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Influence of Irrigation Scheduling and Integrated Nutrient Management on Growth, Yield and Quality of Chickpea (*Cicer arietinum* L.)

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Abstract
A field experiment was conducted during rabi 2025–26 at the Agricultural Farm, Vivekananda Global University, Jaipur to evaluate the effect of irrigation scheduling and integrated nutrient management on growth, yield and quality of chickpea (*Cicer arietinum*). The experiment was laid out in a split-plot design with four irrigation treatments in main plots viz., control (no post-sowing irrigation), irrigation at vegetative and pod formation stages, and irrigation water to cumulative pan evaporation ratio of 0.6 and irrigation water to cumulative pan evaporation ratio of 0.8, and four integrated nutrient management treatments in sub-plots viz., 100% recommended dose of fertilizers, 75% recommended dose of fertilizers + farmyard manure at 5 t ha^{-1}, 50% recommended dose of fertilizers + vermicompost at 2 t ha^{-1}, and 50% recommended dose of fertilizers + vermicompost at 2 t ha^{-1} + Rhizobium + phosphate solubilizing bacteria. Among irrigation treatments, irrigation water to cumulative pan evaporation ratio of 0.8 recorded significantly higher seed yield (1651.89 kg ha^{-1}), haulm yield (2495.11 kg ha^{-1}), biological yield (4147.00 kg ha^{-1}), protein yield and net returns (₹ 47874.07 ha^{-1}) with benefit-to-cost ratio of 2.03. Among integrated nutrient management treatments, 50% recommended dose of fertilizers + vermicompost at 2 t ha^{-1} + Rhizobium + phosphate solubilizing bacteria proved superior with maximum seed yield (1519.74 kg ha^{-1}) and net returns (₹ 38470.92 ha^{-1}) with benefit-to-cost ratio of 1.79. The interaction of irrigation water to cumulative pan evaporation ratio of 0.8 with 50% recommended dose of fertilizers + vermicompost at 2 t ha^{-1} + Rhizobium + phosphate solubilizing bacteria recorded the highest seed yield (2054.15 kg ha^{-1}) and net returns (₹ 66540.90 ha^{-1}) with benefit-to-cost ratio of 2.33. This treatment combination was most effective and economically viable for enhancing chickpea productivity under semi-arid conditions.

Keywords: Chickpea, irrigation scheduling, integrated nutrient management, semi-arid conditions, IW/CPE ratio, Rajasthan

Introduction
Chickpea (*Cicer arietinum* L.) is one of the most important pulse crops cultivated in semi-arid and sub-tropical regions and serves as a major source of dietary protein while improving soil fertility through biological nitrogen fixation. India is one of the leading chickpea-producing countries, highlighting its importance in food and nutritional security [1]. The crop is well adapted to rainfed conditions due to its relatively low water requirement and its symbiotic association with *Rhizobium*, which enhances soil nitrogen status [2]. However, the productivity of chickpea in semi-arid regions remains constrained due to erratic rainfall, limited soil moisture and sub-optimal nutrient management. Moisture stress during critical stages such as flowering and pod formation significantly reduces growth, nodulation and yield [3]. Therefore, efficient irrigation scheduling is essential to maintain optimum soil moisture for better crop performance. Irrigation scheduling based on IW/CPE ratio is widely used to match crop water requirement with atmospheric demand. Moderate IW/CPE ratios (0.6–0.8) have been reported to improve growth and yield of chickpea under semi-arid conditions [4]. In addition, integrated nutrient management (INM) involving the combined use of chemical fertilizers, organic manures and biofertilizers improves nutrient availability, soil health and microbial activity, thereby enhancing crop productivity [5]. Water and nutrient management are closely interrelated, as soil moisture influences nutrient availability and uptake, while nutrient status affects root development and water extraction [6].

Combined application of irrigation and INM has been reported to improve productivity and economic returns compared to their individual application [6]. However, limited information is available on their combined effect under semi-arid conditions of Rajasthan. Therefore, the present investigation was undertaken to evaluate the effect of irrigation scheduling and integrated nutrient management on growth, yield, quality and economics of chickpea under semi-arid conditions of Rajasthan.

Materials and Methods

A field experiment was conducted during rabi 2025–26 at the Agricultural Farm, Vivekananda Global University, Jaipur, Rajasthan. The experimental soil was loamy sand in texture with a pH of 8.22, electrical conductivity (EC) of 0.39 dS m^{-1}, organic carbon of 0.21%, and available nitrogen, phosphorus and potassium of 132.87, 20.64 and 238.10 kg ha^{-1}, respectively. The study was laid out in a split-plot design with three replications, comprising four irrigation treatments in main plots viz., I_1: no post-sowing irrigation, I_2: two irrigations at vegetative and pod formation stages, I_3: three irrigations scheduled based on IW/CPE ratio of 0.6 and I_4: five irrigations scheduled based on IW/CPE ratio of 0.8. The sub-plots consisted of four integrated nutrient management treatments viz., N_1: 100% RDF (Recommended Dose of Fertilizer), N_2: 75% RDF + FYM (Farm Yard Manure) @ 5 t ha^{-1}, N_3: 50% RDF + vermicompost @ 2 t ha^{-1} and N_4: 50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB (Phosphate Solubilizing Bacteria).

