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Critical stage based irrigation scheduling and crop management practices for the maximization of rainfed groundnut productivity and economics in red loam soil

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Abstract

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed crops of India, valued for its dual role as a source of edible oil and high-quality protein. Optimizing irrigation and fertilizer application is crucial therefore crucial, integrating critical-stage-based irrigation scheduling with comprehensive crop management practices to sustainably intensify groundnut production under water-limited conditions. Keeping this in view, a field experiment was conducted during *Kharif*, 2024 in the farmer's field at Perampattu Village, Tirupattur District, Tamil Nadu, India. The experiment was set up using a strip plot design, having 4 irrigation stages viz., no Irrigation (I_1), Irrigation at flowering and pod filling stages (I_2), Irrigation at pegging and pod filling stages (I_3), Irrigation at flowering, pegging and pod filling stages (I_4) in the main plot and 7 crop management practices, viz., absolute control (S_1), RDF alone ($10:10:45 \text{ kg ha}^{-1}$ of NPK) (S_2), INM (RDF + poultry manure compost 1 t ha^{-1} + Micro nutrient mixture 12.5 kg ha^{-1}) (S_3), RDF + paddy straw mulch @ 5 t ha^{-1} + foliar application of K @ 0.5% (S_4), RDF+ kaolin @ 1% + foliar application of K @ 0.5% (S_5), INM + paddy straw mulch @ 5 t ha^{-1} + foliar application of K @ 0.5% (S_6), INM + kaolin @ 1% + foliar application of K @ 0.5% (S_7) in the subplot, replicated thrice. The highest pod yield (2865 Kg ha^{-1}), haulm yield (4240 Kg ha^{-1}) and BCR (2.87) of groundnut was recorded in the treatment of Irrigation at flowering, pegging and pod filling stages along with INM + paddy straw mulch @ 5 t ha^{-1} + foliar application of K @ 0.5% (I_4S_6). The lowest pod yield (505 Kg ha^{-1}), haulm yield (914 Kg ha^{-1}) and BCR (1.06) of groundnut were recorded under the combination of no irrigation with absolute control (I_1S_1).

Keywords: Groundnut, growth stages, irrigation, poultry manure, economics

Introduction

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed crops of India, valued for its dual role as a source of edible oil and high-quality protein. The crop contains about 45-50% oil and 25-30% protein, making it a vital for nutritional security as well as farm income. It is a valuable crop for marginal farmers largely grown during the summer and *Kharif* seasons. In India, groundnut occupies a prominent position among oilseed crops. During the 2024-25, the crop was cultivated over 43.75 lakh hectares with a total production of 113.12 lakh tonnes, registering a substantial increase compared to 86.60 lakh tonnes in 2023-24. The average national productivity during this period was about $2,586 \text{ kg ha}^{-1}$ (GOI, 2025). Among the major producing states, Gujarat emerged as the leading contributor with approximately 19.17 lakh hectares and a production of 50.37 lakh tonnes, followed by Rajasthan with 8.74 lakh hectares and 23.73 lakh tonnes (CEIC, 2025) [4]. In Tamil Nadu, groundnut occupied about 33.0 lakh hectares with a production of 4.46 lakh tonnes and recorded a relatively high productivity of $2,694 \text{ kg ha}^{-1}$, reflecting the importance of the crop in the state's farming systems and the effectiveness of improved management practices (Anonymous, 2024) [1].

Despite its importance, groundnut productivity remains unstable, particularly during the rainy season, due to erratic monsoon behaviour, frequent disease outbreaks, waterlogging and poor drainage conditions (Sanju, 2013) [19]. In particular, groundnut moisture stress during the flowering and pod filling stages is critical for yield. Not only the yield of groundnut but also the

