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INFLUENCE OF IRRIGATION REGIMES AND FERTIGATION SCHEDULES ON GROWTH, YIELD AND QUALITY OF POLE BEAN (*PHASEOLUS VULGARIS* L.)

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ABSTRACT

The present study was conducted to evaluate the influence of different irrigation regimes and fertigation levels on growth, yield and quality of pole bean (*Phaseolus vulgaris* L.). The experiment was carried out at the Department of Vegetable Science, College of Horticulture, Bagalkot, during 2024-2025 in a factorial randomized complete block design with two replications. Irrigation was scheduled through drip at 60, 80 and 100% ETc. Fertigation treatments consisted of 75% RDF through fertigation, 100% RDF through fertigation, 75% N and 100% K through fertigation with 100% P as soil application, 100% N and K through fertigation with 100% P as soil application, 100% N through fertigation with 100% P and K as soil application and 100% RDF through soil application. Results revealed that application of 100% RDF through fertigation combined with irrigation at 80% ETc recorded superior growth, yield and quality of pole bean. This treatment resulted in maximum plant height (284.80 cm), number of branches (12.14) at final harvest, higher dry biomass of roots, shoots, leaves and pods, leaf area index(2.25) and chlorophyll content (62.04 SCMR), along with improved yield attributes such as no. of pods per cluster (10.55), pod length (16.75 cm), pod girth (2.78 mm), pod weight (14.60 g), pod yield (217.83 kg/plant) and pod yield(32.67 t/ha). It also enhanced protein and fibre content, increased nutrient content of plant, uptake(180.77, 47.50 and 73.67 kg/ha of N, P and K) and produced the highest gross and net returns with maximum benefit-cost ratio (2.55). Application of 100% RDF through soil combined with 60% ETc showed early 50% flowering, first and final harvest. Although, higher water use efficiency (300.21 kg/ha/mm) was observed at 60% ETc, overall performance in terms of productivity, quality and profitability was best at 80% ETc, indicating its suitability for pole bean cultivation under Northern dry zone conditions of Karnataka.

Key words : Pole bean, Fertigation, Irrigation regimes, ETc (crop evapotranspiration).

Introduction

French bean (*Phaseolus vulgaris* L.) is an important leguminous vegetable crop belonging to the family Fabaceae with a diploid chromosome number of $2n = 22$. It is widely cultivated in India and is known by various common names such as snap bean, kidney bean, rajma bean and string bean. The crop originated in Southern Mexico and Central America with Peru Ecuador and Bolivia recognized as secondary centres of origin. It is

believed to have evolved from the wild species *Phaseolus aborigineus* and was domesticated about 7000 to 8000 years ago. French bean was introduced to Europe during the 16th and 17th centuries and later brought to India in the 17th century. In India it is mainly cultivated as a tender vegetable while in several developed countries it is grown on a large scale for processing purposes.

French bean is a nutrient rich crop consumed mainly as tender green pods and dried seeds and is often referred

to as the meat of the poor. It is a good source of protein, carbohydrates, vitamins and minerals with 100 g of pods providing approximately 1.7g protein, 4.5 g carbohydrates, 11 mg vitamin C, 221 IU vitamin A and 50 mg calcium (Sardana *et al.*, 2000). In addition to its nutritional importance the crop also possesses therapeutic properties and is reported to be beneficial in the management of diabetes cardiovascular disorders and digestive problems. Pole type French bean is an indeterminate and long duration crop with a well-developed tap root system and vigorous vegetative growth which places a high demand on continuous and balanced nutrient supply throughout the crop growth period. Adequate availability of nitrogen phosphorus and potassium is essential for sustaining vegetative growth flowering pod development and seed filling.

Conventional fertilizer application methods often result in poor nutrient use efficiency due to losses through leaching volatilization and fixation especially under irrigated conditions. Fertigation which involves the application of water soluble fertilizers through drip irrigation offers an efficient alternative by ensuring precise placement timely supply and uniform distribution of nutrients in the active root zone. This approach improves nutrient availability uptake and utilization while reducing nutrient losses and input costs. Several studies have demonstrated that fertigation enhances growth yield quality and nutrient uptake in vegetable crops compared to soil application of fertilizers.

Water availability plays a critical role in nutrient absorption and translocation within the plant. Irrigation scheduling based on crop evapotranspiration helps in maintaining optimum soil moisture conditions and facilitates efficient nutrient uptake. Drip irrigation combined with fertigation ensures synchronized supply of water and nutrients which is particularly important for pole bean due to its indeterminate growth habit and prolonged nutrient requirement. However information on suitable irrigation regimes and fertigation levels for pole bean under Northern dry zone conditions of Karnataka is limited. Therefore, the present study was undertaken to evaluate different irrigation regimes and fertigation levels with the objectives of optimizing water requirement standardizing fertigation schedules and assessing their influence on nutrient uptake growth yield quality and economics of pole bean cultivation.

Materials and Methods

The present investigation was conducted during the *Kharif* season of 2024-25 at the Department of Vegetable Science, College of Horticulture, University of

Horticultural Sciences, Bagalkot, Karnataka, India, located in the Northern Dry Zone of Karnataka. The experiment was laid out in a factorial randomized complete block design with eighteen treatment combinations comprising six fertigation levels and three drip irrigation regimes, replicated twice. Fertigation treatments consisted of different combinations of recommended doses of nitrogen, phosphorus and potassium applied either through fertigation or soil application, while irrigation was scheduled through drip at 60, 80 and 100% ETc. The pole bean hybrid 'MONACO' was used as the test crop and grown at a spacing of 75 cm × 45 cm under polyethylene mulch with staking support.

Observations were recorded from five randomly selected plants per treatment and replication on growth parameters such as plant height(cm), number of branches at 50, 100 and after final harvest, fresh and dry biomass (g), leaf area index and chlorophyll content(SCMR), flowering traits such as early 50% flowering, first and final harvest, yield attributes such as no. of pods per cluster, no. of pod clusters per plant, pod weight(g), pod length(cm), pod girth(mm) pod yield(kg/plant) and pod yield(t/ha). Quality parameters including crude protein, crude fibre and physiological loss in weight(%) were estimated using standard analytical procedures. Plant samples 100 DAS were analyzed for nitrogen, phosphorus and potassium(%) content and uptake(kg/ha), while soil samples collected before and after the experiment were analyzed for pH, EC, organic carbon and available nutrients N, P and K(kg/ha). Water use efficiency (kg/ha/mm) and economics were also computed. The experimental data were subjected to statistical analysis following the procedures described by Sundararaj *et al.* (1972) appropriate for a factorial randomized complete block design to assess the significance of treatment effects.

Results and Discussion

Growth parameters

Growth parameters were significantly influenced by fertigation and irrigation regimes (Tables 1-2). Drip fertigation recorded higher plant height, number of branches, biomass, leaf area index and chlorophyll content compared to conventional soil application. The response was highest with 100% RDF through fertigation combined with irrigation at 80% ETc while 100% RDF through soil and irrigation at 60% ETc resulted in inferior growth indicating the importance of adequate water and nutrient supply.

