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Influence of deficit irrigation on French bean (*Phaseolus vulgaris*) cultivars under North Eastern Region of India

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ABSTRACT

Freshwater used in the irrigation sector is dwindling and has become a scare commodity in the 21st century. Northeastern Region (NER) of India harboring the highest rainfall receiving zones of the globe and having average annual rainfall more than the national average also experiences *in-situ* soil moisture stress during the winter season which drastically affects crop production. Under such scenarios, "deficit irrigation" strategy can be followed to meet crop demands, without much compromising on potential yields. Pulse crops grown during winter season can be suitably accommodated under deficit irrigation regimes. A field experiment has been laid out with split plot experimental design with four deficit irrigation regimes under main plot and three French bean varieties, *viz*., Arka Arjun (V_1), Arka Sharath (V_2) and Zorin bean (V_3) under sub plot treatment. This experiment was replicated thrice. Deficit irrigation regime consists of irrigating the crop at a certain level of available soil moisture depletion (ASMD), *viz.,* M_1 (20% of ASMD), M_2 (40% of ASMD), M_3 (60% of ASMD) and M_4 (80% of ASMD). The results revealed that, irrigation regime followed with M_1 being at par with M_2 exhibited superior performance in terms of growth and yield. The highest seed yield was recorded under 20% ASMD (M_1 treatment) with 1.02 t ha^{-1}, similarly under the sub-plot treatment zorin bean variety registered highest seed yield with 1.10 t ha^{-1} and benefit cost ratio of 2.18. The farmers of NER region may be suggested growing the Zorin bean under deficit irrigation regime M_2, *i.e.*, at irrigating the crops at 40% of available soil moisture depletion.

Key words: Available soil moisture, deficit irrigation, winter, terminal moisture stress, zorin bean

INTRODUCTION

Deficit irrigation (DI) is one of the suitable irrigation strategies that allow a controlled level of deficit in amount of irrigation water with marginal reduction in the crop yield. This approach is mostly accepted for optimizing water use and increasing water productivity under water-scarce areas (Ali et al., 2007; Alomran et al., 2013; Sharma and Rai, 2022; Ray et al., 2023). DI technology is mostly used under dry land farming as well as under water scarcity regimes. Under limited water availability, deficit irrigation is a suitable water management strategy, where irrigation water is supplied in fewer amounts than the requirement to meet crop evapotranspiration demand without substantial compromising the potential yield (Rudnick et al., 2017). It is a crucial agronomic practice to enhance water use efficiency (WUE) by minimizing irrigation water volume. This technique positively impacts water productivity by ensuring optimal water utilization. Through deficit irrigation, crops are subjected to regulated water stress, either seasonally or throughout the growing season, resulting in negligible yield reduction (Ali et al., 2007; Fereres and Soriano, 2007; FAO, 2020). DI could save up to 50% of irrigation water and increase WUE by 200%, with satisfactory yield (Zegbe-Dommguez et al., 2003). However, crops grown under water-deficit conditions, experiences a decline in relative leaf water content and triggers stomatal closure, due to decrease in soil moisture availability which ultimately limits CO_2 availability, and in turn reduces the rate of photosynthesis and water use efficiency (Soureshjani et al., 2019).

To adopt deficit irrigation, it is essential to understand the crop's response to water deficit at different growth stages, simultaneously, for taking a firm decision to adopt this technology techno-economic benefits need to be relooked at with a comparative analysis on the control plots. Deficit irrigation has been shown to boost net farm income, with benefits arising from three key factors: enhanced irrigation efficiency, lower irrigation costs, and the opportunity cost of water (Ali et al., 2007; Abuarab et al., 2020). Reduction in yield is inevitable due to deficit irrigation; however, the extent of yield reduction caused by water shortage needs to be quantified and efforts should be taken to minimize the reduction in yield with saving of irrigation water. Some researchers have opined that the economical decrease in yield under deficit irrigation can be minimized considering the cost of irrigation water into account (Kiziloglu et al., 2006; Abuarab et al., 2020).

The scarcity in water during winter or non-rainy season in Northern Eastern Region (NER), of India may be attributed to hilly topography and non-adherence of water harvesting strategies during rainy season (Ray et al., 2012, 2019). Though this region receives 51% higher rainfall than the national average, it suffers water scarcity as soon as the rain ceases and the dry season starts (Marak et al., 2020). It is primarily because of characteristic high reliefs or undulating terrains and localized small valleys resulted in very high runoff, as rainwater does not have sufficient time to infiltrate into the soil (Rani and Sudhakar, 2018).

