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Profitability of Maize and Groundnut Crop Production under Different Irrigation Systems with Varied Irrigation and Nitrogen Level Application in Southern India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

An experiment was conducted to study the effects of irrigation systems, irrigation, and N levels on the economics of maize and groundnut during 2021-22 and 2022-23 at the College Farm, College of Agriculture, Rajendranagar, PJT Agricultural University, Hyderabad. The experiment consisted of 18 treatment combinations (3 irrigation systems as the main plot, 3 irrigation levels as the sub-plot, and 2 nitrogen levels as the sub-sub-plot) in a split plot design replicated thrice. The experiment revealed that among irrigation systems, irrigation, and N levels in both crops (maize and groundnut) significantly higher gross returns, net returns, and BCR were recorded with M_2 (sub-surface irrigation system), S_1 (1.2 Epan; IW/CPE) and N_1 (100 percent RDN). In both crops, the interaction between irrigation system and irrigation levels (M x S) revealed significantly higher returns and BCR with sub-surface drip irrigation levels@ 1.2 Epan & 0.9 Epan ratios (M_2S_1 and M_2S_2) followed by surface drip irrigation levels @ 1.2 Epan & 0.9 Epan ratios (M_1S_1 and M_1S_2), surface irrigation @ 1.2 IW/CPE ratio (M_3S_1). In contrast, surface irrigation @ 0.6 IW/CPE ratio (M_3S_3) resulted in the least returns and BCR during both the years. The interaction effects of irrigation systems and N levels (M x N), irrigation, and N levels (S x N) were non-significant in the groundnut crop whereas they were significant in maize crop. The M_2N_1 recorded significantly higher mean gross returns (₹. 1,46,852 ha^{-1}), net returns (₹. 90,960 ha^{-1}), and BCR (2.62) whereas M_3N_2 recorded the lowest mean gross return (₹. 97,052 ha^{-1}), net return (₹. 45,305 ha^{-1}) and BCR (1.87). Among S x N interaction effects, the S_1N_1 (1.2 Epan; IW/CPE with 100 percent RDN) resulted in significantly higher gross returns (₹. 1,44,385 ha^{-1}), net returns (₹. 89,256 ha^{-1}) and BCR (2.61) followed by S_2N_1. In contrast, S_3N_2 resulted in significantly least returns and BCR. The interaction effects of irrigation systems, irrigation, and N levels (M x S x N) were non-significant in the groundnut crop while showing a significant impact on the economics of maize. The sub-surface irrigation system (M_2) with 1.2 Epan (S_1) and 100 percent RDN (N_1) recorded significantly higher mean gross returns (₹. 1,58,749 ha^{-1}), net return (₹. 1,10,243 ha^{-1}) and BCR (2.82) followed by $M_2S_2N_1$ (₹. 1,56,106 ha^{-1}, ₹. 1,14,542 ha^{-1} and 2.79), $M_1S_1N_1$ and $M_1S_2N_1$ while $M_3S_3N_2$ (surface irrigation system with 0.6 IW/CPE and 75 per cent RDN) recorded least mean gross returns (₹. 65,253 ha^{-1}), net returns (₹. 14,106 ha^{-1}) and BCR (1.28) thus making it the least remunerative among all treatment combinations studied.

Keywords: Maize; groundnut; irrigation systems; net returns; gross returns and BCR

1. INTRODUCTION

Maize, the fastest-growing cash crop, is increasing throughout the world and has the highest production among all cereals. It is the preferred staple food for 900 million poor, 120 -140 million poor farm families, and about one-third of all malnourished children globally (Murdia et al. 2016). Maize is the third most important food grain following wheat and rice for the Indian population and is cultivated over a 9.6-million-hectare area with an annual production and productivity of 28.7 million tonnes and 3.0 t ha^{-1} (India Stat, 2023). Similarly, groundnut is considered the most important oilseed crop in India with a cultivated area of 4.8 million hectares with an annual production and productivity of 9.95 million tonnes and 2.06 t ha^{-1}. Both maize and groundnut crops rank 4th and 1st in acreage but 6th and 2nd in production globally which indicates that the yield potential of maize and groundnut crops are inevitably smaller than the productivity of USA (10.7 & 4.3 t ha^{-1}), China (6.3 & 3.9 t ha^{-1}) and Argentine (7.5 & 3.5 t ha^{-1}) because achieving maximum yield potential requires near perfect management of crop and soil factors which are lacking in farm fields in India (Sreekanth et al. 2017).