Plant height at 50, 100 DAS and at final harvest was highest under 100% RDF through fertigation with 80%

Table 1 : Plant height and No. of branches at various growth stages of pole bean as influenced by different irrigation regimes and fertigation levels.

Treatments	50 DAS	100 DAS	AFH	50 DAS	100 DAS	AFH
Factor-1	Fertigation (F)					
F1	136.26	258.50	274.79	7.88	10.62	11.46
F2	144.43	269.69	281.12	8.52	11.02	11.89
F3	127.77	251.01	266.58	7.50	10.22	11.35
F4	133.28	253.42	272.55	7.59	10.39	11.39
F5	124.70	249.98	265.50	7.29	10.16	11.27
F6	118.39	242.71	263.29	7.04	9.76	11.08
S.Em±	1.23	2.10	1.36	0.05	0.05	0.04
CD at 5%	3.68	6.24	4.06	0.15	0.15	0.11
Factor-2	Irrigation regimes (I)					
I1	123.30	243.64	264.05	7.27	10.11	10.95
I2	136.80	260.83	275.64	7.90	10.58	11.72
I3	132.31	258.18	273.23	7.74	10.39	11.56
S.Em±	0.87	1.48	0.96	0.04	0.04	0.03
CD at 5%	2.75	4.68	3.04	0.12	0.11	0.09
	Interaction (FI)					
FI11	128.55	250.00	274.38	7.39	10.38	11.05
FI12	140.69	261.25	278.95	8.16	10.85	11.75
FI13	139.55	264.24	277.05	8.09	10.62	11.58
F2I1	140.33	266.25	274.40	7.58	10.57	11.65
F2I2	147.98	275.70	284.80	9.13	11.45	12.14
F2I3	144.98	267.13	281.15	8.85	11.06	11.90
F3I1	117.58	241.42	256.65	7.23	10.00	10.90
F3I2	137.34	254.25	272.65	7.74	10.47	11.61
F3I3	128.39	257.35	270.45	7.53	10.20	11.56
F4I1	121.25	245.38	268.78	7.21	10.24	10.84
F4I2	140.62	260.13	275.48	7.80	10.48	11.71
F4I3	137.97	254.75	273.40	7.77	10.46	11.64
F5I1	118.43	239.45	254.36	7.28	9.90	10.79
F5I2	132.17	257.35	271.70	7.32	10.45	11.53
F5I3	123.50	253.13	270.43	7.28	10.12	11.49
F6I1	113.68	219.38	252.73	6.91	9.56	10.46
F6I2	122.04	256.28	270.26	7.29	9.81	11.57
F6I3	119.46	252.48	266.88	6.93	9.91	11.20
S.Em±	2.13	3.64	2.36	0.09	0.09	0.07
CD at 5%	6.37	10.85	7.04	0.27	0.27	0.20

Treatment details: DAS: Days after sowing; AFH: At final harvest

F1- 75% RDF through fertigation; **F2-** 100% RDF through fertigation; **F3-** 75% N and 100% K through Fertigation + 100% P soil application; **F4-** 100% N and K through Fertigation + 100% P soil application; **F5-** 100% N through Fertigation + 100% P and K soil application; **F6-** 100% RDF through soil

I₁: Drip irrigation at 60% of ET; **I₂**: Drip irrigation at 80% of ET; **I₃**: Drip irrigation at 100% of ET.

ETc irrigation reaching 147.98, 275.70 and 284.80 cm, respectively. The number of branches per plant was 9.13 at 50, 11.45 at 100 DAS and 12.14 at final harvest. Fresh weight of roots, shoots, leaves and pods at 100 DAS was 63.54, 77.95, 776.90 and 98.11 g while corresponding dry weights were 14.28, 16.23, 134.66 and 18.53 g. Leaf area index was 2.25 and chlorophyll content was 62.04 SCMR at 100 DAS. Growth under 100% ETc was comparable to 80% ETc whereas 60% ETc resulted in reduced growth possibly due to moisture stress and limited nutrient uptake.

Superior growth under fertigation with optimal irrigation was attributed to continuous and uniform availability of N, P and K in the root zone which enhanced nutrient uptake chlorophyll synthesis photosynthetic activity and dry matter accumulation. Soil application showed lower growth due to uneven nutrient availability and reduced nutrient use efficiency. These findings are in agreement with earlier reports in cucumber and other vegetable crops, which demonstrated that drip fertigation maintains favorable soil moisture and nutrient status thereby improving vegetative growth and physiological performance (Shukla *et al.*, 2020; Pawar *et al.*, 2018; Chand, 2014 Rahil and Qanadillo, 2015; Venkatesh *et al.*, 2022; Sahana *et al.*, 2018; Ramesh *et al.*, 2021; Rajalingam *et al.*, 2022; Ruban *et al.*, 2023; Balachandrakumar *et al.*, 2024; Jaysawal and Sureshkumar, 2023).

Flowering parameters

Days to 50% flowering, first harvest and final harvest were significantly influenced by fertigation levels and irrigation regimes and followed a similar trend (Table 3). Application of 100% RDF through soil resulted in earlier flowering and harvest compared to fertigation. Lower and less uniform nutrient availability under soil application imposed mild nutritional stress which restricted excessive vegetative growth and promoted early diversion of assimilates towards reproductive development leading to early flowering and crop maturity. Similar observations were reported by Shailaja *et al.* (2024) in marigold Kumar *et al.* (2025) in strawberry and by Doorenbos and Kassam (1979) and Jones *et al.* (2000) in pepper.

Irrigation regimes also had a marked influence on flowering behaviour. Crops irrigated at 100 and 80% ETc required more days to attain flowering and subsequent harvests due to enhanced vegetative growth supported by higher soil moisture. In contrast irrigation at 60% ETc imposed moderate moisture stress which limited vegetative growth altered assimilate partitioning and promoted earlier reproductive development resulting in

Table 2 : Dry weight of plants (gm) at 100 DAS, leaf area index and chlorophyll of pole bean as influenced by different irrigation regimes and fertigation levels.

