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INFLUENCE OF ETc-BASED DRIP IRRIGATION AND IRON FERTILIZATION ON YIELD, PROFITABILITY AND WATER USE EFFICIENCY OF GROUNDNUT

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ABSTRACT

A field trail was carried out during *Kharif* 2023 and 2024 at the College of agriculture, SKRAU, Bikaner, to observe the influence of different irrigation levels and iron nutrition on Yield, Profitability and Water use efficiency of groundnut (*Arachis hypogaea* L.) under drip irrigation system. The field trail comprised 20 treatment combinations, involving four irrigation levels as main plots and five iron sources as subplots, laid out in split plot design with three replications. The results shows that drip irrigation level at 0.85 ETc, significantly, increases Yield, Profitability and Water use efficiency of groundnut crop. Among the iron sources treatments, application of $FeSO_4$ at 25 kg ha^{-1} + FYM at 10 t ha^{-1} as basal application (F_2) remained statistically at par with treatment of iron chelate (EDTA) at 0.5% foliar spray twice (F_5), recorded highest performance in terms of yield, Profitability and Water use efficiency of groundnut. The Interaction of 1.0 ETc level of drip irrigation along with $FeSO_4$ at 25 kg ha^{-1} + FYM at 10 t ha^{-1} as basal application (F_2) recorded, significantly maximum net returns (Rs ha^{-1}) of groundnut. This study highlights the importance of optimum irrigation scheduling and iron nutrition in improving the productivity, profitability and water-use efficiency of groundnut under drip irrigation.

***Key words*: -** Drip irrigation, profitability, Crop Evapotranspiration, water-use efficiency, Fertilization.

Introduction

Oilseed crops occupy an important position in India's farming system as high-income crops well-suited to dry regions (Shahane and Shivay, 2019). Oilseed are rich source of fat and edible oils, have various uses for human beings and animals (Abiodun, 2017). To meet the increasing demand, India imports nearly 15 MT of edible oil, which accounts for 60% of its total needs, while domestic production covers just 40% (Narayan, 2016). As much as 90% of the total edible oil products in the country come from two oilseed crops namely groundnut and mustard. Groundnut is the 4th most important oilseed crop and 13th most important food crop worldwide (Reddy *et al*., 2011). Major groundnut producing states in India are Gujarat, Rajasthan, Andhra Pradesh, Karnataka, Madhya Pradesh, Maharastra, Tamil Nadu and Uttar Pradesh (Misra, 2017). It belongs to family leguminoseae and sub family papilionaceae. It is popular for its multiple uses where it can be consumed as a snack or processed to peanut butter or cooking oil. Groundnut is an important grain legume in the arid and semi-arid regions. Currently, groundnut has shown suitability to arid and semi-arid environments (Chibarabada *et al*., 2017), however, it also shown instability across environments and seasons (Sahay and Sarma, 2005; Nawaz *et al*., 2009). Major reason of lower yield is that the crop is mostly grown under rain-fed condition. Hence, major challenges are to enhance yield as well as to increase water use efficiency

(WUE) of the crop. For solving this problem efficient method of irrigation like drip at different levels should be explored, for estimating the best irrigation practice with appropriate management of irrigation water in arid and semi-arid regions. Adoption of drip irrigation thus save tremendous amount of irrigation water which can be used for bringing more areas under irrigation. Micronutrient deficiencies are major constraints in crop production in present day agricultural programmes. Micronutrient fertilizers are gaining importance day by day and would play a major role in bringing stability and sustainability in the production of food grains, pulses and oilseeds in the coming decade. Iron deficiency is a widespread agricultural problem in many crops, especially in groundnut in calcareous and alkaline soils. The iron deficiency in groundnut first appears as chlorosis of young rapidly expanding leaves which is characterized by inter-venial chlorosis and later severe deficiency. The yield loss due to iron chlorosis was reported to be 16-40% (Hadole *et al.*, 2024).

Materials and Methods

A field Trail entitled "Response of Groundnut (*Arachis hypogaea* L.) to Irrigation and Iron under Drip System" was conducted during two consecutive *Kharif* seasons of 2023 and 2024. The field experiment was conducted at Experimental Farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner (Rajasthan), situated at 28° 10' N latitude and 73° 35' E longitude at an altitude of 235 meters above mean sea level. According to Agro-ecological region map of NBSS&LUP; Bikaner falls under Agro-ecological region No. 2 (MgE_1) under arid ecosystem (Hot Arid Eco-region with desert and Saline soil), which is characterized by deep, sandy and coarse loamy desert soils with low water holding capacity and hot-arid climate.