NER of India bestowed with about 46% of the total water resources in the country, however, during non-rainy seasons with more than 80% of the area in NER remained fallow after rainy season rice (Geerts and Raes, 2009; Singh, 2017; Kumar et al., 2019; Ray et al., 2019). Winter season is favourable for pulse cultivation in NER, but due to lack of appropriate irrigation management practices coupled with lack of suitable soil and water conservation measures and ill irrigation facilities under undulating terrain led to severe water scarcity which forces farmers to leave their land fallow (Saha, 2011; Sah et al., 2020; Das et al., 2021; Shirisha et al., 2023). There is enormous potential to increase the total area of cultivation through incorporating pulses in the cropping system and adopting suitable irrigation strategies like deficit irrigation.

North Eastern region has a deficit of almost 82% of its pulse requirement despite the favorable agro-climatic condition for pulse production. The rice and maize fallow areas are suitable for the cultivation of pulses like pea, chickpea, French bean, black gram, and green gram (Das et al., 2016). French bean (*Phaseolus vulgaris* L.), which is most irrigation-responsive pulse crop due to its shallow root system can be cultivated in the winter season under deficit irrigation to boost food as well as nutritional security of the region along with increasing farmers income. It is the world's third most important grain legume used for direct human consumption after soybeans and peanuts (De Ron et al., 2016). It is also regarded as a major protein and calorie source in the world (Broughton et al., 2003).

French beans exhibit high sensitivity to soil water balance and even minimal stress can significantly reduce yields. Therefore, irrigation scheduling should be aligned with specific physiological growth stages, as these crucial stages substantially influence yield and protein content in french beans (Uddin et al., 2022). Water deficit during the critical flowering and pod formation stages significantly impacts bean yields (Durigon et al., 2019; Anda et al., 2021). Thus, the response of seed yield in french bean to various levels of deficit irrigation should be investigated thoroughly. In the light of above consideration, a field experiment has been taken up to assess the performance of three french bean varieties along with a comparative performance of water productivity and benefit cost ratios.

MATERIALS AND METHODS

Experimental site and meteorological parameters

An agronomic field experiment was conducted during winter season, (November to March) of 2023-24 at the experimental farm of College of Postgraduate Studies, Umiam, Ri-Bhoi district, Meghalaya. The experimental site is situated at 25.6649° North latitude and 91.9029° East longitude at an altitude of 950 m above mean sea level (MSL). The location of the experimental site is shown on Fig. 1.

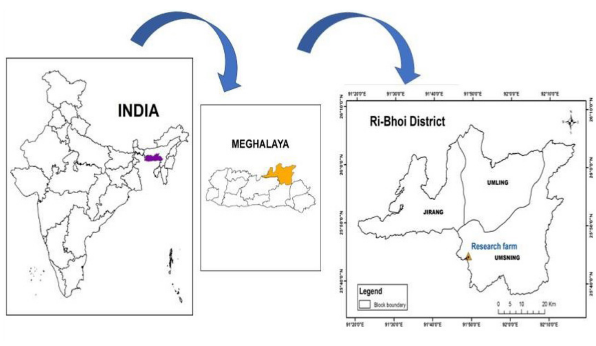

Fig. 1. Location of the experimental site

The annual average rainfall of experimental site is 2617.10 mm with some pre-monsoon showers during March to May (Ray et al., 2012). Total amount of rainfall received throughout the growing period was 11.9 mm out of which maximum weekly rainfall of 5.6 mm was received during 49th standard meteorological week (SMW). Mean weekly maximum temperature was recorded highest during 11th SMW (27.3°C) and the lowest was recorded in 5th SMW (18.7°C). Mean weekly minimum temperature was recorded the highest in 11th SMW (14.2°C) and the lowest was recorded in 3rd SMW (5.6°C). The maximum weekly relative humidity varied between 83 to 93% and the minimum weekly relative humidity ranged from 51 to 75%. The variation in mean weekly the maximum and the minimum temperature was shown in Fig. 2.

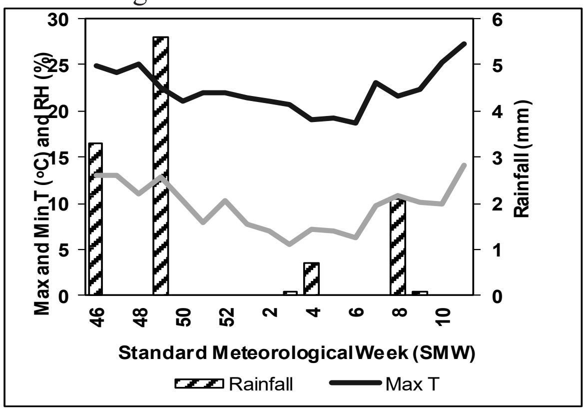

Fig. 2. Variation of mean weekly rainfall and temperature during the experimental period

Prior to the experiment, initial soil samples were collected to determine the basic soil physical and chemical properties. The soil at the experimental site was found to be sandy clay loam. The soil has initial organic carbon and pH of 1.4%, 5.76, respectively. The average values of available nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) at 0-30 cm were 243.54, 14.37, and 193.34 kg ha^{-1}, respectively. The soil of the experimental field is acidic in reaction.