Treatments	Roots	Shoots	Leaves	Pods	Leaf Area Index	Chlorophyll content (SCMR)
Factor I	Fertigation (F)					
F1	13.10	14.44	128.99	15.94	1.96	57.71
F2	13.64	15.65	131.65	17.21	2.11	60.25
F3	11.78	12.88	122.44	13.83	1.62	52.70
F4	12.32	13.67	126.21	14.58	1.66	55.09
F5	10.67	12.05	118.53	12.79	1.51	46.60
F6	9.39	11.18	114.12	12.27	1.43	41.91
S.Em±	0.09	0.11	0.43	0.10	0.03	0.23
CD at 5%	0.26	0.32	1.29	0.31	0.09	0.70
Factor II	Irrigation regimes (I)					
I1	11.22	12.50	119.10	13.12	1.60	50.69
I2	12.42	13.92	126.94	15.34	1.80	54.05
I3	11.80	13.51	124.92	14.86	1.74	52.43
S.Em±	0.06	0.08	0.31	0.07	0.02	0.17
CD at 5%	0.20	0.24	0.97	0.23	0.07	0.52
	Interaction (FI)					
FI1	12.35	13.16	124.84	14.60	1.72	55.96
FI2	13.67	15.21	131.80	16.80	2.14	59.53
FI3	13.30	14.94	130.33	16.43	2.03	57.66
F2I1	12.78	15.01	127.63	15.04	1.88	58.06
F2I2	14.28	16.23	134.66	18.53	2.25	62.04
F2I3	13.85	15.71	132.67	18.05	2.20	60.90
F3I1	11.08	11.74	116.95	13.06	1.57	51.16
F3I2	12.32	13.63	126.56	14.43	1.67	54.46
F3I3	11.94	13.29	123.80	14.02	1.63	52.49
F4I1	11.63	12.72	119.91	12.76	1.62	53.74
F4I2	13.03	14.45	130.15	15.78	1.70	56.90
F4I3	12.29	13.85	128.57	15.22	1.67	54.65
F5I1	10.37	11.39	113.63	11.88	1.47	44.10
F5I2	11.40	12.71	121.87	13.49	1.54	49.02
F5I3	10.26	12.06	120.09	13.01	1.51	46.70
F6I1	9.14	11.00	111.65	11.38	1.37	41.16
F6I2	9.83	11.33	116.63	13.00	1.51	42.39
F6I3	9.19	11.22	114.08	12.45	1.42	42.18
S.Em±	0.15	0.18	0.75	0.18	0.05	0.41
CD at 5%	0.46	0.55	2.24	0.54	0.16	1.21

early flowering and harvest. Similar responses under reduced irrigation levels were reported by Sharma *et al.* (2011) in tomato and Sikarwar and Hardaha (2016) in cucumber.

The interaction of 100 percent RDF through soil with 60% ETc recorded the minimum days to 50% flowering,

first harvest and final harvest at 37.95, 45.94 and 103.97 days, respectively. This response was attributed to gradual nutrient availability combined with mild moisture stress which favoured early floral initiation efficient assimilate partitioning and timely fruit development. Similar findings were reported by Chartzoulakis and Drosos (1997) in pepper.

Yield parameters

Yield was significantly influenced by fertigation and irrigation regimes reflecting the combined effects of nutrient supply water availability and environmental conditions on carbohydrate synthesis, translocation and pod development (Table 4). The experimental results showed marked differences among treatments indicating that both fertilizer dose and irrigation level played a decisive role in determining yield performance in pole bean.

Maximum yield attributes were recorded with 100% RDF through fertigation combined with irrigation at 80% ETc, which resulted in higher number of pods per cluster (10.55) and pod clusters per plant (12.75) along with increased pod length (16.75 cm), pod girth (2.78 cm), pod weight (14.60 g), pod yield per plant (217.83 g) and pod yield per hectare (32.67 t), respectively. Optimum moisture at 80% ETc maintained favourable soil aeration and minimized nutrient leaching thereby supporting efficient photosynthesis flowering and fruit set. Similar improvements in yield under fertigation with optimum irrigation have been reported by Sinha *et al.* (2017) in sunflower, Goramnagar *et al.* (2017) in acid lime, Pawar *et al.* (2018) and Shukla *et al.* (2020) in cucumber.

Higher yield under fertigation was attributed to improved nutrient availability particularly nitrogen and potassium which enhanced photosynthetic activity assimilate translocation and dry matter accumulation in pods. Balanced fertigation ensured efficient conversion of vegetative growth into reproductive structures by improving physiological efficiency and reducing pod drop. The integration of fertigation with regulated irrigation thus improved water and nutrient use efficiency resulting in higher pod yield and better economic returns in pole bean cultivation.

Table 3 : Days taken for 50% flowering, first harvest and final harvest of pole bean as influenced by different irrigation regimes and fertigation levels.

Treatments	50% flowering	First harvest	Final harvest
Factor -1	Fertigation (F)		
F1	44.09	53.04	112.47
F2	45.19	54.28	113.69
F3	42.66	50.34	110.02
F4	43.04	51.04	111.47
F5	41.73	49.24	107.81
F6	39.58	47.94	105.85
S.Em±	0.33	0.30	0.52
CD at 5%	0.99	0.91	1.55
Factor-2	Irrigation regimes (I)		
I1	40.44	49.18	106.73
I2	42.91	50.74	110.37
I3	44.79	53.02	113.55
S.Em±	0.24	0.22	0.37
CD at 5%	0.74	0.68	1.16
	Interaction (FI)		
F1I1	42.05	50.76	108.45
F1I2	44.19	53.18	113.20
F1I3	46.05	55.18	115.77
F2I1	43.07	52.36	109.52
F2I2	45.11	54.48	114.49
F2I3	47.39	56.00	117.08
F3I1	39.72	48.45	104.82
F3I2	43.94	48.72	111.89
F3I3	44.33	53.86	113.35
F4I1	40.49	49.37	107.67
F4I2	44.08	51.23	112.00
F4I3	44.55	52.54	114.73
F5I1	39.37	48.22	105.96
F5I2	42.14	49.63	106.37
F5I3	43.70	49.87	111.10
F6I1	37.95	45.94	103.97
F6I2	38.02	47.20	104.31
F6I3	42.76	50.68	109.27
S.Em±	0.58	0.53	0.90
CD at 5%	1.72	1.57	2.69

Quality parameters

Quality attributes such as crude protein and crude fiber content in pods were significantly influenced by fertigation and irrigation regimes (Table 5). Application of 100% RDF through fertigation combined with irrigation at 80% ETc recorded the highest protein and fiber content of 23.93 and 4.68% at 100 DAS, respectively. Improved

quality under this treatment was attributed to enhanced vegetative growth and efficient nutrient uptake which promoted carbohydrate metabolism and greater accumulation of structural and storage compounds. A positive association between protein and fiber content was evident indicating the role of balanced nutrition in improving pod quality. Similar improvements in quality attributes under fertigation have been reported by Ayub *et al.* (2012) in cluster bean, Saleh *et al.* (2018), Udayakumar *et al.* (2019) in capsicum and Gul *et al.* (2006) in pea.

Postharvest quality parameters were also markedly affected by irrigation and nutrient management. The lowest physiological loss in weight of 23.71% and longer shelf life were recorded under 100% RDF through fertigation with 80% ETc irrigation. Uniform and continuous nutrient supply under fertigation improved tissue firmness and moisture retention while optimum irrigation maintained adequate plant water status without inducing stress. In contrast soil fertilization and irrigation at 60% ETc resulted in higher moisture loss due to poor tissue structure and water deficit stress. Thus combined application of fertigation and optimum irrigation was most effective in improving pod quality and shelf life.