Experimental Details

A field experiment was conducted to observe the effect of Crop evapotranspiration-based drip irrigation and iron fertilization on yield, Profitability and Water use efficiency of groundnut using a split plot design (SPD) with three replications. The experiment comprised 20 treatment combinations, involving four irrigation levels (0.55, 0.70, 0.85, and 1.0 ETc) as main plots and five iron treatments, no iron (control), $FeSO_4$ at 25 kg ha^{-1} + FYM at 10 t ha^{-1} as basal application (F_2), foliar spray of $FeSO_4$ at 0.5% + 0.1% citric acid twice at 30 and 45 DAS (F_3), iron chelate (EDTA) at 0.5% foliar spray once at 30 DAS (F_4), and iron chelate (EDTA) at 0.5% foliar spray twice at 30 and 45 DAS (F_5) as subplots.

Treatment Application

Table 1: The details of the treatments with their symbols.

Treatments	Symbols
A. Main plot treatment (ET_C levels of drip Irrigation)	
1. 0.55 ET_C	I_1
2. 0.70 ET_C	I_2
3. 0.85 ET_C	I_3
4. 1.0 ET_C	I_4
B. Subplot treatment (Iron fertilization)	
1. Control	F_1
2. $FeSO_4$ 25 kg + FYM 10 t ha^{-1} as basal application	F_2
3. $FeSO_4$ at 0.5% + 0.1% citric acid at 30 and 45 DAS	F_3
4. Iron chelate (EDTA) 0.5% at 45 DAS	F_4
5. Iron chelate (EDTA) 0.5% at 30 and 45 DAS	F_5

Drip irrigation levels:

(a) Surface irrigation:

Irrigation was scheduled based on climatological approach. First irrigation (60 mm) was given before sowing. Thereafter drip irrigation was given based on different ETc levels, as per treatment.

(b) Drip irrigation:

For irrigation through drip, first irrigation (25 mm) was given immediately after sowing and subsequent irrigations were scheduled in alternate days as per treatment. The quantity of water was calculated as follows:

Irrigation water (mm) = PE × Kp × Kc

Where,

PE = Pan evaporation (mm)

Kp = Pan factor

Kc = Crop factor

The lateral drip lines are laid on the soil surface as per treatment. Dripper to dripper spacing was 30 cm with 4 lit hr^{-1} discharge.

Iron fertilization:

(a) Iron and citric acid:

Iron was applied as per treatment through ferrous sulphate ($FeSO_4.7H_2O$) containing 19% iron and 10.5% sulphur. The weighed quantity of $FeSO_4$ 25 Kg + FYM 10 t ha^{-1} as basal application was broadcasted uniformly in earmarked plots and thoroughly mixed in soil before sowing. For foliar spray treatment stock solution of 0.5% $FeSO_4$ and 0.1% citric acid were prepared separately and mix together, Iron chelate (EDTA) was applied using 500 liters of water separately or together as per treatment at 30 and 45 DAS. Similarly measured quantity of $FeSO_4$ (as per treatment) were mixed in water using 500 liters water per hectare and sprayed at 30 and 45 DAS.

Treatment Evaluation

Pod yield:

The crop was harvested from net plot area, threshing was done after sun drying the crop on threshing floor, pods were separated from plants in threshing and weight of uniformly sun-dried matured pods was recorded treatment wise and thereafter converted into kg ha^{-1} as pod yield.

Kernel yield:

The sun-dried pods were shelled and kernels were separated from shells and kernels obtained were weighed and kernel yield was recorded treatment wise and expressed as kg ha^{-1}

Haulm Yield:

After removing the pods from the harvested plants of the net plot area, roots were removed from the plants and the haulm was weighed and recorded as haulm weight. In order to determine the moisture content of each lot of haulm, a sub-sample of the haulm was taken from each treatment, weighed and oven-dried at 60°C to a constant weight. The percent moisture content of the sub-sample and the field weight of the bulk haulm were used to calculate the dry weight of the bulk haulm as kg ha^{-1}.