In Telangana, an 8.5-million-hectare area is gross cropped employing 66.13% of state workers which contributed 15 & 19% in real and nominal terms to the state gross value addition (GVA) in the triennium ending 2021-22 (MOSPI, 2021). Similarly, 36% of the state's land is double-cropped, 64.6% of farmers are marginal and 23.7% of farmers are small. Telangana is rice and cotton centric contributing 52% of state crop value of output (VOO), however, the cereal contribution has shrunk from 44% in 2014-15 to

18% in 2019-20 even though apart from gram, pulses do not appear to be profitable for Telangana farmers as Telangana agricultural households earns about ₹. 4,917 per month as compared to Punjab's crop income of ₹.12,597 per month which indicates that the higher agricultural growth in Telangana has not translated into high-income levels for farmers (Saini et al*.,* 2023). On this consideration, there is an imminent need to improve cultural practices like fertilizer application along with the proper method of irrigation as water and nutrients are the basic imperative inputs in crop production due to its diverse needs (Sezen et al*.,* 2011) and on this basis, micro irrigation along with fertigation provides the scope for maximizing the crop productivity and monetary returns per unit area and input (Jain et al*.,* 2021). Selection of appropriate crops especially when micro irrigation systems are resorted is a critical decision to be made, considering the initial costs involved. The significance of the selection is more paramount under sandy loam soils of Telangana wherein increasing the cropping intensity is more challenging due to its innate lower productivity and low water & nutrient-holding capacity nature.

With productive farmland facing increased pressure from the growing population, cereal-legume rotations have been proposed as an effective mean to increase the productivity of nutrient-depleted and low water-holding capacity soils in low-external input systems (Buerkert et al*.,* 2001) and to ensure nutritional security. The resource use efficiency, and gross and net returns can be increased by fertigation wherein the plants' nutrients are applied with irrigation water, mainly through micro irrigation systems (Jat et al*.,* 2011). Fertigation is relatively a recent innovative method by which fertilizers are applied along with irrigation water through a drip system to enhance fertilizer-use efficiency besides increasing crop yields and monetary returns. Studies show that drip-irrigated maize and groundnut had greater yield, market grade, and gross revenue compared with conventional irrigated regimes (Sorensen and Lamb, 2009). However, information on the economics of this intensive cropping system is limited. Particularly under different irrigation systems with varied irrigation and nitrogen levels. Therefore, the present experiment on economics in maize-groundnut crop systems with varied irrigation systems, irrigation levels, and nitrogen levels was conducted.

2. MATERIALS AND METHODS

The current experiment was conducted during the *rabi* and summer seasons of 2021-22 and 2022-23 at College Farm, College of Agriculture, Rajendranagar, PJT Agricultural University, Hyderabad, Telangana. The soil of the experimental site was sandy clay loam in texture, moderately alkaline in reaction (pH 7.90), low in available nitrogen (213.58 kg ha^{-1}), moderately high in phosphorus (25.32 kg ha^{-1}), and medium in potassium content (180.54 kg ha^{-1}). The moisture content at field capacity and permanent wilting point were 18.44 and 7.88% respectively. The bulk density was 1.41 Mg cm^{-3}. The experiment consisted of three irrigation systems as main plots *viz.,* M_1 - surface drip irrigation system, M_2 - sub-surface drip irrigation system, M_3 - surface irrigation system, three irrigation levels as sub-plot *viz.,* S_1-1.2 Epan; IW/CPE, S_2-0.9 Epan; IW/CPE, S_3-0.6 Epan; IW/CPE and two nitrogen levels as sub-sub-plot *viz.,* N_1-100 percent RDN, N_2- 75 percent RDN in split plot design replicated thrice. Maize and groundnut varieties KMNH-4010141 and Leepakshi constituted the experimental material. The gross and net plot sizes were 6.0 m x 4.8 m and 4.8 m x 3.6 m, respectively. A complete drip system was installed by Netafim Irrigation Limited. The water distribution system consisted of a mainline and eighteen sub-mains, each having a control valve for water regulation. Irrigation water from manifolds flowed into 16 mm dripper lines laid out on the ground surface at 0.60 m apart with a spacing of 0.40 m between two inline emitters delivering 2 L hr^{-1} in surface drip irrigation system while in subsurface irrigation system the dripper lines were laid out 15 cm below the soil surface with the same spacing and specification as in surface drip irrigation system. Control valves were fixed separately to each treatment plot to facilitate controlling the water flow as per treatments. A water meter was fixed at the head control unit to quantify the amount of water delivered in each irrigation treatment. Scheduling of irrigation in M_1 and M_2 was fixed daily for maize and groundnut crops based on daily evaporation data recorded from (USWB open pan Evaporimeter) obtained from the ACRC, ARI, Rajendranagar, Hyderabad. In the surface irrigation system (M_3) the sub-treatment plots were leveled manually, and ridge & furrow and flat-bed land configurations were maintained for maize and groundnut crops during both years of the experiment. In maize and groundnut crops the irrigation was scheduled based on a

Table 1. Fertigation schedule for *rabi* maize

Crop growth stage	Nutrient dose (kg ha^{-1} day^{-1})	
	Urea	SOP
After sowing; 20 days (10 – 30 DAS)	3.22	1.48
Grand growth period; 25 days (31-55 DAS)	8.66	2.48
Reproductive stage; 20 days (56 – 75 DAS)	8.16	1.98
Kernel development stage; 25 days (76 – 90 DAS)	4.95	1.98

climatological approach when CPE reached 50- and 60-mm depth respectively.

