrigation and nitrogen fertilization treatments on productive and qualitative traits of broad bean (*Vicia faba* var. Minor L.) in a Mediterranean environment. Legume Research 38(2), 209–218.

Payero, J.O., Steven, M., Irmak, S., Tarkalson, D.D., 2006b. Yield response of corn to deficit irrigation in a semiarid climate. Agricultural Water Management 84, 895-908.

Rabie, K.A.E., Kawthar, A.E., 1991. Effect of sowing dates on endogenous hormones, shedding and yield in vicia faba plants. Annals of Agricultural Sciences, Ain Shams University Cairo 36(2), 323–333.

Rajan, K., Singh, A.K., Pandey, A.K., 2012. Faba bean soils and their management for higher productivity. In: Faba Bean (*Vicia faba* L.): A potential leguminous crop of India (Ed. Singh and Bhatt). ICAR, RC for ER, Patna, 205–212.

Rifaat, M.G.M., 2002. Broad bean response to available soil moisture depletion and phosphorus fertilization in alluvial soil. Egyptian Journal of Applied Sciences 17(9), 334–345.

Rinaldi, M., Vonella, A.V., Soldo, P., Debiase, G., Garofalo, P., 2008. Yield and canopy response of chickpea (*Cicer arietinum* L.) to different irrigation regimes. In: Brebbia, Pratas Rico, D. (Ed.), Sustainable irrigation-management, technologies and policies II, Y. Villacampa Esteve, C.A. WIT Press (UK), WIT Transaction on Ecology and the Environment 112, 123–132.

Said, E.M., 1998. Response of some faba bean (*Vicia faba* L.) varieties to phosphorus and nitrogen fertilization. The Journal of Agricultural Science, Mansoura University 23(6), 2369–2377.

Sharaan, A.N., Ekram, A., Megawer, H.A.S., Hemida, Z.A., 2004. Seed yield, yield components and quality character as affected by cultivars, sowing dates and planting distances in faba bean. Bulletin of Agricultural Economics, Ministry of Agriculture, Egypt.

Singh, A.K., Chandra, N., Bharati, R.C., Dimree, S.K., 2010. Effect of seed size and seeding depth on faba bean (*Vicia faba* L.) productivity. Environment and Ecology 28(3A), 1722–1527.

Singh, A.K., Bharati, R.C., Manibhusan, N.C., Pedpati, A., 2013. An assessment of faba bean (*Vicia faba* L.) current status and future prospect. African Journal of Agricultural Research 8(50), 6634–6641.

Tayel, M.Y., Sabreen, K.P., 2011. Effect of irrigation regimes and phosphorus level on two vicia faba varieties:1-Growth characters. The Journal of Applied Sciences Research 7(6), 1007–1015.

Taylor, S.A., 1965. Managing irrigation water on farm. Transactions of the American Society of Agricultural Engineers 8, 433–436.

Xia, M.Z., 1994. Effects of drought during the generative development phase of faba bean (*Vicia faba* L.) on photosynthetic characters and biomass production. The Journal of Agricultural Science 122, 67–72.

Yang, J.F., Wang, S.Q., Deng, W., Zhang, G.X., 2007. Water fluxes at a fluctuating groundwater table and groundwater contributions to wheat water use in the lower Yellow River flood plain, China. Hydrological Processes 21, 717–724.