Water management studies

Water use (field):

Total water applied to the field was calculated at different ETc levels *viz*. 0.55, 0.70, 0.85 and 1.0. The amount of water received through rainfall during crop growing period was also added.

Water use pattern:

Crop growth wise water use pattern was calculated by dividing irrigation water applied in a particular treatment with total irrigation water applied during crop growing period.

Water use efficiency:

It is calculated as the ratio of groundnut yield to total water used in the particular treatment and expressed in kg ha^{-1} mm.

$$WUE\ (kg\ ha^{-1}mm^{-1}) = \frac{Groundnut\ yield\ (kg\ ha^{-1})}{water\ use\ (mm)}$$

Economic

Gross returns:

The economics of different treatments was worked out in terms of gross return (Rs ha^{-1}), net returns (Rs ha^{-1}) and B:C ratio, on the basis of prevailing market prices for inputs and output. Gross returns were obtained by converting the produce (seed + straw) into monetary terms at the minimum support price (MSP) during the course of studies for each treatment.

Gross return (*Rs. ha*$^{-1}$) = *Seed yield* (*kg ha*$^{-1}$) × *Price of Seed* (*kg ha*$^{-1}$) + *Straw yield* (*kg ha*$^{-1}$) × *Price of straw* (*Rs. ha*$^{-1}$)

Net returns:

The cost of cultivation for each treatment was subtracted from the gross returns worked out for the respective treatment to arrive at net returns for each treatment.

Benefit-cost ratio:

Benefit cost ratio for each treatment was calculated to ascertain economic viability of the treatment using the following formula:

$$\text{B:C} = \frac{\text{Gross returns (Rs ha}^{-1})}{\text{Cost of cultivation (Rs ha}^{-1})}$$

Results and Discussion

Pod yield (kg ha^{-1})

ET$_C$ levels of drip irrigation:

Further appraisal of data (Table 2) shows that pod yield (kg ha^{-1}) during both the individual years as well as pooled mean of both years was significantly influenced by various ETc levels of drip irrigation. Increasing levels of drip irrigation up to 0.85 ETc significantly enhance the pod yield (kg ha^{-1}) during individual years as well as pooled mean, further increase in drip irrigation up to 1.0 ETc remains statistically similar with 0.85 ETc. ETc levels of drip irrigation at 0.85 ETc found significantly higher pooled mean pod yield (kg ha^{-1}) which was increases to the tune of 23.92 and 14.38 per cent, respectively, over 0.55 ETc and 0.70 ETc. Whenever, drip irrigation at 0.70 ETc also recorded significantly higher pooled mean pod yield (kg ha^{-1}) increase of 23.92 per cent over 0.55 ETc at harvest. Higher yields observed under elevated ETc levels in drip irrigation can be attributed to the consistent application of larger water volumes, which created a favourable microclimate and maintained soil moisture close to field capacity, thereby supporting improved crop performance. Efficient scheduling of drip irrigation, such as at 1.0 ETc level in this study, helps reduce water loss through evaporation while enhancing yield (Molden *et al*., 2010). On the other hand, adequate water availability has been found to significantly increase the number of fully developed pods per plant (Bennett *et al*., 2011).

Iron fertilization:

Perusal of data (Table 2) shows that pod yield (kg ha^{-1}) of groundnut significantly, influenced by iron

Table 2: Effect of ET_C levels of drip Irrigation and Iron fertilization on pod, kernel and haulm yield of groundnut.

Treatments	Yield (kg ha^{-1})								
	Pod			Kernel			Haulm		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
ET_C levels of drip Irrigation									
I_1	2507	2351	2429	1755	1636	1696	3969	3737	3853
I_2	3124	2896	3010	2227	2053	2140	4888	4549	4718
I_3	3583	3302	3443	2578	2363	2470	5571	5153	5362
I_4	3719	3423	3571	2682	2455	2569	5774	5333	5554
S.Em.±	83	74	56	64	56	42	124	110	83
$CD_{P=0.05}$	288	255	171	220	195	131	429	380	255
Iron fertilization									
F_1	2806	2615	2711	1984	1838	1911	4424	4139	4281
F_2	3638	3356	3497	2615	2400	2507	5618	5202	5410
F_3	3154	2918	3036	2255	2075	2165	4935	4583	4759
F_4	3079	2856	2968	2192	2022	2107	4830	4498	4664
F_5	3489	3219	3354	2506	2300	2403	5447	5044	5246
S.Em.±	77	68	51	59	52	39	115	101	76
$CD_{P=0.05}$	222	196	145	170	150	111	330	292	216