Experimental design and details of treatments

The split plot experimental design was chosen to conduct the trial with irrigation scheduling under the main plot and three varieties of french bean under the sub plot. The field experiment was replicated thrice. Irrigation scheduling was based on the available soil moisture depletion (ASMD) approach. Four (04) main plot treatments are M_1:

20% of ASMD, M_2: 40% of ASMD, M_3: 60% of ASMD, and M_4: 80% of ASMD. Similarly, three (03) French bean varieties are V_1: Arka Arjun, V_2: Arka Sharath, and V_3: Zorin bean. French bean varieties were mostly sown during winter seasons having a duration of more than three months and with spacing of 30 cm × 10 cm and seed rate of 75 kg ha^{-1} with recommended dose of fertilizers as 80:60:40 kg ha^{-1} (N: P_2O_5: K_2O). The schematic layout of the plan of the experiment is shown in Fig. 3.

M_4V_1	M_4V_3	M_4V_2	M_3V_2	M_3V_1	M_3V_3	M_2V_1	M_2V_3	M_2V_2
M_2V_2	M_2V_1	M_2V_3	M_4V_1	M_4V_2	M_4V_3	M_3V_2	M_4V_1	M_4V_3
M_3V_3	M_3V_2	M_3V_1	M_1V_1	M_1V_3	M_1V_2	M_4V_2	M_3V_1	M_3V_3
M_1V_2	M_1V_3	M_1V_1	M_2V_3	M_2V_2	M_2V_1	M_1V_2	M_1V_3	M_1V_1
R1			R2			R3		

R- Replication, M- Available Soil Moisture Depletion, V- French bean Varieties

Fig. 3. Schematic layout of the experiment

Estimation of soil moisture content (%)

Soil moisture content was calculated by using the formula (Jalota et al., 1998) presented in Eq. 1. Gravimetric readings were taken during early morning at each two days interval. The irrigation scheduling was done based on the soil moisture depletion method.

$$\text{Soil moisture content (\%)} = \frac{\text{Weight of water (g)}}{\text{Weight of oven dry soil (g)}} \times 100$$

Net irrigation requirement

Net irrigation requirement is the depth of irrigation water, along with effective rainfall and carry over soil moisture or other gains in soil moisture, required for consumptive use of crops. Thus, net irrigation requirement is the difference between the field capacity and the soil moisture content in the root zone before application of water. It is given in Eq. 2 below.

$$\text{NIR} = \sum_{i-1}^{n} \frac{Mfc - Mbi}{100} \text{ x Ai x Di}$$

Where, NIR = Net irrigation requirement (cm)

M_{fc} = Soil moisture content (%) at field capacity

M_{bi} = Soil moisture content (%) before irrigation

A_i = Apparent specific gravity of soil in ith layer

D_i = Effective root zone depth of ith soil layer (cm)

The net irrigation requirement was estimated using the above equation for different irrigation regime. The estimated depth of irrigation at 20, 40, 60 and 80% of ASMD were 16.3 mm, 32.7 mm, 49.1 mm and 65.5 mm, respectively for each cycle of irrigation.

Water productivity

The water productivity of crops was calculated as the ratio of seed yield to total amount of water applied as presented in Eq. 3 and it is expressed in kg m^{-3}.

$$\text{Corp water productivity} = \frac{\text{Economic yield}}{\text{Total amount of water applied}}$$

Benefit cost ratio (BCR)

The cost of cultivation was calculated based on the prevailing market price during 2023-24. The BCR was calculated by taking the ratio of gross return obtained for the economic yield and total cost incurred under different irrigation regime due to varying levels of irrigation. It reveals the returns obtained with the per rupee spent in the cultivation of French bean as given in Eq. 4

$$BCR = \frac{\text{Gross return}}{\text{Cost of Cultivation}}$$

Statistical analysis

The data obtained during this field trial were analyzed by using the technique of analysis of variance for split plot designs. The difference between the treatment means was tested as for their statistical significance with appropriate critical difference value at 5% level of probability as explained by (Gomez and Gomez, 1984). All the field data were analyzed using Microsoft Excel of the MS office software.