Nutrient analysis of plant

The application of different fertigation levels in combination with irrigation regimes significantly influenced nitrogen, phosphorus and potassium content in pole bean plants at 100 DAS (Table 6). The treatment with 100% RDF through fertigation combined with irrigation at 80% ETc recorded the highest nitrogen content in roots, shoots, leaves and pods of 0.67, 0.85, 1.37 and 4.10%, respectively. The same treatment also registered maximum phosphorus content of 0.37, 0.46, 0.58 and 0.70% and potassium content of 0.54, 0.56, 0.78 and 1.28% in roots, shoots, leaves and pods respectively. Higher nutrient content was attributed to enhanced nutrient mobility root activity and uptake efficiency under adequate fertilizer supply and optimum soil moisture.

Comparison among fertigation levels showed that nutrient accumulation increased with higher and more frequent fertigation. Continuous and balanced nutrient supply directly to the root zone under fertigation improved absorption efficiency and reduced nutrient losses through leaching especially under regulated irrigation at 80% ETc. Maintenance of optimum soil moisture further created favourable conditions for nutrient uptake and translocation within the plant. Similar improvements in nutrient content under fertigation and drip irrigation have been reported by Singh *et al.* (2016) in cluster bean, Dhinesh and Santhi

Table 4 : Yield and its attributes in pole bean at regular harvests as influenced by fertigation levels and irrigation regimes.

Treatments	No. of pods per cluster	No. of clusters per plant	Pod length (cm)	Pod girth (mm)	Pod weight (g)	Pod yield per plant (g)	Pod yield per ha (t)
Factor I	Fertigation (F)						
F1	9.47	10.18	14.94	2.47	12.99	206.55	30.98
F2	10.13	11.52	16.01	2.62	14.10	212.11	31.82
F3	7.68	8.46	12.86	2.03	12.16	185.76	27.86
F4	8.80	9.60	13.74	2.24	12.73	197.30	29.60
F5	6.82	7.35	12.39	1.50	11.97	170.22	25.53
F6	5.79	6.86	11.27	1.39	11.38	161.95	24.29
S.Em±	0.20	0.16	0.14	0.03	0.08	1.28	0.19
CD at 5%	0.59	0.48	0.42	0.10	0.23	3.83	0.57
Factor II	Irrigation regimes (I)						
I1	7.21	7.88	12.29	1.88	11.86	180.91	27.14
I2	8.95	10.04	14.62	2.23	13.13	196.27	29.45
I3	8.19	9.08	13.69	2.01	12.66	189.77	28.47
S.Em±	0.14	0.11	0.10	0.02	0.06	0.91	0.14
CD at 5%	0.44	0.36	0.32	0.07	0.17	2.86	0.43
	Interaction (FI)						
F1I1	9.01	8.77	13.35	2.34	12.30	196.96	29.54
F1I2	10.00	11.38	15.90	2.60	13.64	213.20	31.98
F1I3	9.40	10.41	15.57	2.49	13.04	209.51	31.43
F2I1	9.80	9.76	15.18	2.47	13.50	204.96	30.74
F2I2	10.55	12.75	16.75	2.78	14.60	217.83	32.67
F2I3	10.05	12.06	16.11	2.62	14.20	213.56	32.03
F3I1	6.53	7.79	11.12	1.72	11.65	182.18	27.33
F3I2	9.15	8.79	14.31	2.41	12.67	191.66	28.75
F3I3	7.35	8.81	13.15	1.95	12.17	183.44	27.52
F4I1	7.25	8.53	12.19	2.08	12.12	183.72	27.56
F4I2	9.75	11.09	15.33	2.46	13.05	206.43	30.96
F4I3	9.39	9.20	13.71	2.19	13.01	201.76	30.26
F5I1	5.50	6.38	11.53	1.35	11.18	163.90	24.59
F5I2	8.00	8.23	13.15	1.67	12.83	180.45	27.07
F5I3	6.95	7.45	12.50	1.48	11.90	166.33	24.95
F6I1	5.16	6.05	10.41	1.31	10.44	153.78	23.07
F6I2	6.22	8.00	12.30	1.50	12.03	168.05	25.21
F6I3	5.98	6.53	11.10	1.37	11.67	164.03	24.60
S.Em±	0.34	0.28	0.25	0.06	0.13	2.22	0.33
CD at 5%	1.02	0.83	0.73	0.17	0.40	6.64	1.00

(2016) in brinjal, Enigi *et al.* (2013), Neogi and Das (2022) and Lakshmi *et al.* (2012) in potato.

Soil nutrient status

The available nitrogen, phosphorus and potassium content in soil after harvest was significantly influenced by fertigation and irrigation regimes (Table 7). The lowest residual soil N, P and K of 222.65, 21.49 and 236.37 kg/ha respectively, were recorded under 100% RDF through

fertigation with irrigation at 100% ETc. This reduction was attributed to enhanced nutrient uptake by the crop and greater leaching losses under higher moisture availability. Fertigation supplies nutrients in readily available forms directly to the active root zone which improves nutrient use efficiency and supports continuous absorption particularly under adequate soil moisture. In contrast soil application of 100% RDF resulted in higher

Table 5 : Quality attributes in pole bean at regular harvests as influenced by fertigation levels and irrigation regimes.

Treatments	Crude protein (%)	Crude fibre (%)	Physiological loss of weight (%)
Factor-1	Fertigation (F)		
F1	20.83	4.48	26.38
F2	22.09	4.60	25.13
F3	19.60	4.34	30.75
F4	20.34	4.40	30.03
F5	18.11	4.32	32.78
F6	17.55	4.20	34.61
S.Em±	0.19	0.09	0.19
CD at 5%	0.56	NS	0.57
Factor-2	Irrigation regimes (I)		
I1	18.57	4.32	31.39
I2	20.95	4.43	28.63
I3	19.74	4.42	29.82
S.Em±	0.13	0.06	0.13
CD at 5%	0.42	NS	0.42
	Interaction (FI)		
FI1	19.35	4.48	27.48
FI2	22.10	4.42	25.53
FI3	21.04	4.54	26.12
F2I1	20.00	4.49	26.81
F2I2	23.93	4.68	23.71
F2I3	22.35	4.61	24.88
F3I1	18.83	4.24	32.80
F3I2	20.65	4.42	28.88
F3I3	19.33	4.36	30.57
F4I1	19.12	4.31	31.76
F4I2	21.22	4.45	28.03
F4I3	20.70	4.45	30.30
F5I1	17.57	4.24	34.42
F5I2	18.96	4.37	31.47
F5I3	17.80	4.34	32.44
F6I1	16.58	4.15	35.06
F6I2	18.86	4.24	34.16
F6I3	17.21	4.20	34.60
S.Em±	0.32	0.15	0.33
CD at 5%	0.96	NS	0.98

residual nutrients due to slower nutrient release lower uptake efficiency and partial fixation or limited availability reducing total plant removal.