I_1=0.55 ET_C, **I_2**=0.70 ET_C, **I_3**=0.85 ET_C, **I_4**=1.00 ET_C, **F_1**= Control, **F_2**= $FeSO_4$ 25 kg + FYM 10 t ha^{-1} as basal application, **F_3**= $FeSO_4$ at 0.5% + 0.1% citric acid at 30 and 45 DAS, **F_4**= Iron chelate (EDTA) 0.5% at 45 DAS, **F_5**= Iron chelate (EDTA) 0.5% at 30 and 45 DAS

fertilization during the year 2023, 2024 and on pooled mean. Application of $FeSO_4$ at 25 Kg ha^{-1} + FYM 10 t ha^{-1} as basal application (F_2), produced significantly higher pod yield (kg ha^{-1}) as compare to control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and foliar application of iron chelate (EDTA) 0.5% once (F_4). However, it was remained statistically similar with foliar application of iron chelate (EDTA) 0.5% twice (F_5). $FeSO_4$ 25 kg ha^{-1} + FYM 10 t ha^{-1} as basal application (F_2) increases the pod yield (kg ha^{-1}) to the tune of 29.00, 15.19 and 17.84 per cent, respectively, over control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and iron chelate (EDTA) 0.5% once (F_4). The increase in pod yield under the basal $FeSO_4$ + FYM treatment can be attributed to improved soil fertility and iron availability, which are critical for various physiological and biochemical processes in groundnut, including chlorophyll synthesis, nitrogen fixation, and enzymatic activities (Kheravat *et al*., 2020). The inclusion of FYM improves soil structure, moisture retention, and microbial activity, which further facilitates nutrient uptake and plant growth, leading to enhanced pod formation and development (Poonia *et. al*., 2022).

Kernel yield (kg ha^{-1})

ET_C levels of drip irrigation:

Kernel yield (kg ha^{-1}) also significantly influenced by various ETc levels of drip irrigation during both the years as well as pooled mean of both years (Table 2). Increasing levels of drip irrigation up to 0.85 ETc significantly enhance the kernel yield (kg ha^{-1}) during individual years as well as pooled mean of both years, further increase in drip irrigation up to 1.0 ETc remains statistically at par with 0.85 ETc. ETc levels of drip irrigation at 0.85 ETc found significantly higher pooled mean kernel yield (kg ha^{-1}) which was increases to the tune of 26.18 and 15.45 per cent, respectively over 0.55 ETc and 0.70 ETc. Whenever, drip irrigation at 0.70 ETc also recorded significantly higher pooled mean kernel yield (kg ha^{-1}) increase of 26.19 per cent over 0.55 ETc at harvest. Maintaining a consistently high soil water potential and avoiding large fluctuations in soil moisture may be a key factor contributing to increased yield (Bodner *et al*., 2015). Moisture stress during the flowering and pod formation stages in groundnut has a significant impact on yield, making irrigation during these periods critical to minimize losses (Thiyagarajan *et al*., 2010).

Iron fertilization:

Data presented (Table 2) that kernel yield (kg ha^{-1}) of groundnut significantly influenced by iron fertilization during both the year 2023, 2024 and on pooled basis. Application of $FeSO_4$ at 25 Kg ha^{-1} + FYM 10 t ha^{-1} as basal application (F_2), produced significantly higher kernel yield (kg ha^{-1}) over control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and foliar application of iron chelate (EDTA) 0.5% once (F_4). However, it was remained statistically, similar with foliar application of iron chelate (EDTA) 0.5% twice (F_5). $FeSO_4$ 25 kg ha^{-1} + FYM 10 t ha^{-1} as basal application (F_2), increases the kernel yield (kg ha^{-1}) to the tune of 31.20, 15.83 and 18.98

Table 3: Effect of ET_C levels of drip Irrigation and Iron fertilization on water use and water use efficiency of groundnut.