RESULTS AND DISCUSSION

Soil moisture variation

The soil moisture was estimated from each irrigation regime for the whole growing season at each two days interval for scheduling of irrigation. The variation of soil moisture throughout the growing period is presented in Fig. 4. The variation in soil moisture was found inconsistent for different irrigation regime. A uniform variation in soil moisture was observed under the irrigation regime M_1, where lower depth of irrigation was provided with higher frequency. However, the depletion in soil moisture under irrigation regime M_4 was found to be steady than other regimes as higher depth of irrigation was provided to bring the soil moisture nearer to field capacity. The variation curve also showed the requirement of relative depth of irrigation under respective irrigation regime. As shown in Fig. 4, the rainfall has not much influenced the soil moisture content due to its insignificant amount and high surface runoff, very less amount may have infiltrated into the soil.

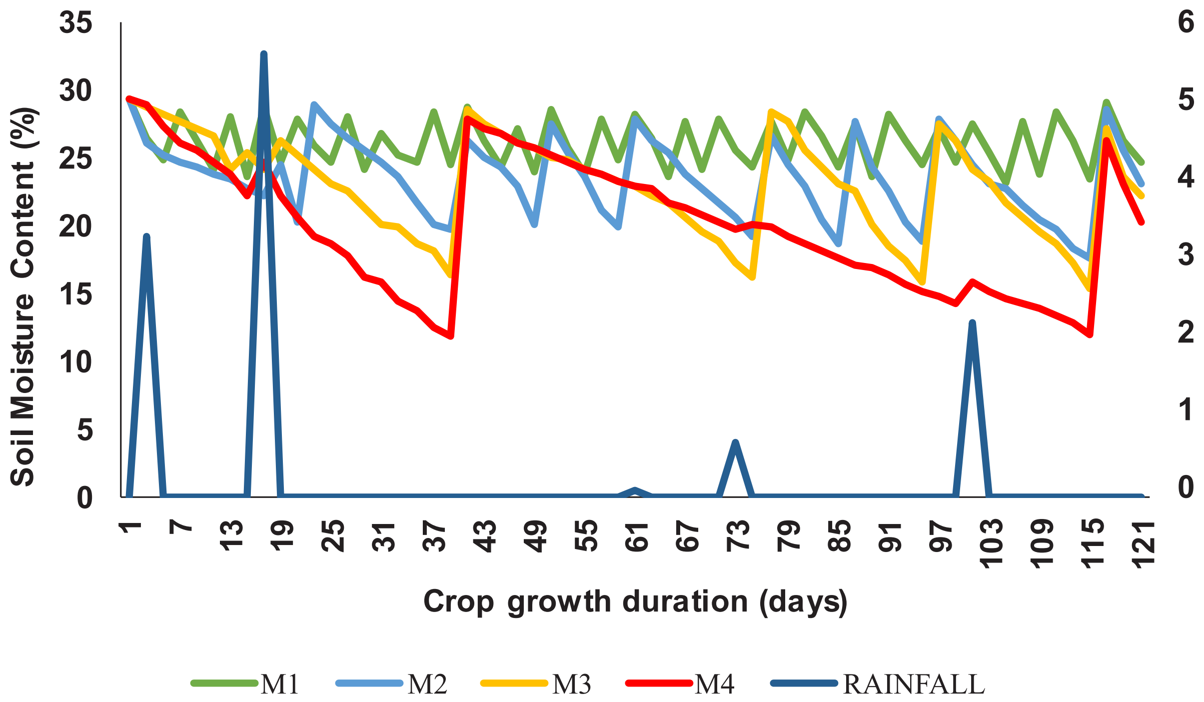

Fig. 4. Soil moisture variations throughout the growing period

Irrigation scheduling

Scheduling of irrigation with desired depth and frequency was performed based on pre-determined soil moisture content at 20, 40, 60 and 80% ASMD. The depth of irrigation at each moisture depletion level is the depth of water required to bring the moisture content of the soil to field capacity, and it was calculated using suitable protocols for determining net irrigation requirement (NIR). Therefore, soil moisture content was monitored gravimetrically every two days throughout the season to decide the irrigation requirement. For maintaining the uniformity of moisture content in soil, initially all the treatments plots were irrigated with 6 cm of water immediately after sowing to bring the soil moisture content nearer to field capacity and this amount of water was not considered for making further calculation in the experiment. The depth of irrigation at M_1 (20% of ASMD), M_2 (40% of ASMD), M_3 (26% of ASMD) and M_4 (80% of ASMD) were 16.3, 32.7, 49.1 and 65.5 mm, respectively per a single irrigation at respective soil moisture depletion level to bring the moisture content nearer to field capacity. The number of days taken to attain physiological maturity plays a vital role in calculating the total depth of water applied to each variety. The three varieties under our study are not of uniform duration and the total number of days taken by the varieties to attain maturity varied significantly. Variety Arka Arjun (V_1) and Arka Sharath (V_2) matured at 85-90 DAS while Zorin bean (V_3) took around 110 days to attain its maturity. The depth and frequency of irrigation water provided throughout the growing season is illustrated in Fig. 5.