Irrigation at 60% ETc recorded higher residual soil nutrients compared to 80 and 100% ETc due to reduced leaching and limited nutrient uptake under lower soil

moisture. The highest available N, P₂O₅ and K₂O of 246.02, 32.54 and 268.64 kg/ha were observed under 100% RDF applied through soil which was attributed to gradual nutrient release and incomplete uptake resulting in greater nutrient retention after harvest. Soil pH, EC and OC content did not differ significantly among treatments likely due to the buffering capacity of clay loam soil and the short duration of the experiment. Similar trends in postharvest soil nutrient status have been reported by Talali (2005), Beaudoin *et al.* (2005), Kumari *et al.* (2017), Puli *et al.* (2019) and Nabum *et al.* (2024).

Nutrient uptake

The uptake of nitrogen, phosphorus and potassium was significantly affected by irrigation regimes (Table 8) with higher uptake recorded at 80% ETc followed by 100% ETc, while the lowest uptake occurred at 60% ETc. Irrigation at 80% ETc provided optimum soil moisture which improved nutrient solubility, mobility and mass flow towards the roots and supported active root growth resulting in maximum uptake. Although, 100% ETc ensured adequate moisture excessive water likely reduced root zone aeration and increased nutrient losses through leaching particularly nitrogen which slightly limited uptake. In contrast irrigation at 60% ETc induced moisture stress that restricted nutrient movement root activity and physiological processes leading to reduced uptake of N, P and K. Similar trends were reported by Elzopy *et al.* (2017) and Wu *et al.* (2022).

Nutrient uptake was higher under 100% RDF applied through fertigation compared to soil application due to precise and uniform delivery of nutrients in readily available forms to the active root zone. The highest uptake of N, P and K of 180.77, 47.50 and 73.67 kg/ha was observed under 100% RDF through fertigation combined with 80% ETc due to the synergistic effect of optimal water and nutrient supply. Fertigation synchronized nutrient availability with crop demand while adequate moisture at 80% ETc supported efficient transport and absorption. In contrast soil application and sub optimal or excessive irrigation limited nutrient availability or increased losses thereby reducing overall uptake. These findings are in agreement with Jain *et al.* (2021) and Kanwar *et al.* (2024).

Water use efficiency

Efficient irrigation scheduling is crucial under increasing water scarcity and rising energy costs, as higher productivity depends on improved water use efficiency (Table 9). In the present study, water use efficiency was highest at 60% ETc despite slightly lower yield compared to 80 and 100% ETc, mainly due to reduced irrigation

Table 6 : Nitrogen, phosphorous and potassium content of plant (%) at 100 DAS of pole bean as influenced by fertigation levels and irrigation regimes.

Treatments	Roots	Shoots	Leaves	Pods	Roots	Shoots	Leaves	Pods	Roots	Shoots	Leaves	Pods
Factor I Fertigation (F)												
F1	0.64	0.82	1.32	3.83	0.32	0.42	0.53	0.64	0.48	0.50	0.73	1.22
F2	0.65	0.84	1.34	3.99	0.34	0.44	0.56	0.67	0.50	0.53	0.76	1.25
F3	0.59	0.79	1.24	3.50	0.24	0.36	0.50	0.60	0.46	0.45	0.70	1.21
F4	0.63	0.82	1.28	3.68	0.28	0.37	0.51	0.62	0.47	0.48	0.71	1.21
F5	0.57	0.77	1.22	3.36	0.22	0.35	0.46	0.55	0.44	0.44	0.68	1.15
F6	0.52	0.75	1.21	3.18	0.21	0.34	0.45	0.54	0.43	0.43	0.65	1.15
S.Em±	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD at 5%	0.03	0.02	0.02	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
Factor II Irrigation regimes (I)												
I1	0.56	0.77	1.25	3.48	0.25	0.36	0.47	0.57	0.45	0.45	0.66	1.17
I2	0.63	0.82	1.28	3.68	0.28	0.40	0.52	0.62	0.48	0.49	0.73	1.22
I3	0.60	0.80	1.27	3.61	0.27	0.38	0.51	0.61	0.46	0.48	0.71	1.20
S.Em±	0.01	0.01	0.01	0.02	0.01	0.004	0.004	0.00	0.00	0.00	0.01	0.01
CD at 5%	0.02	0.02	0.02	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Interaction (FI)												
F1I1	0.61	0.81	1.29	3.80	0.29	0.40	0.50	0.61	0.47	0.45	0.71	1.20
F1I2	0.66	0.84	1.34	3.86	0.34	0.44	0.55	0.66	0.49	0.53	0.75	1.26
F1I3	0.64	0.82	1.33	3.83	0.33	0.43	0.54	0.65	0.47	0.51	0.74	1.19
F2I1	0.64	0.82	1.31	3.84	0.31	0.42	0.53	0.64	0.46	0.48	0.74	1.20
F2I2	0.67	0.85	1.37	4.10	0.37	0.46	0.58	0.70	0.54	0.56	0.78	1.28
F2I3	0.65	0.84	1.35	4.04	0.35	0.44	0.56	0.68	0.50	0.55	0.76	1.27
F3I1	0.55	0.72	1.23	3.31	0.23	0.35	0.44	0.54	0.45	0.44	0.64	1.14
F3I2	0.62	0.83	1.26	3.62	0.26	0.37	0.53	0.63	0.47	0.47	0.73	1.24
F3I3	0.61	0.82	1.24	3.56	0.24	0.35	0.52	0.63	0.45	0.46	0.73	1.25
F4I1	0.60	0.80	1.25	3.59	0.25	0.32	0.46	0.57	0.46	0.47	0.66	1.19
F4I2	0.65	0.83	1.32	3.75	0.32	0.40	0.54	0.64	0.48	0.49	0.75	1.24
F4I3	0.64	0.82	1.27	3.70	0.27	0.39	0.53	0.64	0.46	0.49	0.71	1.21
F5I1	0.50	0.75	1.23	3.30	0.23	0.33	0.45	0.54	0.44	0.42	0.62	1.15
F5I2	0.60	0.80	1.21	3.43	0.21	0.37	0.48	0.57	0.45	0.46	0.73	1.16
F5I3	0.60	0.76	1.22	3.37	0.22	0.34	0.47	0.55	0.44	0.46	0.71	1.15
F6I1	0.46	0.72	1.20	3.05	0.2	0.32	0.44	0.53	0.42	0.43	0.61	1.14
F6I2	0.59	0.78	1.21	3.34	0.21	0.36	0.46	0.57	0.45	0.45	0.69	1.16
F6I3	0.50	0.76	1.21	3.17	0.21	0.34	0.45	0.54	0.44	0.43	0.64	1.16
S.Em±	0.02	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD at 5%	0.05	0.04	0.04	0.11	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.05

water and its efficient utilization by the crop. The treatment receiving 100% RDF through fertigation combined with irrigation at 60% ETc recorded the maximum WUE of 300.21 kg/ha/mm, as mild moisture stress promoted effective use of soil moisture reduced deep percolation and evaporation losses and encouraged deeper root growth. At higher irrigation levels yield gains were not proportional to the additional water applied resulting in lower WUE. Thus the combination of 100% RDF through

fertigation with 60% ETc was most effective for maximizing WUE, in agreement with the findings of Pippal *et al.* (2025) and Saleh *et al.* (2018).