Chickpea variety GNG-1581 (developed by Agricultural Research Station, Sriganganagar) was sown on 12 November 2025 by line sowing using a seed rate of 80 kg ha^{-1} with a row spacing of 30 cm. The recommended dose of fertilizers (20:40:20 kg N:P_2O_5:K_2O ha^{-1}) was applied through urea, DAP (Di-Ammonium Phosphate) and MOP (Muriate of Potash). Organic manures were applied at the time of sowing as per treatments, while biofertilizers (Rhizobium and PSB) were applied as seed inoculation prior to sowing. Irrigation was applied through the furrow method with a depth of 50 mm in accordance with treatment schedules. All other agronomic practices were kept uniform across treatments. The crop was harvested on 20 March 2026. Observations on growth parameters, yield attributes and yield were recorded following standard procedures. The data were subjected to analysis of variance (ANOVA) appropriate for split-plot design, and treatment means were compared at 5% level of significance using critical difference (CD).

Results

Effect of irrigation scheduling

Irrigation scheduling significantly influenced growth, yield attributes, yield and economics of chickpea. Among treatments, I_4 (IW/CPE ratio 0.8) recorded the highest seed yield (1651.89 kg ha^{-1}), haulm yield (2495.11 kg ha^{-1}) and biological yield (4147.00 kg ha^{-1}), followed by I_3, while the lowest values were observed under I_1 (control) (Table 1). Economic analysis indicated that I_4 recorded the highest net returns (₹ 47874.07 ha^{-1}) and Benefit-to-Cost (B:C) ratio (2.03), followed by I_3 (₹ 33691.18 ha^{-1}; B:C ratio 1.75), whereas the lowest was observed under I_1 (B:C ratio 1.33) (Table 1). Among treatments, I_4 also recorded significantly higher dry matter accumulation at all crop growth stages (11.0, 41.75 and 49.0 g $plant^{-1}$ at 40 days after sowing (DAS), 80 DAS and at harvest, respectively), whereas the lowest values were recorded under I_1 (control) (Table 2). However, protein content was not significantly influenced by irrigation treatments (Table 2). A similar trend was observed for yield attributes; the highest number of pods $plant^{-1}$ (50.06), seeds pod^{-1} (1.82) and seed index (20.99 g) were recorded under I_4 (Table 3).

Effect of integrated nutrient management (INM)

Integrated nutrient management significantly influenced growth, yield attributes, yield and economics of chickpea. Among treatments, N_4 (50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB) recorded the highest seed yield (1519.74 kg ha^{-1}), haulm yield (2310.04 kg ha^{-1}) and biological yield (3829.78 kg ha^{-1}), which was superior to all other treatments, while the lowest values were recorded under N_1 (Table 1). Economic analysis showed that N_4 recorded the highest net returns (₹ 38470.92 ha^{-1}) and B:C ratio (1.79), followed by N_3 (B:C ratio 1.63), whereas the lowest was observed under N_1 (B:C ratio 1.52) (Table 1). Among treatments, N_4 also recorded significantly higher dry matter accumulation (10.0, 37.25 and 44.56 g $plant^{-1}$ at 40 DAS, 80 DAS and at harvest, respectively), followed by N_3, whereas the lowest values were observed under N_1 (Table 2). Protein content (19.62%) and protein yield (299.11 kg ha^{-1}) were also highest under N_4 (Table 2). The highest number of pods $plant^{-1}$ (44.38), seeds pod^{-1} (1.72) and seed index (20.58 g) were recorded under N_4 (Table 3).

Interaction effect of irrigation scheduling and INM (I × N)

The interaction between irrigation scheduling and INM significantly influenced seed yield of chickpea (Table 4). Among all treatment combinations, I_4N_4 (IW/CPE ratio 0.8 + 50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB) recorded the highest seed yield of 2054.15 kg ha^{-1}, which was significantly superior to all other combinations. The lowest seed yield (825.07 kg ha^{-1}) was recorded under I_1N_1 (no post-sowing irrigation + 100% RDF alone). Within each irrigation level, I_4 consistently produced the highest seed yield, and within each INM treatment, N_4 consistently recorded the highest yield.