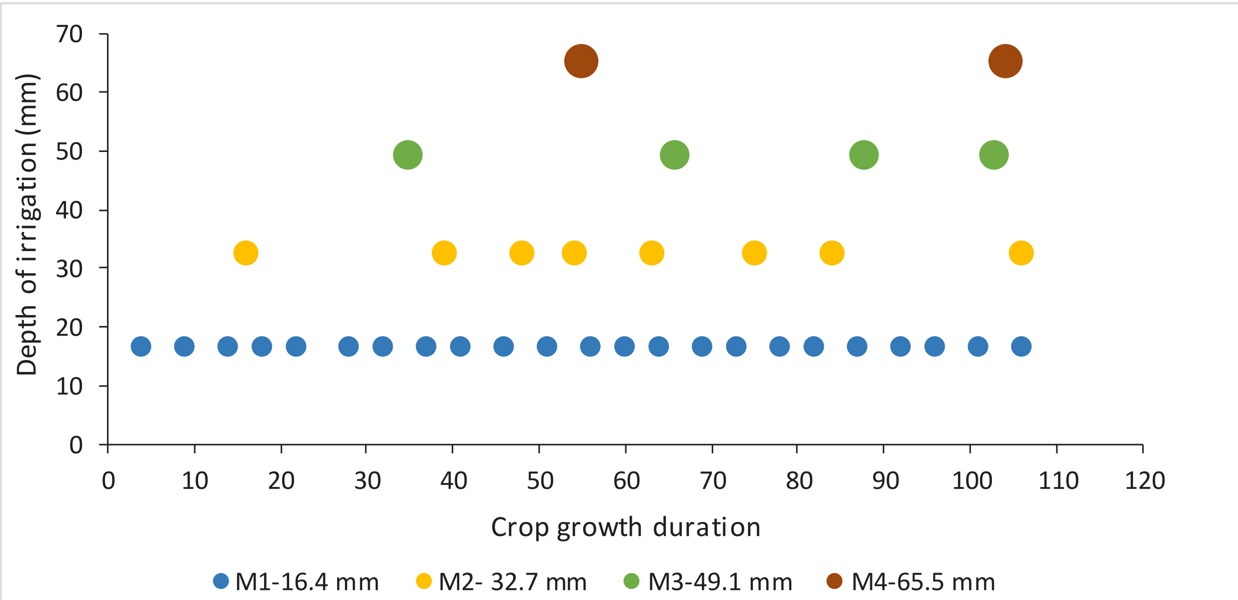

Fig. 5. Irrigation depths (mm) and frequency of irrigations at M1, M2, M3 and M4

Irrigation depths of 16.4, 32.7, 49.1, and 65.5 mm were applied at M_1, M_2, M_3, and M_4, respectively, to replenish soil moisture in the root zone to field capacity during each irrigation cycle, corresponding to 20, 40, 60, and 80% of the available soil moisture depletion (ASMD). The frequency of irrigation at M_1, M_2, M_3 and M_4 were 23, 8, 4, and 2 for V_3 accounting to a total depth of 377.2, 261.6, 196.4, and 131 mm and 19, 6, 3, and 2 for V_1 and V_2 accounting to a total depth of at respective irrigation regime 311.6, 196.2, 147.3 and 131 mm. Effective rainfall was calculated from the total amount of rainfall received using the formula given by USDA soil conservation service in CROPWAT 8.0 software. In the present study, the effective rainfall was the same as total rainfall due to the insignificant amount of rainfall received during the growing season. An effective rainfall of 11.9 mm was added with the irrigation depth to calculate the total amount of water received by each variety under each irrigation regime. The average depth of water received under each irrigation regime was computed taking the water received by each variety into account. The total depth of water (irrigation + effective rainfall) has furnished in Table 1.