quality also decreased under moisture stress. Even short periods of stress can substantially reduce pod set and final yield. Flowering, pegging and pod setting phases are the major water-requiring stages, and that better irrigation scheduling during these windows can improve yield and water-use efficiency. Therefore, irrigation scheduling that prioritizes these critical growth stages has emerged as an effective strategy to stabilize yield and enhance water use efficiency and water productivity (Zhang *et al.*, 2021) ^[22]. Alongside irrigation management, groundnut responds strongly to balanced nutrition. Adequate supply of essential nutrients supports early root growth and enhances pod development. Integration of organic manures, micronutrients, and foliar fertilization which enhances the nutrient availability, uptake efficiency and soil health, especially under moisture limited environments (Priyadharshini *et al.*, 2025) ^[17]. Furthermore, stress-alleviating practices such as mulching, kaolin sprays, and foliar potassium application play an important role in reducing soil moisture loss by moderating canopy temperature, regulating transpiration and improving assimilate translocation under summer conditions (Gajera *et al.*, 2024) ^[9]. Mulching could reduce soil evaporation, moderates soil temperature, suppresses weeds and improves soil moisture retention, often translating into improved pod yield and water productivity (Biswal *et al.*, 2022) ^[3]. Along with antitranspirants and growth regulators, including film-forming polymers and metabolic compounds such as salicylic acid, ABA analogues and growth retardants, can reduce transpiration, maintain leaf water status and protect reproductive organs during short drought periods, which has been shown to improve flower and peg survival and reduced yield loss. While individual approaches such as improved irrigation or fertilizer management can enhance productivity, their combined and interactive effects under field conditions remain inadequately explored for this region. Optimizing irrigation and fertilizer application is therefore crucial, integrating critical-stage-based irrigation scheduling with comprehensive crop management practices to sustainably intensify groundnut production under water-limited conditions.

Materials and Methods

A field experiment was conducted during *Kharif*, 2024 in the farmer's field at Perampattu Village, Tirupattur District, Tamil Nadu, India. The experimental field was located geographically at (12° 38' N latitude, 78° 58' E longitude) to study the effect of different stages of irrigation and integrated crop management practices for groundnut in North Eastern Zone of Tamil Nadu. The soil of the experimental field is red loam. It is low in available nitrogen (153.4 kg ha⁻¹), medium in available phosphorus (15.4 kg ha⁻¹) and potassium (133.1 kg ha⁻¹). The experiments was set up using a strip plot design, having 4 irrigation stages viz., no Irrigation (I₁), Irrigation at flowering and pod filling stages (I₂), Irrigation at pegging and pod filling stages (I₃), Irrigation at flowering, pegging and pod filling stages (I₄) in the main plot and 7 crop management practices, viz., absolute control (S₁), RDF alone (10:10:45 kg ha⁻¹ of NPK)(S₂), INM(RDF + poultry manure compost 1 t ha⁻¹ + Micro nutrient mixture 12.5 kg ha⁻¹) (S₃), RDF + Paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% (S₄), RDF+ kaolin @ 1% + foliar application of K @ 0.5% (S₅), INM + paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% (S₆), INM + kaolin @ 1% + foliar application of K @ 0.5% (S₇) in subplot, replicated thrice. Irrigation was given immediately after sowing and the life irrigation was given at 3 DAS to all the plots. The subsequent irrigation was given to the crop as per the treatment schedule. The RDF (10:10:45 kg ha⁻¹ of NPK) was applied in the

form of urea, single super phosphate and muriate of potash was applied to the groundnut crop. Based on the treatments, poultry manure compost (1 t ha⁻¹) was applied to the field before groundnut sowing. The paddy straw mulch (5 t ha⁻¹) was applied on 20 DAS and the MN mixture (12.5 kg ha⁻¹) was applied as basal according to the treatment schedules. The foliar application of potassium through MOP as well as Kaolin spray were applied during 25 DAS @ 0.5% and 1%, respectively. The variety which is used for the experimental trial was VRI 10, with a duration of 90-95 days. The seed was sown manually in the field. Spacing adopted between the rows and plants was 30 cm and 10 cm, respectively. Biometric observations on yield of grain yield and haulm yield were recorded at the harvest stage, and also the economics of groundnut were also obtained in the experiment. The existing market price of the inputs and outputs was used to calculate cost of cultivation. Similarly, gross return was calculated based on the grain and haulm of groundnut and their prevailing market price. In this experiment the market price of grain and haulm was Rs. 72 kg⁻¹ and 1 kg⁻¹ respectively. The benefit cost ratio (BCR) was worked out by dividing net return by variable cost.