Economics

Drip fertigation in vegetable crops requires higher initial investment mainly due to the cost of water soluble fertilizers, but its long service, life and yield advantage make it economically viable (Table 10). In the present

Table 7 : Nutrient status of soil after crop harvest of pole bean as influenced by fertigation levels and irrigation regimes.

Treatments	pH	EC (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Factor I	Fertigation (F)					
F1	7.76	0.46	0.56	233.01	24.96	244.20
F2	7.79	0.47	0.57	227.11	23.74	236.78
F3	7.75	0.45	0.55	240.17	27.54	256.71
F4	7.75	0.46	0.55	238.48	26.49	251.67
F5	7.72	0.44	0.54	242.33	28.61	258.88
F6	7.67	0.42	0.53	244.52	30.64	263.84
S.Em±	0.05	0.01	0.01	0.98	0.41	1.97
CD at 5%	NS	NS	NS	2.94	1.21	5.87
Factor II	Irrigation regimes (I)					
I1	7.72	0.44	0.54	240.93	28.41	257.14
I2	7.76	0.45	0.56	237.84	27.25	253.84
I3	7.74	0.45	0.55	234.04	25.34	245.06
S.Em±	0.03	0.01	0.01	0.70	0.29	1.39
CD at 5%	NS	NS	NS	2.19	0.90	4.39
	Interaction (FI)					
F1I1	7.74	0.45	0.56	237.89	27.06	248.70
F1I2	7.77	0.47	0.57	230.70	24.92	241.72
F1I3	7.77	0.46	0.56	230.44	22.92	242.20
F2I1	7.76	0.46	0.55	233.02	24.96	237.30
F2I2	7.81	0.48	0.58	225.67	24.77	236.66
F2I3	7.79	0.47	0.57	222.65	21.49	236.37
F3I1	7.73	0.45	0.54	244.48	28.36	262.49
F3I2	7.76	0.45	0.55	243.88	27.11	260.49
F3I3	7.75	0.45	0.55	232.15	27.15	247.15
F4I1	7.73	0.46	0.54	240.78	26.41	260.49
F4I2	7.77	0.47	0.55	239.21	27.08	259.00
F4I3	7.75	0.47	0.55	235.45	25.99	235.53
F5I1	7.71	0.44	0.53	243.43	31.14	265.25
F5I2	7.73	0.45	0.55	242.73	28.31	257.29
F5I3	7.72	0.45	0.54	240.84	26.40	254.11
F6I1	7.64	0.42	0.52	246.02	32.54	268.64
F6I2	7.71	0.42	0.54	244.84	31.31	267.87
F6I3	7.66	0.42	0.54	242.70	28.08	255.02
S.Em±	0.08	0.02	0.02	1.71	0.70	3.41
CD at 5%	NS	NS	NS	5.09	2.10	10.17

study the treatment receiving 100% RDF through fertigation combined with 80% ETc recorded the highest gross return, net return and benefit cost ratio of Rs. 8,16,843/ha Rs. 4,96,965/ha and 2.55 respectively, owing to higher yield and efficient use of water and nutrients. In contrast the lowest economic returns were observed under 100% RDF through soil with 60% ETc. The

Table 8 : Nutrient uptake (kg/ha) of pole bean as influenced by fertigation levels and irrigation regimes.

Treatments	Nitrogen (kg/ha)	Phosphorous (kg/ha)	Potassium (kg/ha)
Factor -1	Fertigation (F)		
F1	158.00	40.41	64.43
F2	169.97	43.64	68.49
F3	132.66	34.44	57.61
F4	145.09	36.74	60.10
F5	125.65	30.77	53.17
F6	115.56	28.86	49.75
S.Em±	1.45	0.52	0.86
CD at 5%	4.33	1.55	2.56
Factor-2	Irrigation regimes (I)		
I1	129.35	31.70	53.17
I2	149.51	38.61	63.08
I3	144.60	37.12	60.53
S.Em±	1.03	0.37	0.61
CD at 5%	3.24	1.16	1.91
	Interaction (FI)		
F1I1	147.79	36.13	59.34
F1I2	165.07	43.87	69.73
F1I3	161.13	41.22	64.23
F2I1	154.53	38.78	61.51
F2I2	180.77	47.50	73.67
F2I3	174.61	44.63	70.28
F3I1	115.66	27.86	48.88
F3I2	143.57	37.87	61.67
F3I3	138.76	37.60	62.27
F4I1	131.09	31.05	53.30
F4I2	153.85	39.51	64.40
F4I3	150.33	39.67	62.60
F5I1	117.55	28.56	48.38
F5I2	130.66	32.33	56.05
F5I3	128.73	31.41	55.07
F6I1	109.46	27.82	47.58
F6I2	123.16	30.59	52.96
F6I3	114.07	28.18	48.73
S.Em±	2.52	0.90	1.48
CD at 5%	7.51	2.69	4.43

improvement in benefit cost ratio under fertigation indicates enhanced profitability through better resource use, which is in line with the findings of Kakade *et al.* (2019), Vijayakumar *et al.* (2010), Pooja *et al.* (2022) and Biswas *et al.* (2023).

Table 9 : Water use efficiency of pole bean cultivation as influenced by fertigation levels and irrigation regimes.

Treatments	Yield (t/ha)	Water Use Efficiency (kg/ha/mm)
Factor I	Fertigation (F)	
F1	30.98	219.98
F2	31.82	258.03
F3	27.86	212.86
F4	29.60	224.38
F5	25.53	194.82
F6	24.29	184.66
S.Em±	0.19	1.51
CD at 5%	0.57	4.49
Factor II	Irrigation regimes (I)	
I1	27.14	264.99
I2	29.45	207.79
I3	28.47	174.59
S.Em±	0.14	1.06
CD at 5%	0.43	3.35
	Interaction (FI)	
F1I1	29.54	288.48
F1I2	31.98	187.35
F1I3	31.43	184.11
F2I1	30.74	300.21
F2I2	32.67	239.28
F2I3	32.03	234.59
F3I1	27.33	266.83
F3I2	28.75	210.53
F3I3	27.52	161.20
F4I1	27.56	269.09
F4I2	30.96	226.76
F4I3	30.26	177.30
F5I1	24.59	240.06
F5I2	27.07	198.22
F5I3	24.95	146.16
F6I1	23.07	225.23
F6I2	25.21	184.60
F6I3	24.60	144.15
S.Em±	0.33	2.61
CD at 5%	1.00	7.78

Conclusion

In the present study, the treatment comprising 100% RDF through fertigation combined with irrigation at 80% ETc was found most effective in improving growth, yield and quality of pole bean. This treatment recorded higher vegetative growth yield attributes pod yield quality

Table 10 : Economics of pole bean cultivation as influenced by fertigation levels and irrigation regimes.