Table 1. Total amount of water received by each variety under different irrigation regimes

Irrigation regimes	Total depth of water received (mm)			Average depth of water received under each regime (mm)
	V1	V2	V3	
M1	323.5	323.5	389.1	345.3
M2	208.1	208.1	273.5	229.9
M3	159.2	159.2	208.3	175.5
M4	142.9	142.9	142.9	142.9

Water productivity

The total depth of water received by each variety under each irrigation regime is listed in Table 1. Similarly, a significant variation in water productivity was registered under main plot as well as sub-plot treatment. The details are given in Table 2. Water productivity (kg m^{-3}) was estimated by taking the economic yield obtained and total amount of water (irrigation + effective rainfall) consumed during the growing season into account. The maximum value of water productivity was obtained under irrigation regime, M_4, where crop was irrigated at 80% of available soil moisture depletion. The water productivity of the four irrigation treatments can be ranked in the following order: M_4 being the highest (0.45 kg m^{-3}), followed by M_2 (0.39 kg m^{-3}), then M_3 (0.31 kg m^{-3}), and finally M_1 being the lowest (0.26 kg m^{-3}).

Perusal of the data pertinent to water productivity revealed that the highest water productivity obtained under the irrigation regime where the consumptive water use was lowest while the reverse is true for other regimes. This means water productivity decreases with increase in consumptive water use and vice versa. These significant results were also established by various reports (Chaudhari et al., 2008; Tyagi et al., 2012; Darwesh et al., 2016; Gupta et al., 2017; Saleh et al., 2018). Webber et al. (2006) showed that French beans exhibit a greater potential to increase water productivity when subjected to deficit irrigation. This finding is supported by Geerts and Raes (2009), who demonstrated that deficit irrigation can lead to increased water productivity across a range of crops. Saleh et al. (2018) found that decreasing irrigation from 20% of ASMD to 40% ASMD increases water productivity and remarked that profitability and productivity of bean can be increased with irrigation management. Also, the reason for relatively higher water productivity under M_2 over M_1 may be because of marked decrease in depth and frequency of irrigation water in M_2 relative to M_1 while an insignificant reduction in seed yield. The slight decline in water productivity at M_2 over M_4 might be due to a lower increase in seed yield with proportionately higher use of irrigation water as explained by Darwesh et al. (2016). The significant decline in water productivity under M_1 than M_2 resulting from substantial evapotranspiration losses of irrigation water than the marked increase in seed yield as suggested by El-Sherif et al. (2015). Among the varieties, Zorin bean registered significantly highest water productivity over Arka Sharath followed by Arka Arjun. This might be due to higher seed yield in Zorin bean resulting in higher water productivity.

Table 2. Effect of irrigation regimes on water productivity of french bean varieties

Treatments	Water productivity (kg m^{-3})
Main plot (Number of irrigation regimes = 04)	
M_1 – 20% of ASMD	0.26
M_2– 40% of ASMD	0.39
M_3 – 60% of ASMD	0.31
M_4- 80% of ASMD	0.45
S.E. (m) ±	0.02
C.D. (P=0.05)	0.07
Sub-plot (Number of varieties = 03)	
V_1 – Arka Arjun	0.27
V_2 – Arka Sharath	0.32
V_3 – Zorin bean	0.47
S.E. (m) ±	0.02
C.D. (P=0.05)	0.06

Plant growth parameter

The various plant growth parameters, *viz.,* plant height, leaf area index (LAI), root length and dry matter accumulation per plant are significantly influenced by different irrigation regimes. French bean varieties and are presented in Table 3. It can be observed that the highest value of all the growth parameters was recorded under irrigation regime, M_1, where crops were frequently irrigated throughout the growing period. However, the values of all the growth parameters recorded under M_2 were statistically at par with M_1. The irrigation regime M_4, where crops were least irrigated, recorded the lowest value for all the parameters.

The taller plant under M_1 and M_2 might be due to optimum soil moisture availability throughout the growing period which facilitates nutrient uptake in desired quantities and promotes vegetative growth of plants by increasing cell division and elongation which increased the plant growth in terms of plant height. These outcomes agree with the findings of Abdel-Mawgoud (2006) and Tyagi et al. (2012). The reduced plant height under M_3 and M_4 may be attributed to inadequate irrigation, which hindered cell division, carbohydrate and protein synthesis, and impaired the normal functioning of cambium tissue. Similar findings were reported by Uddin et al. (2022).

The highest LAI under M_1 and M_2 might be attributed to high soil moisture availability that promotes increased cell division and enlargement, leading to a corresponding increase in leaf area with higher irrigation levels. Identical findings were reported by (El-Noemani et al., 2010; Kumar and Singh, 2014; Kalaydjieva et al., 2015). The lower value of LAI reported under M_3 and M_4 might be due to availability of limited moisture often restricts leaf area expansion primarily due to an imbalance in water relations, which reduces the expansion and development of the leaf area as suggested by Soureshjani et al. (2019).