Recommended doses of N, P_2O_5, and K_2O were 240:80:80 and 30:40:50 kg ha^{-1} NPK for maize and groundnut respectively, applied in the form of urea, single super phosphate, and sulfate of potassium for maize while urea, single super phosphate, and muriate of potash for groundnut. In both surface and sub-surface drip irrigation systems (M_1 and M_2) a comprehensive fertigation schedule was adopted for maize crop which was already developed by PJT Agricultural University based on crop growth stages and their uptake patterns (Table 1) while in groundnut crop due to lesser amount (30 kg RDN ha^{-1}) and fertigation upto only 30 DAS the fertigation of total applied N was done in 4 splits at one-week interval after proper crop establishment. In the surface irrigation system (M_3) for maize crop, 1/3rd N, full dose of P_2O_5 and K_2O were applied as basal while remaining 2/3rd N was applied in two splits; 1/3rd N at knee height stage and remaining 1/3rd at tasseling depending on irrigation levels in both years whereas in groundnut crop under surface irrigation system, 2/3rd N, full dose of P_2O_5 and K_2O were applied as basal dose while remaining 1/3rd N was applied at 30 DAS.

3. RESULTS AND DISCUSSION

3.1 Effects of Irrigation Systems, Irrigation, and N Levels on Economics in Maize and Groundnut

3.1.1 Effects of irrigation systems

A scrutiny of data (Tables 2 and 3) indicated that the mean gross returns (₹. 1,40,507 and 1,91,409 ha^{-1}), net returns (₹. 85,006 and 1,39,683 ha^{-1}) and BCR (2.53 and 3.70) in sub-surface drip irrigation system (M_2) were significantly highest in both maize and groundnut crops when compared to surface drip irrigation (M_1) and surface irrigation systems (M_3) while the returns and BCR under M_3 remained significantly inferior to M_1 and M_2 in both crops during both the seasons and in means. In maize crop, the M_2 recorded 13.12% & 40.94%, 23.1% & 78.7%, 12.4% & 32.5% increased mean gross returns, net returns, and BCR when compared to M_1 and M_3 (Table 2) while in groundnut crop with same irrigation system (M_2) an increased (8.8% & 47.3%, 12.1% & 71.2% and 8.1% & 37.9%) mean gross returns, net returns and BCR was recorded over two other irrigation systems (M_1 and M_3) (Table 3). The higher returns and BCR in drip irrigation systems could be attributed to higher economic yields, lesser cost of cultivation, and efficient use of fertilizers. Current results are also in similarity with Sivanappan, (1978) who worked out the economics of drip irrigation and reported that drip irrigation gave an additional amount of ₹. 10,000 year^{-1} on a small farm where the available water was not sufficient to irrigate by surface method. Pawar et al. (2015) also reported that the drip irrigation system resulted in 27% higher gross returns (₹. 1,13,480 ha^{-1}) than surface irrigation system (₹. 89,302 ha^{-1}). Joshi et al (2015) also observed higher net returns and BCR in drip irrigation over surface irrigation systems. These findings are also supported by Shruti and Aladakatti (2017) who observed furrow method of irrigation recorded the least net returns (₹. 58,317 ha^{-1}) as well as the lowest BCR (2.18) when compared with the drip irrigation system.

3.1.2 Effects of irrigation levels

Data presented in Tables 2 and 3 indicated that, among the three irrigation levels, 1.2 Epan; IW/CPE (S_1) recorded significantly higher gross returns, net returns, and BCR over the other two irrigation levels (S_2 and S_3) in both crops (maize and groundnut) during both the seasons and in mean while the lowest returns and BCR was recorded under irrigation scheduled at 0.6 Epan; IW/CPE (S_3). In the maize crop an overall 5.83% & 44.89%, 9.31% & 100.75%, 4.96% & 42.95%, and in the groundnut crop 3.64% & 53.3%, 4.7% & 88.2%, 2.7% & 50.9% increased mean gross, net returns and BCR was witnessed with S_1 over two other irrigation levels (S_2 & S_3) (Tables 2 and 3). The reason for higher returns and BCR with S_1 (1.2 Epan; IW/CPE) could be attributed to favorable soil moisture conditions maintained throughout the crop growth period which enhanced the photosynthetic rate, biomass accumulation, and partition into economic parts. The lowest returns and BCR under S_3 (0.6 Epan; IW/CPE) might be because moisture was not sufficient for the crop to absorb the nutrients efficiently, as water is a medium for nutrient absorption, which resulted in reduced leaf area, photosynthesis, biomass production and consequently lesser economic yield. Similar findings were also reported by Shivakumar et al. (2011), Sharan (2012), and Bibe et al. (2017).