Treat-ments	WUF			WUE		
	2023	2024	Pooled	2023	2024	Pooled
ET_C levels of drip Irrigation						
I_1	619.64	544.33	581.99	4.05	4.32	4.18
I_2	716.91	597.27	657.09	4.36	4.85	4.60
I_3	814.17	650.23	732.20	4.40	5.08	4.74
I_4	911.44	703.16	807.30	4.08	4.87	4.47
S.Em.±				0.11	0.12	0.08
$CD_{P=0.05}$				0.38	0.41	0.25
Iron fertilization						
F_1	765.54	623.75	694.64	3.70	4.20	3.95
F_2	765.54	623.75	694.64	4.72	5.34	5.03
F_3	765.54	623.75	694.64	4.13	4.67	4.40
F_4	765.54	623.75	694.64	4.03	4.57	4.30
F_5	765.54	623.75	694.64	4.53	5.12	4.83
S.Em.±				0.10	0.11	0.07
$CD_{P=0.05}$				0.29	0.31	0.21

WUF: Water use in field (mm);
WUE: Water use efficiency (kg ha^{-1} mm)

per cent, respectively, over control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and iron chelate (EDTA) 0.5% once (F_4). Basal application of $FeSO_4$ with FYM is a practical and sustainable strategy for enhancing groundnut yield, especially in iron-deficient soils, while foliar applications of iron chelates, provide an alternative or supplementary method for rapid micronutrient correction (Noreen *et al.*, 2018).

Haulm yield (kg ha^{-1})

ET_C levels of drip irrigation:

It is explicit from the data (Table 2) shows that haulm yield (kg ha^{-1}) significantly influenced by various ETc levels of drip irrigation during both the individual years as well as pooled mean of both years. Increasing levels of drip irrigation up to 0.85 ETc, significantly improve the haulm yield (kg ha^{-1}) during individual years as well as pooled mean of both years, further increase in drip irrigation up to 1.0 ETc remains statistically at par with 0.85 ETc. ETc levels of Drip irrigation at 0.85 ETc found significantly higher pooled mean haulm yield (kg ha^{-1}) which was increases to the tune of 22.45 and 13.64 per cent, respectively, over 0.55 ETc and 0.70 ETc. Whenever, drip irrigation at 0.70 ETc also recorded significantly higher pooled mean haulm yield (kg ha^{-1}) increase of 22.45 per cent over 0.55 ETc at harvest. Irrigation at 0.85 ETc is considered optimal for maximizing seed weight without wasting water resources, similarly, Rathod and Trivedi (2011) reported the highest pod yield of 3082 kg ha^{-1} at an IW/CPE ratio of 0.90. Their results

Table 4: Water use pattern during *kharif*, 2023 on percent basis.

Crop growth stage	Drip irrigation levels (ET_C) Percent			
	0.55 ET_C	0.70 ET_C	0.85 ET_C	1.0 ET_C
Initial stage	7.13	7.13	7.13	7.13
Crop development stage	11.53	10.97	10.55	10.22
Mid-season stage	71.34	70.90	70.56	70.29
Maturity stage (Last 30 Days)	10.00	11.00	11.77	12.37
Total	100.00	100.00	100.00	100.00

indicated a steady increase in pod yield as the IW/CPE ratio rise from 0.60 to 0.90. This improvement can be explained by better water availability during the grain-filling period, which ensures optimal translocation of photosynthates into developing seeds, thereby increasing seed size and weight (Sehgal *et al.*, 2018). Drip irrigation at 1.0 ETc resulted in a significantly higher haulm yield, though it was statistically similar to the yield at 0.85 ETc. Drip irrigation also had a notable positive effect on stover yield in maize, as reported by Payero *et al.*, (2008).

Iron fertilization:

Data shows (Table 2) that haulm yield (kg ha^{-1}) of groundnut significantly, influenced by iron fertilization during both the individual year of 2023, 2024 and on pooled data. Application of $FeSO_4$ at 25 Kg ha^{-1} + FYM 10 t ha^{-1} as basal application (F_2), produced significantly higher haulm yield (kg ha^{-1}) as compare to control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and foliar application of iron chelate (EDTA) 0.5% once (F_4). However, it was remained statistically at par with foliar application of iron chelate (EDTA) 0.5% twice (F_5). $FeSO_4$ 25 kg ha^{-1} + FYM 10 t ha^{-1} as basal application(F_2), increases the haulm yield (kg ha^{-1}) to the tune of 26.36, 13.68 and 15.98 per cent, respectively, over control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and iron chelate (EDTA) 0.5% once (F_4). Sonwani, (2019) also found that application of 25 kg ha^{-1} $FeSO_4$ on groundnut at 40, 60, and 90 DAS significantly increased haulm, pod yield and shelling percentage compared to the control and rest of treatments. The highest biological yield was recorded with the same treatment as well. Similarly, Dhaliwal *et al.*, (2022) reported maximum biological yield in soybean when iron was applied at 25 and 50 kg ha^{-1}.