Table 1: Effect of irrigation scheduling and INM on yield and economics of chickpea

Treatments	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
Irrigation					
Control (no post-sowing irrigation)	979.77	1700.24	2680.01	14118.17	1.33
Irrigation at vegetative + pod formation stages	1120.28	1923.02	3043.31	20495.99	1.47
Irrigation at IW/CPE ratio 0.6	1370.45	2180.04	3550.49	33691.18	1.75
Irrigation at IW/CPE ratio 0.8	1651.89	2495.11	4147.00	47874.07	2.03
SEm ±	42.37	47.98	69.14	2318.12	0.05

CD (P=0.05)	146.59	166.01	239.21	8020.84	0.18
INM					
100% RDF through chemical fertilizer	1037.95	1809.24	2847.20	20541.57	1.52
75% RDF + FYM @ 5 t ha^{-1}	1205.44	2020.39	3225.83	26894.34	1.63
50% RDF + vermicompost @ 2 t ha^{-1}	1359.26	2158.74	3518.00	30272.58	1.63
50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB inoculation	1519.74	2310.04	3829.78	38470.92	1.79
SEm ±	22.84	50.87	51.95	1225.39	0.03
CD (P=0.05)	66.65	148.46	151.6	3576.29	0.08

RDF: Recommended Dose of Fertilizer; FYM: Farm Yard Manure; PSB: Phosphate Solubilizing Bacteria; INM: Integrated Nutrient Management; IW/CPE: Irrigation Water to Cumulative Pan Evaporation ratio; SEm±: Standard Error of Mean; CD: Critical Difference at P=0.05.

Table 2: Effect of irrigation scheduling and INM on dry matter accumulation and quality parameters of chickpea

Treatments	**Dry matter accumulation (g plant^{-1})**			**Protein content (%)**	**Protein yield (kg ha^{-1})**
	40 DAS	**80 DAS**	**At Harvest**		
Irrigation					
Control (no post-sowing irrigation)	7.0	28.0	35.0	18.9	185.48
Irrigation at vegetative + pod formation stages	8.2	33.62	36.6	19.13	214.25
Irrigation at IW/CPE ratio 0.6	9.8	37.5	41.73	19.31	265.15
Irrigation at IW/CPE ratio 0.8	11.0	41.75	49.0	19.45	321.29
SEm ±	0.21	0.85	0.58	0.17	6.39
CD (P=0.05)	0.71	2.95	2.02	NS	22.11
INM					
100% RDF through chemical fertilizer	8.0	32.37	36.21	18.87	196.15
75% RDF + FYM @ 5 t ha^{-1}	8.7	34.65	38.97	19.0	229.43
50% RDF + vermicompost @ 2 t ha^{-1}	9.3	36.6	42.59	19.3	262.63
50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB inoculation	10.0	37.25	44.56	19.62	299.11
SEm ±	0.19	0.64	0.84	0.14	5.04
CD (P=0.05)	0.56	1.88	2.45	0.41	14.71

DAS: Days After Sowing; RDF: Recommended Dose of Fertilizer; FYM: Farm Yard Manure; PSB: Phosphate Solubilizing Bacteria; SEm±: Standard Error of Mean; CD: Critical Difference at P=0.05; NS: Non-Significant.

Table 3: Effect of irrigation scheduling and INM on yield attributes of chickpea

Treatments	**Number of pods per plant**	**Number of seeds per pod**	**Seed index (g)**
Irrigation			
Control (no post-sowing irrigation)	31.24	1.43	18.55
Irrigation at vegetative + pod formation stages	37.74	1.54	19.03
Irrigation at IW/CPE ratio 0.6	46.18	1.74	19.44
Irrigation at IW/CPE ratio 0.8	50.06	1.82	20.99
SEm ±	1.11	0.03	0.24
CD (P=0.05)	3.83	0.10	0.84
INM			
100% RDF through chemical fertilizer	38.00	1.56	18.69
75% RDF + FYM @ 5 t ha^{-1}	40.13	1.61	19.02
50% RDF + vermicompost @ 2 t ha^{-1}	42.70	1.66	19.73
50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB inoculation	44.38	1.72	20.58
SEm ±	0.73	0.02	0.30
CD (P=0.05)	2.14	0.05	0.88

RDF: Recommended Dose of Fertilizer; FYM: Farm Yard Manure; PSB: Phosphate Solubilizing Bacteria; SEm±: Standard Error of Mean; CD: Critical Difference at P=0.05.