3.1.3 Effects of nitrogen levels

Among N levels significantly higher mean gross returns (₹. 1,27,180 and ₹.1,72,190 ha^{-1}), net returns (₹. 72,524 and ₹.1,21,650 ha^{-1}) and BCR (2.31 and 3.39) was observed with N_1 (100 percent RDN) in both maize and groundnut crops and hence proved economically profitable over N_2 (75 percent RDN) which resulted in comparatively lesser mean gross returns (₹. 1,15,756 and ₹.1,59,336 ha^{-1}), net returns (₹. 61,879 and ₹. 1,08,892 ha^{-1}) and BCR (2.14 and 3.14) (Tables 2 and 3). The mean increase with N_1 over N_2 was 9.87%, 17.2% & 8.23% in maize and 8.1%, 11.7%, and 7.9% in groundnut crop in terms of mean gross returns, net returns and BCR. The application of 100 percent RDN (N_1) was by the plants' nutrient needs resulting in higher economic yields. The higher returns and BCR in N_1 are attributed to the higher availability of N in the soil solution, which resulted in higher absorption and improved crop growth and ultimately final yield, which resulted in higher economic returns. Similarly, Fanish et al. (2011) and Sharan (2012) also reported higher economic returns under increased levels of fertilizers.

3.2 Interaction Effects

The interaction effects of different treatments on the economics of maize and groundnut are depicted in (Tables 4, 5, 6, 7 and 8). The interaction between irrigation systems and irrigation levels (M x S), irrigation systems and N levels (M x N), irrigation levels and N levels (S x N), and the interaction effect within irrigation systems, irrigation levels and N levels (M x S x N) was significant in maize crop while in groundnut all the interactions were non-significant except for the interaction between irrigation systems and irrigation levels (M x S) during both the years.

3.2.1 Interaction between different irrigation systems and irrigation levels

Whenever maize and groundnut crops are grown with limited water specific methodologies/ systems shall be adopted to ensure maximum returns. In the current study in case of interaction between the irrigation systems and irrigation levels (M x S), the sub-surface drip irrigation levels with either 1.2 or 0.9 Epan (M_2S_1 and M_2S_2) resulted in higher gross returns, net returns, and BCR followed by surface drip irrigation levels with 1.2 or 0.9 Epan (M_1S_1 and M_1S_2) over surface flood irrigation with 1.2, 0.9 or 0.6 IW/CPE ratios (M_3S_1, M_3S_2 or M_3S_3) (Tables 4 and 5). The mean gross returns (₹. 1,51,594 and ₹. 2,13,539 ha^{-1}), net returns (₹. 95,760 and ₹. 1,61,479 ha^{-1}) & BCR (2.71 and 4.10) were significantly higher in sub-surface drip irrigation system with 1.2 Epan (S_1) and decreased in order: M_2S_2 > M_1S_1 > M_1S_2 > M_3S_1 > M_2S_3 > M_3S_2 > M_1S_3 > M_3S_3 in both maize and groundnut crops. An overall 6.3, 15.2, 53.8, 1.4, 25.7, 25.6, 36.4 & 125.5% increased mean gross returns and 10.0, 25.5, 19.0, 2.04, 46.3, 41.2, 61.9 & 510.0% increased mean net returns were observed in maize crop (Table 4) whereas in groundnut crop an overall 5.03, 6.4, 72.5, 3.7, 37.9, 39.4, 48.9 & 129.1% increased mean gross returns and 6.5, 8.1, 121.9, 4.8, 56.1, 55.1, 69.7 & 255.5% increased mean net returns were recorded with M_2S_1 over M_1S_1, M_1S_2, M_1S_3, M_2S_2, M_2S_3, M_3S_1, M_3S_2 and M_3S_3 respectively (Table 5). Similarly, M_2S_2 registered 4.8, 13.6, 51.6, 23.9, 23.7, 34.4 and 122.2% increased mean gross returns and 7.8, 23.0, 14.5, 43.4, 38.3, 58.7 and 497.7% increased net returns in maize and 1.3, 2.6, 66.3, 33.0, 34.4, 43.6 & 120.9% increased mean gross returns and 1.7, 3.2, 111.8, 49.0, 48.0, 61.9 & 239.3% increased net returns in groundnut over M_1S_1, M_1S_2, M_1S_3, M_2S_3, M_3S_1, M_3S_2, and M_3S_3 respectively. The maximum returns and BCR returns in sub-surface drip irrigation systems with 1.2 and 0.9 Epan are because of maximum economic yield under the same irrigation system and levels. These findings acquire reasonable support from Aladakatti et al. (2012) who reported better monetary returns (₹. 34,025 ha^{-1}) and BCR (1.93) under drip irrigation at 1.0 Epan over surface irrigation system (₹. 29,556 ha^{-1} and 1.79).