Treatments	Yield (t/ha)	Cost of production (Rupees)	Gross returns (Rupees)	Net returns (Rupees)	B:C
Factor I	Fertigation (F)				
F1	30.98	315019.28	774568.75	459549.47	2.46
F2	31.82	319878.75	795425.00	475546.25	2.49
F3	27.86	319349.13	696587.50	377238.37	2.18
F4	29.60	318221.70	739875.00	421653.30	2.33
F5	25.53	290721.70	638337.50	347615.80	2.20
F6	24.29	290721.70	607318.75	316597.05	2.09
Factor II	Irrigation regimes (I)				
I1	27.14	308985.38	678428.13	369442.75	2.19
I2	29.45	308985.38	735996.88	427011.50	2.38
I3	28.47	308985.38	711631.25	402645.87	2.30
	Interaction (FI)				
F1I1	29.54	315019.28	738581.25	423561.97	2.34
F1I2	31.98	315019.28	799481.25	484461.97	2.54
F1I3	31.43	315019.28	785643.75	470624.47	2.49
F2I1	30.74	319878.75	768600.00	448721.25	2.40
F2I2	32.67	319878.75	816843.75	496965.00	2.55
F2I3	32.03	319878.75	800831.25	480952.50	2.50
F3I1	27.33	319349.13	683156.25	363807.12	2.14
F3I2	28.75	319349.13	718706.25	399357.12	2.25
F3I3	27.52	319349.13	687900.00	368550.87	2.15
F4I1	27.56	318221.70	688950.00	370728.30	2.17
F4I2	30.96	318221.70	774093.75	455872.05	2.43
F4I3	30.26	318221.70	756581.25	438359.55	2.38
F5I1	24.59	290721.70	614625.00	323903.30	2.11
F5I2	27.07	290721.70	676668.75	385947.05	2.33
F5I3	24.95	290721.70	623718.75	332997.05	2.15
F6I1	23.07	290721.70	576656.25	285934.55	1.98
F6I2	25.21	290721.70	630187.50	339465.80	2.17
F6I3	24.60	290721.70	615112.50	324390.80	2.12

parameters nutrient content and uptake along with reduced physiological loss in weight and lower residual soil N, P and K after harvest. It also resulted in the highest gross return net return and benefit cost ratio. Although water use efficiency was highest at 60% ETc overall crop performance and profitability were superior at 80% ETc. Therefore application of 100% RDF through fertigation with 80% ETc is recommended for pole bean cultivation in the Northern dry zone of Karnataka under limited water availability.

References

Ayub, M., Nadeem M.A., Naeem M., Tahir M., Tariq M. and Ahmad W. (2012). Effect of different levels of P and K on

- growth, forage yield and quality of cluster bean (*Cyamopsis tetragonolobus* L.). *J. Anim. Plant. Sci.*, **22(2)**, 479-483.
- Balachandrakumar, V., Sowmiya K., Shofiya M., Gopika K. and Nithika M. (2024). Impact of nano dap and zn edta on cowpea growth and yield. *Int. J. Plant Soil Sci.*, **36(6)**, 317-326.
- Biswas, A., Prasad V.M. and Topno S.E. (2023). Effect of nano fertilizer on growth, quality and yield of bottle gourd (*Lagenaria siceraria*) var. Sarita under Prayagraj agro climatic conditions. *Int. J. Environ.*, **13(9)**, 2557-2563.
- Chand, A.J. (2014). Nutrient use efficiency and economics of salad cucumber using drip fertigation in naturally ventilated polyhouse. *J. Agric. Vete. Sci.*, **7(12)**, 22-25.
- Chartzoulakis, K. and Drosos N. (1997). Water requirements of greenhouse grown pepper under drip irrigation. *Acta Hort.*, **449(1)**, 175-180.
- Doorenbos, J. and Pruitt W.O. (1977). *Crop Water Requirements. Irrigation and Drainage*, **24**, 144.
- Elzopy, K.A., Biradar M.S., Channal H.T., Manjunath M.V., Palled Y.B., Radder B.M. and Patil P.L. (2017). NPK uptake of tomato as influenced by irrigation regimes and fertigation levels under greenhouse condition. *Asian J. Adv. Agric. Res.*, **3(1)**, 1-10.
- Goramnagar, H.B., Nagre P.K., Bharad S.G. and Paithankar D. (2017). Effect of micro-irrigation and fertigation on growth parameter and fruit yield of acid lime. *Int. J. Chem. Stud.*, **5(6)**, 15-48.
- Gul, N.I., Jilani M.S. and Waseem Kashif (2006). Effect of split application of nitrogen levels on the quality and quality parameters of pea (*Pisum sativum* L.). *Int. J. Agric. Biol.*, **8(2)**, 226-230.
- Jain, N.K., Yadav R.S. and Jat R.A. (2021). Drip fertigation influences yield, nutrient uptake and soil properties of peanut (*Arachis hypogaea*). *The Indian J. Agric. Sci.*, **91(2)**, 258-262.
- Jaysawal, N. and Sureshkumar R. (2023). Effect of nano nitrogen, nano zinc and nano copper on certain growth and yield characters of ridge gourd (*Luffa acutangula* L.) cv. COH 1. *Crop Res.*, **58**, 64-68.
- Jones, T., Bessin R., Strang J., Rowell B. and Spalding D. (2000). *Kentucky pepper integrated crop management*. Cooperative Extension Service, Univ. Kentucky, College of Agric., Kentucky, USA, 38.
- Kakade, S.U., Mohurle L.A., Bhale V.M. and Deshmukh J.P. (2019). Effect of drip fertigation on growth, weed dynamics, yield and economics of pigeon pea. *J. Agric. Res. Technol.*, **44(1)**, 51-57.
- Kanwar, P., Sonkamble A.M. and Meena S. (2024). Nutrient Uptake and Soil Nutrient Status as Influenced by Drip Fertigation Levels and Schedules in Broccoli. *Int. J. Plant & Soil Sci.*, **36(11)**, 173-185.
- Kumar, L., Bisen B.P., Yadav A. and Chouhan A. (2025). Influence of nutrient application on growth and yield of strawberry (*Fragaria × ananassa* Duch.) cv. *Camarosa* in Kymore Plateau. *Int. J. Adv. Biochem. Res.*, **9(4)**, 367-371.
- Kumari, R., Kumar S., Kumar R., Das A., Kumari R., Choudhary C.D. and Sharma R.P. (2017). Effect of long-term integrated nutrient management on crop yield, nutrition and soil fertility under rice-wheat system. *J. Appl. Nat. Sci.*, **9(3)**, 1801.
- Lakshmi, D.V., Padmaja G. and Rao R.C. (2012). Effect of levels of nitrogen and potassium on soil available nutrient status and yield of potato (*Solanum tuberosum* L.). *Indian J. Agric. Res.*, **46(1)**, 36-41.
- Nabum, D., Banwasi R. and Jamir T.I. (2024). Effect of liquid microbial consortium on physio chemical properties of Rice field (*Oryza Sativa*) in a Vertisol. *Arch. Curr. Res. Int.*, **24(10)**, 365-375.
- Neogi, S. and Das S.K. (2022). Effect of nitrogen and zinc in nano forms on growth and productivity of potato (*Solanum tuberosum* L.) in inceptisols. *J. Crop. Weed.*, **18(1)**, 32-38.
- Pawar, D.P., Bhakar S.R., Lakhawat S.S., Kothari M. and Patil V. (2018). Interactive impact of irrigation and fertigation level on growth and yield attributes of cucumber under naturally ventilated polyhouse. *Int. J. Curr. Microbiol. Appl. Sci.*, **7(6)**, 2604-2612.
- Pippal, R., Singh S.K., Kumar H., Singh N.K., Sahu A. and Srivastava M. (2025). Impact of Irrigation Water Requirements and Fertigation Levels on Wheat Growth, Yield and Water Productivity. *J. Exp. Agric. Int.*, **47(8)**, 600-610.
- Pooja, S.S., Bahadur V. and Kerketta A. (2022). Effect of nano fertilizer on growth, yield and quality of broccoli (*Brassica oleracea* var. *italica*). *Int. J. Plant Soil Sci.*, **34(22)**, 328-335.
- Puli, M.R., Prasad P.R.K., Babu P.R., Rao K.L. and Subbaiah G. (2019). Residual Effect of different Sources of Nutrients on Available NPK in Soil after Harvest of Maize in Rice Fallow Maize Cropping System. *Int. J. Plant & Soil Sci.*, **30(2)**, 1-11.
- Rahil, M.H. and Qanadillo A. (2015). Effects of different irrigation regimes on yield and water use efficiency of cucumber crop. *Agric. Water Manag.*, **148**, 10-15.
- Ramesh, G., Maheshwara Babu B. and Patil S.S. (2021). Effect of mulching and fertigation on growth yield and quality of french bean (*Phaseolus vulgaris* L.). *J. Pharm. Innov.*, **10(3)**, 138-144.
- Ruban, J.S., Nandinidevi M., Naik B. and Rajan R. (2023). Effect of nano DAP on growth and yield of vegetable cow pea. *Agrica*, **12(1)**, 70-76.
- Sahana, P., Adivappar N., Srinivasa V., Girijesh G.K. and Ganapathi M. (2018). Effect of nutrients and mulching on growth and yield of pole bean (*Phaseolus vulgaris* L.) Under polyhouse. *J. Farm Sci.*, **31(5)**, 592-594.
- Saleh, S., Liu G., Liu M., Ji Y., He H. and Gruda N. (2018). Effect of irrigation on growth, yield, and chemical composition of two green bean cultivars. *Horticulturae*, **4(1)**, 3.