Gross return (Rs. ha⁻¹) = [Grain yield (kg ha⁻¹) X cost of one kg grain] + [Haulm yield (kg ha⁻¹) X cost of one kg haulm]

Net return (Rs. ha⁻¹) = [Gross return (Rs. ha⁻¹) - Total cost of cultivation (Rs. ha⁻¹)]

B:C ratio = [Net return (Rs. ha⁻¹) - Total cost of cultivation (Rs. ha⁻¹)]

Statistical analysis

The experimental data were statistically analysed as suggested by Gomez and Gomez (2010) ^[11]. For significant results, the critical difference was worked out at the 5% level.

Results and Discussion

Yield

Pod and haulm yields of groundnut were significantly influenced by irrigation stages and integrated crop management practices at the harvest stage and are furnished in Table 1. Among irrigation treatments, irrigation at flowering, pegging and pod filling stages (I₄) recorded the highest pod yield and haulm yield (2258 kg ha⁻¹ and 3453 kg ha⁻¹, respectively) which were statistically on par with irrigation at flowering and pod filling stages (I₂). This may be attributed to the maintenance of optimum soil moisture during critical phenological stages, which enhanced nutrient availability, uptake and utilization. Adequate moisture during flowering and pegging promoted effective peg penetration and pod initiation, while sufficient water during pod filling ensured efficient assimilate translocation, kernel development, and sustained vegetative growth. These favourable physiological conditions resulted in higher pod formation, improved biomass accumulation, delayed senescence and ultimately enhanced yield of groundnut. These results are reported by Channabasava and Singh (2024) ^[5].

In contrast, the lowest pod yield and haulm yield (1066 kg ha⁻¹ and 1796 kg ha⁻¹, respectively) were recorded under no irrigation (I₁). This reduction was mainly due to prolonged soil moisture stress throughout the crop growth period, which restricted nutrient dissolution, root activity and nutrient uptake. Moisture deficit during flowering, pegging, and pod development caused flower and peg abortion, poor pod filling, reduced leaf area development and early senescence, ultimately resulting in lower pod and haulm yields. These results corroborate the findings of Behera *et al.* (2015) ^[2].

Among crop management practices, INM + paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% (S₆) recorded the highest pod yield and haulm yield (2285 kg ha⁻¹ and 3491 kg ha⁻¹, respectively) followed by INM + kaolin @ 1% + foliar application of K @ 0.5% (S₇), which was on par with INM (RDF + poultry manure compost @ 1 t ha⁻¹ + micronutrient mixture @ 12.5 kg ha⁻¹) (S₃). This may be attributed to improved soil moisture conservation and balanced nutrient supply, which enhanced nutrient availability and uptake in groundnut through increased soil nutrient status and microbial activity, along with improved water use efficiency. These conditions supported key physiological processes such as effective peg establishment and pod development. Adequate and balanced supply of macro- and micronutrients further promoted vegetative growth, enhanced dry matter accumulation, and ultimately resulted in higher pod and haulm yields with greater yield stability. These findings are in agreement with Sathiya *et al.* (2020) [20] and Gowsalya *et al.* (2023) [12]. The absolute control (S₁) recorded the lowest pod yield and haulm yield (687 kg ha⁻¹ and 1213 kg ha⁻¹, respectively) which may be attributed to inadequate nutrient supply, resulting in poor nutrient uptake, reduced photosynthetic activity, impaired reproductive development, limited vegetative growth and poor biomass accumulation. These results are reported by Chaudhary *et al.* (2015) [6].