Table 2. Effects of irrigation systems, irrigation, and N levels on the profitability of *rabi* maize (2021-22 and 2022-23)

Treatment	Cost of Cultivation (₹. ha^{-1})			Gross returns (₹. ha^{-1})			Net returns (₹. ha^{-1})			Benefit-cost ratio (BCR)		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Main plots (M - Irrigation systems)												
M_1 (Surface drip irrigation)	53687	56637	55162	116347	132058	124202	62659	75421	69040	2.16	2.33	2.25
M_2 (Sub-surface drip irrigation)	54026	56976	55501	128364	152651	140507	74337	95674	85006	2.37	2.68	2.53
M_3 (Surface furrow irrigation)	50662	53612	52137	94585	104805	99695	43923	51193	47558	1.86	1.95	1.91
S.Em±	-	-	-	1066	336	-	1066	336	-	0.020	0.006	-
C.D. (P = 0.05)	-	-	-	4186	1319	-	4186	1319	-	0.078	0.025	-
Subplots (S - Irrigation levels)												
S_1 (1.2 Epan; IW/CPE)	53264	56214	54739	128023	148554	138288	74758	92340	83549	2.40	2.64	2.52
S_2 (0.9 Epan; IW/CPE)	52764	55714	54239	120598	140751	130674	67834	85036	76435	2.28	2.52	2.40
S_3 (0.6 Epan; IW/CPE)	52347	55297	53822	90674	100209	95442	38327	44912	41619	1.72	1.80	1.76
S.Em±	-	-	-	1613	1000	-	1613	1000	-	0.030	0.018	-
C.D. (P = 0.05)	-	-	-	4972	3082	-	4972	3082	-	0.092	0.055	-
Sub-subplots (N - Nitrogen levels)												
N_1 (100 per cent RDN)	47864	50519	49191	118356	136005	127180	65174	79873	72524	2.22	2.41	2.31
N_2 (75 per cent RDN)	47162	49817	48489	107841	123671	115756	55439	68319	61879	2.05	2.23	2.14
S.Em±	-	-	-	761	764	-	761	764	-	0.014	0.013	-
C.D. (P = 0.05)	-	-	-	2260	2271	-	2260	2271	-	0.042	0.040	-

Table 3. Effects of irrigation systems, irrigation, and N levels on the profitability of summer groundnut (2022 and 2023)

Treatment	Cost of Cultivation (₹. ha^{-1})			Gross returns (₹. ha^{-1})			Net returns (₹. ha^{-1})			Benefit-cost ratio (BCR)		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Main plots (M - Irrigation systems)												
M_1 (Surface drip irrigation)	50013	52763	51388	174885	177000	175943	124872	124238	124555	3.49	3.35	3.42
M_2 (Sub-surface drip irrigation)	50352	53102	51727	190969	191849	191409	140618	138747	139682	3.79	3.61	3.70
M_3 (Surface flood irrigation)	46987	49737	48362	128212	131663	129937	81225	81926	81575	2.72	2.64	2.68
S.Em±	-	-	-	1787	3150	-	1787	3150	-	0.036	0.062	-
C.D. (P = 0.05)	-	-	-	7017	12368	-	7017	12368	-	0.141	0.243	-
Subplots (S - Irrigation levels)												
S_1 (1.2 Epan; IW/CPE)	49589	52339	50964	189425	190627	190026	139836	138288	139062	3.81	3.63	3.72
S_2 (0.9 Epan; IW/CPE)	49089	51839	50464	182463	184210	183337	133374	132371	132872	3.70	3.54	3.62
S_3 (0.6 Epan; IW/CPE)	48673	51423	50048	122177	125675	123926	73505	74252	73878	2.50	2.43	2.46
S.Em±	-	-	-	1572	2284	-	1572	2284	-	0.031	0.045	-
C.D. (P = 0.05)	-	-	-	4845	7040	-	4845	7040	-	0.097	0.139	-
Sub-subplots (N - Nitrogen levels)												
N_1 (100 per cent RDN)	44249	46724	45486	171598	172782	172190	122433	120867	121650	3.47	3.31	3.39
N_2 (75 per cent RDN)	44162	46637	45400	157780	160893	159336	108711	109074	108892	3.20	3.09	3.14
S.Em±	-	-	-	1319	1684	-	1319	1684	-	0.027	0.033	-
C.D. (P = 0.05)	-	-	-	3919	5005	-	3919	5005	-	0.080	0.098	-

Table 4. Interaction effects of irrigation systems and irrigation levels on the profitability of *rabi* maize (2021-22 and 2022-23)

Treatment	Cost of Cultivation (₹. ha^{-1})			Gross returns (₹. ha^{-1})			Net returns (₹. ha^{-1})			Benefit-cost ratio (BCR)		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
M_1S_1	54021	56971	55496	131020	154096	142558	76999	97125	87062	2.42	2.70	2.56
M_1S_2	53720	56671	55196	121932	141096	131514	68212	84425	76318	2.27	2.49	2.38
M_1S_3	53321	56271	54796	96088	100982	98535	42767	44711	43739	1.80	1.79	1.80
M_2S_1	54360	57310	55834	139071	164118	151594	84711	106808	95760	2.56	2.86	2.71
M_2S_2	54060	57010	55534	134102	164641	149371	80042	107631	93837	2.48	2.89	2.68
M_2S_3	53659	56610	55135	111917	129194	120556	58258	72584	65421	2.09	2.28	2.18
M_3S_1	51412	54362	52887	113977	127450	120713	62565	73088	67826	2.22	2.34	2.28
M_3S_2	50512	53462	51987	105760	116515	111137	55248	63053	59150	2.09	2.18	2.14
M_3S_3	50062	53012	51537	64018	70452	67235	13956	17440	15698	1.28	1.33	1.30
Irrigation systems means at the same or different levels of irrigation levels.												
S.Em±	-	-	-	2403	1434	-	2403	1434	-	0.045	0.026	-
C.D. (P = 0.05)	-	-	-	7769	4485	-	7769	4485	-	0.144	0.081	-
Irrigation levels mean at the same or different levels of irrigation systems.												
S.Em±	-	-	-	2795	1732	-	2795	1732	-	0.052	0.031	-
C.D. (P = 0.05)	-	-	-	8612	5339	-	8612	5339	-	0.160	0.096	-