The significant increase in dry matter accumulation under M_1 could be attributed to frequent irrigation under this regime that facilitates moisture availability in the root zone, leading to improved plant water status and increased stomatal conductance, which ultimately boosts photo assimilation production. Identical revelations were also reported by various workers (Abdel-Mawgoud, 2006; El-Noemani et al., 2010; Kumar and Singh, 2014; Gopal et al., 2015).

Interestingly, unlike other growth attribute, root length exhibited a different trend under irrigation regimes. The longest root was produced under irrigation regime M_4, where crops were irrigated at 80% of ASMD while the shortest was found under frequently irrigated crops, *i.e.*, M_1 (20% of ASMD). Gopal et al. (2015) reported that longer root length was obtained where the least amount of irrigation was applied. French bean plants shift resources from seed production to root growth, sacrificing yield for enhanced water uptake under moisture stress condition indicates a compelling ground for higher root growth as stated by Webber et al. (2006).

Among sub-plot treatments, Zorin bean registered significantly highest value for all growth parameters. The significant variation in growth parameters among varieties might be attributed to the differences in genetic makeup of the propagating material and the native environmental condition. These findings are in line with the findings of various scientific teams in French bean (El-Noemani et al., 2010) and in soybean (Khichi et al., 2017).

Table 3. Effect of different irrigation regime on plant growth parameter

Treatments	Growth parameter			
Main plot (Levels of irrigation = 04)	Plant height (cm)	Leaf area index	Dry matter accumulation (g plant^{-1})	Root length (cm)
M_1 – 20% of ASMD	73.43	3.02	30.19	19.93
M_2 – 40% of ASMD	69.92	2.66	26.42	20.95
M_3 – 60% of ASMD	63.03	2.21	19.37	23.67
M_4 – 80% of ASMD	59.62	1.97	16.49	24.82
S.E. (m) ±	1.81	0.13	1.10	0.82
C.D. (P=0.05)	6.28	0.44	3.80	2.85
Sub-plot (No. of varieties = 03)				
V_1 – Arka Arjun	50.30	1.86	21.08	19.56
V_2 – Arka Sharath	52.74	2.24	22.38	21.43
V_3 – Zorin bean	96.47	3.29	25.89	26.04
S.E. (m) ±	1.79	0.10	0.92	0.77
C.D. (P=0.05)	5.37	0.30	2.75	2.31

Economic (seed) yield, biological yield and harvest index

Seed yield, biological yield and harvest index as influenced by different irrigation regime and varietal treatment have been presented in Table 4. The highest seed yield, biological yield and harvest index were reported under irrigation regime M_1 where crop was provided frequent irrigation. However, results obtained that M_2 (40% of ASMD) was statistically at par with M_1. Irrigation at 20% ASMD (M_1) resulted in the highest yield due to minimal water stress and consistent soil moisture availability throughout the growing season. This allowed for optimal stomatal function, enabling plants to meet evapotranspiration demands and maintain photosynthesis rates. Comparable results were obtained by various reports (Abdel-Mawgoud, 2006; Patel et al., 2010; Gopal et al., 2015; Gupta et al., 2017; Lado et al., 2017; Singh et al., 2018; Uddin et al., 2022). In contrast, larger irrigation intervals in other treatments, *viz*., M_3 and M_4

may have caused water stress, leading to stomatal closure, reduced photosynthesis, and lower yields as explained by Lado et al. (2017).

Similarly higher harvest index was reported under M_1 where crop was irrigated at 20% of ASMD. Identical findings were reported by Rani and Sudhakar (2018) and Uddin et al. (2022). This might be attributed to sufficient soil moisture availability under M_1 which found to be crucial for optimal dry matter partitioning, leading to higher harvest index. Harvest index decreases under lower irrigation regime, *i.e.,* M_3 and M_4 with decrease in depth of irrigation. It might be due to greater reduction in seed yield as compared to vegetative biomass which led to lower harvest index. Similar result was reported by Ghosh et al. (2010). Among varieties, Zorin bean registered higher seed yield, biological yield and harvest index. This could be due to the genotypic variability regarding efficacy in partitioning of dry matter as reported by Mustafa et al. (2008).

An average irrigation depth of 230 mm at M_2 (40% of ASMD) experienced a marginal yield reduction (978 kg ha^{-1}) but it was at par with the highest yield (1024 kg ha^{-1}) obtained at 20% of ASMD, *i.e.*, M_1 with application of 344 mm of irrigation depth. Thus, M_2 exhibited higher water productivity over M_1 due to lower water usage while maintaining comparable yields. Therefore, it may be noted that under water scarce situations, providing irrigation at 40% of available soil moisture depletion (M_2) can produce yields equivalent to those achieved under M_1 (20% of ASMD), with a significant of 114 mm of water saving, leading to higher water productivity over $M_{1.}$ The substantial reduction in seed yield under M_4 is due to increase in water stress. The result obtained by Abuarab et al. (2020) revealed the drastic yield reduction in green bean is proportionally higher with increase in water deficit.