Water management studies

Water use (mm):

ET_C levels of drip irrigation:

The data regarding total use of water in experimental

Table 5: Water use pattern during *kharif*, 2024 on percent basis.

Crop growth stage	Drip irrigation levels (ET_C) Percent			
	0.55 ET_C	0.70 ET_C	0.85 ET_C	1.0 ET_C
Initial stage	5.78	6.43	6.99	7.45
Crop development stage	25.28	24.96	24.69	24.46
Mid-season stage	66.42	65.68	65.06	64.53
Maturity stage (Last 30 Days)	2.53	2.93	3.27	3.55
Total	100.00	100.00	100.00	100.00

field described in Table 3 during both the individual years of 2023, 2024 and pooled mean. The maximum use of water was observed under the treatment of 1.0 ETc (911.44, 703.16 and 807.30 mm) followed by 0.85 ETc (814.17, 650.23 and 732.20 mm) and 0.70 ETc (716.91, 597.27 and 657.09 mm) and minimum water use was recorded as (619.64, 544.33 and 581.99 mm) with 0.55 ETc levels of drip irrigation in the years of 2023, 2024 and on pooled mean basis, respectively.

Iron fertilization:

Total use of water was not influenced, significantly by different iron fertilization during both the individual years of 2023, 2024 and on pooled mean basis (Table 3). In all the treatment of iron fertilization water use observed as 765.54, 623.75 and 694.64 during both the individual year of 2023, 2024 and pooled mean, respectively.

Water use efficiency (kg ha^{-1} mm^{-1})

ET_C levels of drip irrigation:

It is discernible from the data furnished in Table 3 that the water use efficiency influenced, significantly by various ETc levels of drip irrigation during both the individual years as well as pooled mean of both years. Application of ETc levels of drip irrigation significantly effect water use efficiency of groundnut during both the individual years as well as pooled mean of both years. Drip irrigation level at 0.85 ETc remained statistically at par with 1.0 ETc, recorded, significantly higher water use efficiency (4.40, 5.08 and 4.74 kg ha^{-1} mm^{-1}) over 0.55 ETc levels of drip irrigation, 0.70 ETc levels of drip irrigation during both the individual year 2023, 2024 and pooled mean. ETc levels of drip irrigation at 0.85 ETc increased significantly, pooled mean water use efficiency to the tune of 10.06 and 2.97 per cent, respectively over 0.55 ETc and 0.70 ETc. This improvement suggests that deficit irrigation at 0.85 of crop evapotranspiration can maximize water productivity by reducing water losses while maintaining yield, a finding consistent with previous research that emphasizes the benefits of deficit drip irrigation in enhancing water use efficiency without compromising crop performance (Pande *et al.*, 2023). Therefore, the results support the adoption of 0.85 ETc as an optimal irrigation level that balances water input with crop water demand, improving sustainable water management in groundnut cultivation (Zahoor *et al*., 2019). Choudhary *et al*., (2020) found that subsurface drip irrigation resulted in greater water use efficiency (WUE), with the highest WUE of 5.6 kg/ha-mm observed in the variety HNG 123, followed by Mallika.

Table 6: Interaction effect of ET_C levels of drip Irrigation and Iron fertilization on Net returns of groundnut on pooled mean basis.