Table 5. Interaction effects of irrigation systems and irrigation levels on the profitability of summer groundnut (2022 and 2023)

Treatment	Cost of Cultivation (₹. ha^{-1})			Gross returns (₹. ha^{-1})			Net returns (₹. ha^{-1})			Benefit-cost ratio (BCR)		
	2022	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**	**2022**	**2023**	**Mean**
M_1S_1	50346	53096	51721	202986	203622	203304	152640	150526	151583	4.03	3.83	3.93
M_1S_2	50046	52796	51421	199460	202010	200735	149414	149214	149314	3.99	3.83	3.91
M_1S_3	49646	52396	51021	122209	125369	123789	72563	72973	72768	2.46	2.39	2.43
M_2S_1	50685	53435	52060	213052	214026	213539	162367	160591	161479	4.20	4.01	4.10
M_2S_2	50385	53135	51760	206035	205745	205890	155650	152610	154130	4.09	3.87	3.98
M_2S_3	49985	52735	51360	153821	155776	154798	103836	103041	103438	3.08	2.95	3.02
M_3S_1	47737	50487	49112	152237	154235	153236	104500	103748	104124	3.19	3.05	3.12
M_3S_2	46837	49587	48212	141896	144876	143386	95059	95289	95174	3.03	2.92	2.98
M_3S_3	46387	49137	47762	90502	95880	93191	44115	46743	45429	1.95	1.95	1.95
Irrigation systems means at the same or different levels of irrigation levels.												
S.Em±	-	-	-	2558	3924	-	2558	3924	-	0.051	0.077	-
C.D. (P = 0.05)	-	-	-	8729	13708	-	8729	13708	-	0.175	0.270	-
Irrigation levels means at the same or different levels of irrigation systems.												
S.Em±	-	-	-	2723	3957	-	2723	3957	-	0.054	0.078	-
C.D. (P = 0.05)	-	-	-	8391	12193	-	8391	12193	-	0.168	0.241	-

Table 6. Interaction effects of irrigation systems and N levels on the profitability of *rabi* maize (2021-22 and 2022-23)

Treatment	Cost of Cultivation (₹. ha^{-1})			Gross returns (₹. ha^{-1})			Net returns (₹. ha^{-1})			Benefit-cost ratio (BCR)		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
M_1N_1	54078	57027	55552	123409	141294	132351	69331	84267	76799	2.28	2.48	2.38
M_1N_2	53298	56248	54772	109285	122822	116053	55987	66574	61281	2.05	2.18	2.12
M_2N_1	54417	57367	55892	135139	158565	146852	80722	101198	90960	2.48	2.76	2.62
M_2N_2	53637	56587	55112	121589	146737	134163	67952	90150	79051	2.27	2.59	2.43
M_3N_1	51052	54001	52526	96519	108157	102338	45467	54156	49812	1.89	2.00	1.94
M_3N_2	50272	53222	51747	92650	101453	97052	42378	48231	45305	1.84	1.90	1.87
Irrigation systems means at the same or different levels of nitrogen levels.												
S.Em±	-	-	-	1416	995	-	1416	995	-	0.026	0.018	-
C.D. (P = 0.05)	-	-	-	4974	3063	-	4974	3063	-	0.093	0.055	-
Nitrogen levels mean at the same or different levels of irrigation systems.												
S.Em±	-	-	-	1317	1324	-	1317	1324	-	0.025	0.023	-
C.D. (P = 0.05)	-	-	-	3915	3933	-	3915	3933	-	0.073	0.069	-

Table 7. Interaction effects of irrigation and N levels on the profitability of *rabi* maize (2021-22 and 2022-23)

Treatment	Cost of Cultivation (₹. ha^{-1})			Gross returns (₹. ha^{-1})			Net returns (₹. ha^{-1})			Benefit-cost ratio (BCR)		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
S_1N_1	53655	56604	55129	135012	153759	144385	81357	97155	89256	2.51	2.71	2.61
S_1N_2	52874	55824	54349	121033	143350	132192	68159	87526	77843	2.29	2.56	2.42
S_2N_1	53154	56104	54630	127238	149149	138194	74084	93045	83564	2.39	2.65	2.52
S_2N_2	52374	55324	53849	113958	132352	123155	61584	77028	69306	2.17	2.39	2.28
S_3N_1	52738	55688	54213	92817	105109	98963	40079	49421	44750	1.75	1.88	1.81
S_3N_2	51958	54908	53433	88532	95310	91921	36574	40402	38488	1.69	1.73	1.71
Irrigation levels mean at the same or different levels of nitrogen levels.												
S.Em±	-	-	-	1863	1370	-	1863	1370	-	0.035	0.024	-
C.D. (P = 0.05)	-	-	-	5690	4151	-	5690	4151	-	0.106	0.074	-
Nitrogen levels mean at the same or different levels of irrigation levels.												
S.Em±	-	-	-	1317	1324	-	1317	1324	-	0.025	0.023	-
C.D. (P = 0.05)	-	-	-	3915	3933	-	3915	3933	-	0.073	0.069	-