The interaction effect revealed that irrigation at flowering, pegging, and pod filling stages combined with INM + paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% (I₄S₆) produced the highest pod yield and haulm yield (2865 kg ha⁻¹ and 4240 kg ha⁻¹, respectively) which was on par with irrigation at flowering and pod filling stages with INM + paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% (I₂S₆). This may be due to the synergistic interaction between adequate soil moisture and balanced nutrient supply, which ensured optimal nutrient uptake efficiency, enhanced photosynthate translocation to reproductive sinks, sustained vegetative growth and minimized stress-induced yield losses. These results are in close conformity with the findings of Hosamani and Janawade (2007) [13].

Conversely, the lowest pod yield and haulm yield (505 kg ha⁻¹ and 914 kg ha⁻¹, respectively) were recorded under the combination of no irrigation and absolute control (I₁S₁). This may be due to severe moisture stress coupled with nutrient deficiency, which severely restricted root activity, nutrient uptake, vegetative growth and reproductive development, leading to poor peg establishment, reduced pod set, low biomass production, and early senescence in groundnut was reported by Devi *et al.* (2019) [8].

The harvest index was not appreciably influenced by the irrigation stages and integrated crop management practices in groundnut and it was found non-significant.

Economics

Economics of groundnut was significantly influenced by irrigation stages and integrated crop management practices at the harvest stage and are furnished in Table 2. Irrigation at flowering, pegging and pod filling stages (I₄) was recorded the highest gross income, net income and BCR (Rs. 168266 ha⁻¹, Rs. 104705 ha⁻¹, 2.57) which was on par with irrigation at flowering and pod filling stages (I₂). This might be due to increased pod and haulm yield resulting from adequate moisture during critical stages. This, improved water availability enhanced resource-use efficiency and yield per unit cost, thereby improving overall profitability. Similar findings were reported by Saha and Gunri (2024) [18]. The lowest gross income, net income and BCR (Rs. 79596 ha⁻¹, Rs. 17647 ha⁻¹, 1.27) was recorded under no Irrigation (I₁). This might be due to reduced yields caused by moisture stress led to lower gross income, net income and Benefit -cost ratio of groundnut was reported by Suresh *et al.* (2013) [21].

In comparison to the other the crop management practices, INM + Paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% (S₆) recorded the highest gross income, net income and BCR (Rs. 170278 ha⁻¹, Rs. 96709 ha⁻¹, 2.31) followed by INM + Kaolin @ 1% + foliar application of K @ 0.5% (S₇) which was on par with INM (RDF + Poultry manure compost 1 t ha⁻¹ + Micro nutrient mixture 12.5 kg ha⁻¹) (S₃). The superior economics observed with integrated nutrient application may be attributed to substantial yield improvement resulting from enhanced nutrient uptake and utilization efficiency, which ultimately led to higher net returns and benefit-cost ratio. Similar findings were reported by Dash *et al.* (2013) [7]. The lowest gross income, net income and BCR (Rs. 51345 ha⁻¹, Rs. 14897 ha⁻¹, 1.41) was recorded under absolute control (S₁). Poor crop productivity arising from inherent soil fertility constraints that reduced pod and haulm yields leading to lower profitability has been reported by Patel *et al.* (2009) [16].

With regards to interaction, irrigation at flowering, pegging and pod filling stages along with INM + paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% (I₄S₆) significantly recorded the highest gross income, net income and BCR (Rs. 213385 ha⁻¹, Rs. 139144 ha⁻¹, 2.87). Synergistic effects on yield, resource-use efficiency, and crop stability, which enhanced productivity under optimum moisture and nutrient availability, maximized the economics of the crop. Similar findings were reported by Naresha *et al.* (2018) [15]. The lowest gross income, net income and BCR (Rs. 37779 ha⁻¹, Rs. 2271 ha⁻¹, 1.06) was recorded under the combination of no irrigation with absolute control (I₁S₁). Compounded moisture and nutrient stress, resulting in minimal yields under these conditions was insufficient to recover production costs, leading to poor economic viability has been reported by Maurya *et al.* (2017) [14].