- Sardana, V., Dhingra K.K., Gille M.S. and Singh I.J. (2000). Production technology of french bean (*Phaseolus Vulgaris* L.) Cultivation: A review. *Agric. Rev.*, **21(3)**, 141-154.
- Shailaja, K., Seenivasan N., Laxminaraya D., Kaladhar Babu K. and Praneeth Kumar S. (2024). Effect of nano NPK on growth, yield and quality of marigold (*Tagetes erecta* L.) cv. BM 4. *Int. J. Res. Agron.*, **7(10S)**, 659–665.
- Sharma, U. (2011). Response of tomato to irrigation and fertilizer management practices. *J. Hill Agric.*, **2(1)**, 122-125.
- Shukla, A., Bhakar S.R., Chippa B.G and Singh M. (2020). Study the effect of different irrigation and fertigation levels on growth and yield parameters of cucumber crop under naturally ventilated polyhouse. *Int. J. Curr. Microbiol. Appl. Sci.*, **9(10)**, 3730-3738.
- Shukla, A., Bhakar S.R., Chippa B.G and Singh M. (2020). Study the effect of different irrigation and fertigation levels on growth and yield parameters of cucumber crop under naturally ventilated polyhouse. *Int. J. Curr. Microbiol. Appl. Sci.*, **9(10)**, 3730-3738.
- Sikarwar, P. and Hardaha M.K. (2016). Effect of fertigation levels on growth, quality and yield of polyhouse cucumber (*Cucumis sativus*). *Int. J. Agric. Sci.*, **8(43)**, 1863–1866.
- Singh, A.P., Lal Munna, Pal A.K. and Singh A.P. (2016). Effect of FYM, potassium and zinc on yield, quality and uptake of nutrients in forage cluster bean in alluvial soil. *Ann. Plant Soil Res.*, **18(3)**, 246-250.
- Sinha, I., Buttar G.S. and Brar A.S. (2017). Drip irrigation and fertigation improve economics, water and energy productivity of spring sunflower (*Helianthus annuus* L.) in Indian Punjab. *Agric. Water Manag.*, **185**, 58-64.
- Sundararaj, N., Nagaraju S.C.S., Venkataramu M.N. and Jaganath M.K. (1972). Design and analysis of field experiment, University of Agricultural Science, Technical Series, Bangalore.
- Udayakumar, R., Anburani A. and Kumar S.R. (2019). Effect of fertigation and foliar application of nutrients on growth, yield and shelf life of capsicum, *Int. J. Curr. Microbiol. Appl. Sci.*, **8(6)**, 1072–1081.
- Venkatesh, C., Kamalakannan S., Haripriya K. and Dhanasekaran K. (2022). Effect of nano zinc and boron on growth and yield of cabbage (*Brassica oleracea* var. *capitata* L.) in Dharmapuri district, Tamil Nadu, India. *Crop Res.*, **57**, 386-390.
- Vijayakumar, G, Tamilmani D. and Selvaraj P.K. (2010). Irrigation and fertigation scheduling under drip irrigation in brinjal (*Solanum melongena* L.) Crop. *Int. J. Bio-res. Stress Manage.*, **1(2)**, 72-76.
- Wu, W., Liu M., Wu X., Wang Z. and Yang H. (2022). Effects of deficit irrigation on nitrogen uptake and soil mineral nitrogen in alfalfa grasslands of the inland arid area of China. *Agric. Water Manage.*, **269**, 107724.