Table 8. Interaction effects of irrigation systems, irrigation levels, and N levels on the profitability of *rabi* maize (2021-22 and 2022-23)

Treatment	Cost of Cultivation (₹. ha^{-1})			Gross returns (₹. ha^{-1})			Net returns (₹. ha^{-1})			Benefit-cost ratio (BCR)		
	2021-22	**2022-23**	**Mean**	**2021-22**	**2022-23**	**Mean**	**2021-22**	**2022-23**	**Mean**	**2021-22**	**2022-23**	**Mean**
$M_1S_1N_1$	54411	57361	55885	138438	160973	149705	84027	103612	93820	2.54	2.81	2.68
$M_1S_1N_2$	53631	56581	55106	123601	147219	135410	69970	90638	80304	2.30	2.60	2.45
$M_1S_2N_1$	54111	57061	55586	133970	156786	145378	79859	99725	89792	2.48	2.75	2.61
$M_1S_2N_2$	53331	56281	54806	109895	125407	117651	56564	69126	62845	2.06	2.23	2.14
$M_1S_3N_1$	53711	56661	55186	97819	106124	101971	44108	49463	46785	1.82	1.87	1.85
$M_1S_3N_2$	52931	55881	54406	94358	95840	95099	41427	39959	40693	1.78	1.72	1.75
$M_2S_1N_1$	54750	57700	56225	149554	167943	158749	94804	110243	102524	2.73	2.91	2.82
$M_2S_1N_2$	53969	56920	55445	128588	160292	144440	74619	103372	88995	2.38	2.82	2.60
$M_2S_2N_1$	54449	57400	55925	140269	171942	156106	85820	114542	100181	2.58	3.00	2.79
$M_2S_2N_2$	53670	56620	55145	127935	157339	142637	74265	100719	87492	2.38	2.78	2.58
$M_2S_3N_1$	54050	57000	55525	115592	135809	125701	61542	78809	70176	2.14	2.38	2.26
$M_2S_3N_2$	53270	56220	54745	108243	122580	115411	54973	66360	60666	2.03	2.18	2.11
$M_3S_1N_1$	51801	54751	53276	117042	132360	124701	65241	77609	71425	2.26	2.42	2.34
$M_3S_1N_2$	51022	53972	52497	110911	122539	116725	59889	68567	64228	2.17	2.27	2.22
$M_3S_2N_1$	50902	53852	52377	107476	118719	113097	56574	64867	60720	2.11	2.20	2.16
$M_3S_2N_2$	50122	53072	51597	104044	114311	109177	53922	61239	57580	2.08	2.15	2.11
$M_3S_3N_1$	50452	53402	51926	65040	73393	69216	14588	19991	17290	1.29	1.37	1.33
$M_3S_3N_2$	49672	52622	51147	62996	67510	65253	13324	14888	14106	1.27	1.28	1.28
Nitrogen levels mean at the same combination of irrigation systems and irrigation levels												
S.Em±	-	-	-	2282	2293	-	2282	2293	-	0.043	0.040	-
C.D. (P = 0.05)	-	-	-	6780	6813	-	6780	6813	-	0.127	0.120	-
Irrigation levels mean at the same combination of irrigation system and levels of nitrogen.												
S.Em±	-	-	-	3227	2373	-	3227	2373	-	0.060	0.042	-
C.D. (P = 0.05)	-	-	-	9855	7190	-	9855	7190	-	0.183	0.128	-
Irrigation systems means the same combination of irrigation levels and levels of nitrogen.												
S.Em±	-	-	-	2991	2178	-	2991	2178	-	0.056	0.039	-
C.D. (P = 0.05)	-	-	-	9442	6622	-	9442	6622	-	0.176	0.118	-