Table 4: Interaction effect of irrigation scheduling and INM on seed yield and economics of chickpea

Treatment	**Seed Yield (kg ha^{-1})**	**Haulm Yield (kg ha^{-1})**	**Net returns (₹ ha^{-1})**	**B:C ratio**
I1N1	825.07	1498.85	10494.91	1.28
I1N2	919.00	1669.19	12908.20	1.32
I1N3	1080.00	1778.40	16387.79	1.36
I1N4	1095.00	1854.52	16681.78	1.36
I2N1	960.50	1743.83	16629.94	1.43
I2N2	1104.20	1940.67	21626.48	1.52
I2N3	1189.10	2101.39	21369.30	1.45
I2N4	1227.33	1906.20	22358.24	1.47
I3N1	1079.83	1882.71	22529.99	1.57
I3N2	1269.00	2111.68	30048.13	1.71
I3N3	1430.50	2221.76	33883.84	1.71

I3N4	1702.48	2504.01	48302.75	2.00
I4N1	1286.42	2111.58	32511.43	1.80
I4N2	1529.55	2360.03	42994.56	1.98
I4N3	1737.45	2533.40	49449.38	2.01
I4N4	2054.15	2975.43	66540.90	2.33
SEm ±	64.59	143.88	3465.92	0.08
CD (P=0.05)	133.32	296.97	7153.66	0.16

I_1: No post-sowing irrigation; I_2: Irrigation at vegetative and pod formation stages; I_3: IW/CPE ratio 0.6; I_4: IW/CPE ratio 0.8; N_1: 100% RDF; N_2: 75% RDF + FYM @ 5 t ha^{-1}; N_3: 50% RDF + vermicompost @ 2 t ha^{-1}; N_4: 50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB; SEm±: Standard Error of Mean; CD: Critical Difference at P=0.05.

Discussion

The present study demonstrated that irrigation scheduling significantly improved growth, yield and economic returns of chickpea. The consistently superior performance under I_4 (IW/CPE ratio 0.8) affirms that maintaining optimal soil moisture through judicious irrigation scheduling is crucial for achieving high chickpea productivity under semi-arid conditions. Adequate moisture availability during vegetative and reproductive stages supports better root development, enhanced nutrient uptake, improved photosynthetic efficiency and greater assimilate production, all of which contribute to higher yield [3, 4]. The improvement in yield attributes such as pods plant^{-1} and seeds pod^{-1} under higher IW/CPE ratios further substantiates the role of timely and adequate irrigation in reducing reproductive stage stress. These findings are in conformity with the findings of Singh *et al.* [4] and Patel *et al.* [7].

The superiority of N_4 (50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB) over other INM treatments can be attributed to the synergistic effects of organic, inorganic and biological nutrient sources. Vermicompost improves soil physical properties and provides a slow-release source of nutrients, while biofertilizers such as Rhizobium enhance biological nitrogen fixation and PSB increases phosphorus availability, collectively improving soil nutrient status and root activity [2]. The combined application also enhances microbial biomass and enzyme activity, thereby improving nutrient cycling and long-term soil health. Despite recording slightly higher seed yield, treatment combination I_2N_3 registered lower net returns than I_2N_2 due to the higher cost involved in vermicompost application under integrated nutrient management, which offset the additional economic gain from yield improvement. Similar findings have been reported by Sharma *et al.* [5], Meena *et al.* [8] and Rathore *et al.* [9]. The significant and positive interaction effect of $I_4 \times N_4$ on seed yield and economics of chickpea can be attributed to the complementary roles of adequate moisture supply and balanced nutrition. Adequate soil moisture facilitates better nutrient dissolution and transport to root surfaces, while good nutritional status promotes root proliferation and water use efficiency. The highest seed yield (2054.15 kg ha^{-1}) and B:C ratio (2.33) recorded under I_4N_4 indicate that the combination of optimum irrigation and integrated nutrient management not only maximizes productivity but also ensures economic sustainability for chickpea cultivators under semi-arid conditions. These findings are in broad agreement with those of Patel *et al.* [10] and Singh *et al.* [6].

Conclusion

Based on the findings of the present investigation, it is concluded that among irrigation treatments, I_4 (IW/CPE ratio 0.8) recorded the highest seed yield (1651.89 kg ha^{-1}), haulm yield (2495.11 kg ha^{-1}) and biological yield (4147.00 kg ha^{-1}) along with maximum B:C ratio (2.03). Among integrated nutrient management treatments, N_4 (50% RDF + vermicompost @ 2 t ha^{-1} + Rhizobium + PSB) proved superior, producing the highest seed yield (1519.74 kg ha^{-1}) and B:C ratio (1.79). The interaction I_4N_4 was the most productive and economically viable combination, with seed yield of 2054.15 kg ha^{-1} and B:C ratio of 2.33, highlighting the synergistic role of optimum moisture supply and integrated nutrient application for improving chickpea productivity and profitability under semi-arid conditions of Rajasthan. Future research should investigate the long-term effect of these treatments on soil health and explore their performance across different agro-climatic zones and chickpea varieties to validate and broaden the findings.

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