Iron fertilization	Net returns (Rs ha^{-1})			
	ET_C levels of drip Irrigation			
	I_1	I_2	I_3	I_4
F_1	112686	143356	152570	149221
F_2	115831	164088	214768	237298
F_3	113917	154412	183433	184010
F_4	110322	151722	174696	176216
F_5	113887	161742	204290	226207
	Irrigation at same level of Iron		Iron at same level of Irrigation	
S.Em.±	4059		4165	
$CD_{P=0.05}$	12508		12399	

Iron fertilization:

Perusal of data (Table 3) shows that different iron fertilization treatments significantly influenced the water use efficiency of groundnut during both the individual years and on pooled mean data basis. Basal application of $FeSO_4$ at 25 Kg ha^{-1} + FYM 10 t ha^{-1} (F_2), recorded significantly higher water use efficiency as compare to control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and foliar application of iron chelate (EDTA) 0.5% once (F_4). However, it was remained statistically at par with foliar application of iron chelate (EDTA) 0.5% twice (F_5). Basal application of $FeSO_4$ 25 kg ha^{-1} + FYM 10 t ha^{-1} (F_2), improve the water use efficiency to the tune of 27.22, 14.36 and 16.88 per cent, respectively, over control (F_1), foliar application of 0.5% $FeSO_4$ + 0.1% citric acid twice (F_3) and iron chelate (EDTA) 0.5% once (F_4). This increase in WUE because improved micronutrient status allowed the crop to better utilize available water through enhanced physiological processes, reducing non-productive losses.

Water use pattern (Crop growth stage wise):

Water use by crop during different crop growth stages *i.e.*, initial stage, crop development stage, mid-season stage and maturity stage of last 30 days was computed to find out the water use pattern of crop and

presented in (Table 4,5) for *Kharif* 2023 and 2024, respectively. When total water use of different treatments was considered 100%, then maximum water was used in mid-season stage of the crop, irrespective of drip irrigation level and year of experimentation.

Economics of treatments

Net returns (Rs ha^{-1}):

Interaction effect:

Interaction between levels of drip irrigation and iron fertilization observed significant on net return in groundnut on pooled mean (Table 6). Among all treatment combinations, the significantly higher net return (237298 Rs ha^{-1}) was recorded with the basal application of $FeSO_4$ at 25 Kg ha^{-1} + FYM 10 t ha^{-1} (F_2), under 1.0 ETc level of drip irrigation, followed by the foliar application of iron chelate (EDTA) 0.5% twice (F_5), under the same irrigation level. Among all iron treatments, it was observed that application of $FeSO_4$ at 25 Kg ha^{-1} + FYM 10 t ha^{-1} as basal application (F_2) and iron chelate (EDTA) 0.5% twice (F_5) increased net return, significantly up to 1.0 ETc. While, in control (F_1), foliar application of $FeSO_4$ at 0.5% + 0.1% citric acid twice (F_3) and iron chelate (EDTA) 0.5% once (F_4), significantly increase was up to 0.85 ETc level of drip irrigation. The minimum net return (112686 Rs ha^{-1}) was recorded in the control treatment (no iron application) under 0.55 ETc level of drip irrigation. This economic gain arises from higher pod, kernel, and haulm yields coupled with improved quality (oil and protein) and nutrient use efficiency, reflecting the value of integrated water-nutrient management. Studies in groundnut production systems have demonstrated that calibrated drip irrigation with balanced nutrient inputs increases profitability by improving water and nutrient use efficiency, reducing wastage, and achieving higher economic returns per unit input (Poonia *et al.*, 2024).

Conclusion

The study clearly demonstrated that both irrigation levels and iron fertilization significantly influenced groundnut, yield, Profitability and water use efficiency, under drip irrigation in arid conditions. The combination of 1.0 ETc level of drip irrigation with $FeSO_4$ at 25 kg ha^{-1} + FYM at 10 t ha^{-1} as basal application (F_2) produced the highest pod yield, kernel yield, haulm yield, net return, and overall profitability of groundnut, followed closely by the foliar application of Iron chelate (EDTA) 0.5% twice at 30 and 45 DAS (F_5), under the same irrigation level. The significantly maximum water use efficiency was recorded in 0.85 ETc level of drip irrigation in 2023 and 2024 and in iron fertilization maximum water use efficiency was recorded with basal application of $FeSO_4$ at 25 Kg ha^{-1} + FYM 10 t ha^{-1} (F_2) which was at par with Iron chelate (EDTA) 0.5% twice at 30 and 45 DAS (F_5).

Author's Contribution

Rajesh Choudhary: Conceptualized the research, conducted the experiments and analysed the data as part of his Ph.D. research work. M.L Reager: Assisted with the experimental design, provided guidance on agronomic practices and contributed to the interpretation of results. Naveen Kumar and Ashok kumar samota: Assisted with data collection and contributed to the manuscript preparation.

Declaration

The authors declare no conflicts of interest regarding this manuscript.

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