3.2.2 Interaction between the different irrigation systems and N levels

The interaction effects of irrigation systems and N levels were non-significant in groundnut crops however in maize crops a significant interaction was observed. Across irrigation systems and N levels, the M_2N_1 had significantly higher mean gross returns (₹. 1,46,852 ha^{-1}), net returns (₹. 90,960 ha^{-1}), and BCR (2.62) whereas M_3N_2 recorded lowermost mean gross returns (₹. 97,052 ha^{-1}), net returns (₹. 45,305 ha^{-1}) and BCR (1.87) (Table 6). An overall 10.9, 26.5, 9.45, 43.5 and 51.3% increased mean gross returns and 18.4, 48.4, 15.1, 82.6 and 100.7% mean net returns were observed with M_2N_1 over M_1N_1, M_1N_2, M_2N_2, M_3N_1, and M_3N_2 respectively while M_2N_2 registered 1.3, 15.6, 31.1 and 38.2% increased mean gross returns and 2.9, 29.0, 58.7 and 74.5% increased net returns over M_1N_1, M_1N_2, M_3N_1, and M_3N_2 respectively. Similar results were also reported by Selvakumar, (2006) who observed that drip irrigation at 1.0 Epan recorded additional net returns (₹. 1,23,679) and BCR (3:30) in chili followed by 0.8 Epan with 100% RDF registering an additional net return of (₹. 1,19,488) and BCR over surface irrigation system. These results findings are in further accordance with the findings of Senthilkumar (2000), Ramaprabha Nalini (1999) in groundnut, and Suresh Kumar (2000) in capsicum under a drip irrigation system.

3.2.3 Interaction between different irrigation levels and N levels

The interaction effects of irrigation and N levels were non-significant in groundnut crops however in maize crops the interaction effects between irrigation levels and N levels showed that S_1N_1 (1.2 Epan; IW/CPE with 100 percent RDN) resulted in significantly higher gross returns (₹. 1,44,385 ha^{-1}), net returns (₹. 89,256 ha^{-1}) and BCR (2.61) followed by S_2N_1 which obtained ₹. 1,38,194 ha^{-1} gross returns, ₹. 83,564 ha^{-1} net returns and 2.52 BCR (Table 7). The S_1N_1 registered 9.2, 4.5, 17.2, 45.9 & 75.1% increased mean gross returns and 14.7, 6.8, 28.8, 99.5 & 131.9% increased mean net returns over S_1N_2, S_2N_1, S_2N_2, S_3N_1 and S_3N_2 respectively while S_2N_1 registered 4.5, 12.2, 39.6 & 50.3% increased mean gross returns and 7.4, 20.6, 86.7 & 117.1% increased net returns over S_1N_2, S_2N_2, S_3N_1 and S_3N_2 respectively. Similar results were also observed by Sharan (2012) who recorded significantly higher net returns and BCR with drip irrigation level with 1.2 Epan (₹. 57,266 ha^{-1} and 2.6) followed by 1.0 Epan (₹. 54,331 ha^{-1} and 2.6) and 0.8 Epan (₹. 39,655 ha^{-1} and 2.2) and lowest with surface irrigation level with 1.0 IW/CPE. (₹. 19,489 ha^{-1} and 1.5). These findings are in further accordance with the findings of Vishwanatha et al. (2000) and Ramah et al. (2010).

3.2.4 Interaction between different irrigation systems, irrigation levels, and N levels

The interaction effects of irrigation systems (M), irrigation levels (S) and N levels (N) showed a significant impact on the economics of maize and revealed that sub-surface irrigation system (M_2) with 1.2 Epan (S_1) and 100 percent RDN (N_1) recorded significantly higher mean gross returns (₹. 1,58,749 ha^{-1}), net returns (₹. 1,10,243 ha^{-1}) and BCR (2.82) followed by $M_2S_2N_1$ which resulted in ₹. 1,56,106 ha^{-1}, ₹. 1,14,542 ha^{-1} and 2.79 mean gross returns, net returns, and BCR. In later treatments $M_1S_1N_1$ (surface drip irrigation system with 1.2 Epan and 100 percent RDN) and $M_1S_2N_1$ (surface drip irrigation system with 0.9 Epan and 100 percent RDN) resulted in comparatively higher gross returns (₹. 1,49,705 and 1,45,378 ha^{-1}), net returns (₹. 93,820 and 89,792 ha^{-1}) and BCR (2.68 and 2.61), however, $M_1S_2N_1$ remained statistically at par with $M_2S_1N_2$ (sub-surface drip irrigation system with 1.2 Epan and 75 percent RDN) during both the years (2021-22 and 2022-23) whereas the surface irrigation system with 0.6 IW/CPE and 75 percent RDN ($M_3S_3N_2$) recorded least gross returns (₹. 65,253 ha^{-1}), net returns (₹. 14,106 ha^{-1}) and BCR (1.28) thus making it the least remunerative among all treatment combinations studied (Table 8). Higher gross returns, net returns, and BCR in the current study were due to higher crop yields, and efficient use of fertilizers & irrigation water under a sub-surface irrigation system (M_2).

These findings are also supported by Shruti and Aladakatti (2017) who observed higher net returns (₹. 1,34,262 ha^{-1}) and improved BCR (3.25) under drip fertigation combination of 1.0 Epan with 100 percent RDNK over other treatments combinations such as 1.0 Epan with 75 percent RDNK.

4. CONCLUSION

Based on the results obtained in the present investigation it can be concluded that among different irrigation systems with varied irrigation and N levels, the implementation of a sub-surface drip irrigation system, 1.2 & 0.9 Epan ratios and 100 percent RDN could result in significant higher mean gross returns, net returns, and BCR in both maize and groundnut crops while satisfactory economics returns couldn't be achieved with surface irrigation system with 0.9 and 0.6 IW/CPE ratios and 75 percent RDN in both crops.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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