Table 1: Effect of different irrigation stages and integrated crop management practices on grain yield (kg ha⁻¹), haulm yield (kg ha⁻¹) and harvest index of groundnut in Red loam soil

Treatments	Grain yield (kg ha ⁻¹),					Haulm yield (kg ha ⁻¹)					Harvest index				
	I ₁	I ₂	I ₃	I ₄	Mean	I ₁	I ₂	I ₃	I ₄	Mean	I ₁	I ₂	I ₃	I ₄	Mean
S ₁	505	763	701	778	687	914	1335	1248	1354	1213	35.59	36.37	35.97	36.50	36.11
S ₂	1011	2186	1670	2213	1770	1727	3442	2738	3474	2845	36.93	38.84	37.88	38.91	38.14
S ₃	1220	2533	1949	2564	2067	2027	3864	3087	3884	3215	37.57	39.61	38.70	39.76	38.91
S ₄	1111	2405	1828	2437	1945	1877	3703	2904	3715	3050	37.18	39.37	38.63	39.59	38.69
S ₅	1016	2278	1733	2303	1833	1728	3519	2755	3548	2888	37.04	39.30	38.58	39.36	38.57
S ₆	1372	2852	2050	2865	2285	2264	4223	3239	4240	3491	37.74	40.31	38.76	40.33	39.28
S ₇	1225	2615	1951	2646	2109	2033	3935	3088	3955	3253	37.60	39.92	38.72	40.08	39.08
Mean	1066	2233	1697	2258		1796	3432	2723	3453		37.09	39.10	38.18	39.22	
	I	S	I at S			I	S	I at S			I	S	I at S		
S. Em	8.07	14.12	31.66			12.84	22.29	50.27			0.01	0.01	0.01		
CD (p = 0.05)	27.92	43.52	92.72			44.44	68.68	147.23			NS	NS	NS		

Table 2: Effect of different irrigation stages and integrated crop management practices on economics of groundnut in Red loam soil

Treatments	Total cost of cultivation (Rs. ha ⁻¹)					Gross income (Rs. ha ⁻¹)					Net income (Rs. ha ⁻¹)					Benefit cost ratio				
	I ₁	I ₂	I ₃	I ₄	Mean	I ₁	I ₂	I ₃	I ₄	Mean	I ₁	I ₂	I ₃	I ₄	Mean	I ₁	I ₂	I ₃	I ₄	Mean
S ₁	35508	36583	36583	37120	36448	37779	57034	52421	58148	51345	2271	20451	15838	21027	14897	1.06	1.56	1.43	1.57	1.41
S ₂	61136	62211	62211	62749	62077	75530	163020	124648	165023	132055	14393	100809	62437	102274	69978	1.24	2.62	2.00	2.63	2.12
S ₃	65780	66855	66855	67393	66721	91087	188846	145364	191056	154088	25307	121990	78508	123663	87367	1.38	2.82	2.17	2.83	2.30
S ₄	67984	69059	69059	69597	68925	82980	179268	136348	181470	145017	14996	110209	67289	111874	76092	1.22	2.60	1.97	2.61	2.10
S ₅	62980	64055	64055	64593	63921	75920	169813	129118	171667	136630	12940	105758	65063	107075	72709	1.21	2.65	2.02	2.66	2.13
S ₆	72628	73703	73703	74241	73569	102420	212419	152889	213385	170278	29791	138716	79185	139144	96709	1.41	2.88	2.07	2.87	2.31
S ₇	67624	68699	68699	69237	68565	91458	194830	145511	197113	157228	23834	126131	76812	127877	88663	1.35	2.84	2.12	2.85	2.29
Mean	61949	63024	63024	63561		79596	166462	126614	168266		17647	103438	63590	104705		1.27	2.57	1.97	2.57	

Conclusion

From the findings of the study it can be concluded that the highest pod yield and haulm yield were recorded in the treatment comprising irrigation at flowering, pegging, and pod filling stages along with INM + paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5%. Additionally, maximum net returns and benefit cost ratio were achieved under irrigation at flowering and pod filling stages along with INM + paddy straw mulch @ 5 t ha⁻¹ + foliar application of K @ 0.5% in red loam soil.

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