Table 4. Effect of irrigation regimes on economic yield, biological yield and harvest index of French bean varieties

Treatments			
Main plot (Levels of irrigation = 04)	Economic yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest Index (%)
M_1 – 20% of ASMD	1024.33	3004.82	34.21
M_2– 40% of ASMD	978.23	2968.18	33.29
M_3 – 60% of ASMD	717.23	2438.38	29.02
M_4 – 80% of ASMD	638.48	2379.21	26.53
S.E. (m) ±	58.65	155.32	1.41
C.D. (P=0.05)	202.94	537.42	4.87
Sub-plot (No. of varieties = 03)			
V_1 – Arka Arjun	641.00	2380.83	27.00
V_2 – Arka Sharath	773.67	2756.07	27.89
V_3 – Zorin bean	1104.04	2956.05	37.40
S.E. (m) ±	53.94	171.09	1.49
C.D. (P=0.05)	161.69	512.88	4.46

Economics of French bean production

Economic attributes *viz*., gross return, net return and BCR were significantly influenced by different irrigation regimes and french bean varieties as shown in Table 5. The cost of cultivation under different irrigation regime followed the decreasing trend *viz*., $M_1 > M_2 > M_3 > M_4$. The difference in cost of cultivation was due to increase in variable cost as a greater number of irrigations were applied under M_1 (23 times) over M_2 (8 times), M_3 (4 times) and M_4 (2 times). Among irrigation regimes, highest gross return was registered under M_1, where crops were irrigated with maximum frequency and depth of irrigation water but M_2 was statistically at par with it. However, highest net returns and BCR was obtained under M_2 which was statistically at par with M_1. It may be observed that higher values of economic attributes were registered under irrigation regimes those received more number and depth of irrigation. Although higher input costs were incurred under M_1 and M_2, the resulting increase in yield had a positive impact, leading to higher gross income, net returns, and an improved benefit-cost ratio. Identical findings were supported by various reports (Mustafa et al., 2008; Dwivedi et al., 2013; Tyagi et al., 2013; Gupta et al., 2017; Sadaf and Tahir, 2017; Marak et al., 2020). However, findings of Singh et al. (2018) which states that higher net returns and BCR were obtained under M_2 than M_1 due to higher water productivity at M_2 that aligned with present findings. Among sub-plot treatment significantly highest gross return, net return and BCR was registered for variety V_3 -Zorin bean.

Table 5. Effect of irrigation regimes on economics of french bean production

Treatments	Economic analysis			
Main plot (Levels of irrigation = 04)	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	BCR
M_1 – 20% of ASMD	83,468	1,53,649	70,181	1.84
M_2– 40% of ASMD	75,711	1,46,734	71,023	1.94
M_3 – 60% of ASMD	72,268	1,07,585	35,317	1.49
M_4 – 80% of ASMD	70,648	95,772	25,124	1.33
S.E. (m) ±	-	8077	8798	0.10
C.D. (P=0.05)	-	27946	30441	0.35
Sub-plot (No. of varieties = 03)				
V_1 – Arka Arjun	75,524	96,150	20,626	1.25
V_2 – Arka Sharath	75,524	1,16,050	40,526	1.52
V_3 – Zorin bean	75,524	1,65,606	90,082	2.18
S.E. (m) ±	-	5462	8091	0.07
C.D. (P=0.05)	-	16372	24253	0.21

CONCLUSION

The seed yield of french bean varieties was highest under irrigation regime M_1 (1,024 kg ha^{-1}) where crops were irrigated very frequently. Similarly, among sub plot treatments, traditionally grown variety of Mizoram known as 'Zorin bean' exhibited superior performance in all the growth behavior and yield attribute over high yielding improved variety Arka Sharath and Arka Arjun. The result also revealed a marginal reduction in seed yield under M_2 (978 kg ha^{-1}) but it was statistically at par with maximum yield obtained under M_1 (1024 kg ha^{-1}). Hence, irrigating french bean with an irrigation depth of 230 mm water at 40% of ASMD saves a significant depth of irrigation water, *i.e*., 110 mm than M_1 (20% of ASMD) and consequently, cost of cultivation decreased with increasing net return and benefit cost ratio at 40% of ASMD. The results of the field experiment revealed that zorin bean variety of french bean was performing better over others, hence it may be taken up during non-rainy season by the farmers of NER. Deficit irrigation can be performed for french bean and with eight number of irrigations at an irrigation interval of two weeks can help in enhancing water productivity.

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