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INFLUENCE OF DEFICIT IRRIGATION LEVELS AND FOLIAR SPRAY OF OSMOREGULANTS ON GROWTH, YIELD, WATER PRODUCTIVITY AND ECONOMICS OF *RABI* MAIZE

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ABSTRACT

Water is one of the major constraints limiting the productivity of irrigated maize during the *rabi* season, necessitating the adoption of efficient irrigation strategies coupled with suitable stress-mitigating practices. A field experiment was conducted during *rabi* 2024-25 and 2025-26 at the Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad, Karnataka, on clay loam soil, to understand the response of *rabi* maize to deficit irrigation levels and foliar spray of osmoregulants. The experiment was laid in strip plot design with three replications comprising of sixteen treatment combinations. Treatments included 4 irrigation levels (drip irrigation at 0.8 ETc, 0.9 ETc and 1.0 ETc and furrow irrigation at 1.0 IW/CPE ratio) and foliar spray of osmorgulants (S_1:KNO_3 @ 0.5 per cent, S_2: hydrated aluminium silicate @ 0.5 per cent, S_3:glycine betaine @ 0.3 per cent and S_4:No foliar spray) at 30 and 60 DAS. The pooled data over two years indicated that furrow irrigation at 1.0 IW/CPE ratio and drip irrigation at 1.0 ETc recorded significantly higher and on par growth and yield parameters, grain yield (99.2 q/ha and 93.8 q/ha, respectively) and economic returns. Drip irrigation at 1.0 ETc minimized irrigation water use by 65.3-123.8 mm, corresponding to a water saving of 15.9-24.2 per cent and also recorded higher water productivity (2.57 kg m^{-3}) over furrow irrigation at a 1.0 IW/CPE ratio (2.19 kg m^{-3}). Among osmoregulants, foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS was found superior response over other treatments which was on par with KNO_3 @ 0.5 per cent spray at 30 and 60 DAS. The combination of furrow irrigation with foliar spray of osmoregulants at 30 and 60 DAS recorded significantly higher growth and yield parameters as well as grain yield, water productivity and economic returns over rest of the treatment combinations. However, this treatment combinations remained on par with drip irrigation at 1.0 ETc with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS and KNO_3 @ 0.5 per cent spray at 30 and 60 DAS. However, drip irrigation at 1.0 ETc with KNO_3 spray is effective in maximizing the productive use of available water and sustaining maize yield with better economic returns due to the lower cost of KNO_3.

***Keywords* :** Deficit irrigation, drip irrigation, osmoregulants, glycine betaine, potassium nitrate and water productivity.

Introduction

Water is most important natural resources supporting agricultural production, yet its availability for irrigation is declining because of climate change, erratic rainfall, rapid urbanization and excessive exploitation of groundwater resources. Agriculture alone accounts for nearly 70% of global freshwater withdrawals, making efficient irrigation management essential for ensuring food security and sustainable agricultural development. Among the Sustainable Development Goals (SDGs), several goals are directly associated effective utilization and conservation of water resources emphasizing the importance of improving water use efficiency in crop production systems.

Maize (*Zea mays* L.) is the most versatile crop having wider adaptability under varied agro-climatic conditions, high yield potential and multiple uses as food, feed and industrial raw material. In India, the crop is cultivated in an area of 10.74 m ha with the production of 43.41 m t and productivity of 4.04 t ha^{-1} (Anon., 2024). Particularly in *rabi*, crop is being cultivated over an area of 2.37 m ha with the production of 14.75 m t and productivity of 6.22 t ha^{-1} (Anon., 2025). The *rabi* maize yields are 20–50% higher than *kharif* maize but its complete dependence on irrigation makes it highly vulnerable, with yield losses ranging from 30-90% under moisture stress (Ray *et al.*, 2024), hence it calls for an effective on-farm management of water in field through micro irrigation to boost crop and water productivity. Drip irrigation is a proven technology to reduce the water conveying and application losses over furrow irrigation. Further, Government of India is also promoting the farmers to adopt micro irrigation through PMKSY with a motto of 'more crop per drop' and 'har khet ko paani'. Apart from this, the application of osmoregulants plays a crucial role in enhancing water productivity under water limited conditions. Osmoregulants such as KNO_3, hydrated aluminium silicate and glycine betaine help plants to maintain cellular osmotic balance, improve water uptake and mitigate the adverse effects of drought stress. Several studies have reported that exogenous application of osmoregulants enhances physiological processes, growth, yield and grain quality by improving plant tolerance to moisture stress. However, their effectiveness may vary depending on irrigation regimes, environmental conditions and crop management practices. Therefore, the hypothesis of the present study was that different drip irrigation levels and osmoregulant applications would significantly influence the growth, yield and water productivity of maize.

Materials and Methods

The experiment was conducted at Main Agriculture Research Station (MARS), University of Agricultural Sciences, Dharwad (Karnataka) under irrigated condition during *rabi* 2024-25 and 2025-26. During the crop growth period, total rainfall received was 15.2 mm during 2024-25 and 11.4 mm during 2025-26. The soil of the experimental site was clay loam with neutral to slight alkaline in reaction (7.72 pH), normal EC (0.27 dS/m), medium in organic carbon (0.57%), low in available nitrogen (263.45 kg/ha), medium in available phosphorus (31.50 kg/ha) and high in available potassium (348.52 kg/ha). The experiment was laid out in strip plot design involving 16 treatment combinations replicated thrice. The treatments included 4 irrigation levels (vertical strip plot), *viz.*, drip irrigation at 0.8 ETc (I_1), 0.9 ETc (I_2) and 1.0 ETc (I_3) and furrow irrigation at 1.0 IW/CPE ratio (I_4) and Horizontal strip includes 4 osmorgulants spray treatments *viz.*, S_1:KNO_3 @ 0.5 per cent, S_2:hydrated aluminium silicate @ 0.5 per cent, S_3:glycine betaine @ 0.3 per cent and S_4:No foliar spray. The maize hydrid DKC 9133 is sown by selecting healthy seeds manually with seed rate of 22.5 kg/ha at a spacing of 60 cm × 20 cm. N, P_2O_5 and K_2O were applied @150:65:65 kg/ha. Initially, 3 common (5 cm) irrigations were given through sprinkler at 8 to 10 days interval one before sowing and two after uniform germination and establishment of maize. Twenty days after sowing, irrigation was scheduled according to the treatments. The laterals (16 mm) and emitters 45 cm space (4.0 litre/hr discharge) were used for drip irrigation.

Table 1 : Total amount of water used during maize growing period

Irrigation	2024-25						2025-26					
	R (mm)	ER (mm)	E (mm)	IWA (mm)	TWU (mm)	WZD (cm)	R (mm)	ER (mm)	E (mm)	IWA (mm)	TWU (mm)	WZD (cm)
I_1= 0.8 ETc	15.2	10.8	475.1	297.8	308.6	34.0	11.4	11.4	543.7	331.0	342.4	33.1
I_2= 0.9 ETc	15.2	10.8	475.1	316.2	327.0	41.4	11.4	11.4	543.7	353.6	365.0	40.9
I_3= 1.0 ETc	15.2	10.8	475.1	334.7	345.5	45.0	11.4	11.4	543.7	376.2	387.6	43.8
I_4=1.0 IW/CPE	15.2	10.8	475.1	400.0	410.8	*	11.4	11.4	543.7	500.0	511.4	*

Where R: Rainfall, ER: Effective Rainfall, E: Evaporation, CPE: Cumulative Pan Evaporation, IWA: Irrigation Water Applied, TWU: Total Water Used and WZD: Wetting zone diameter, *- Entire furrow is wetted

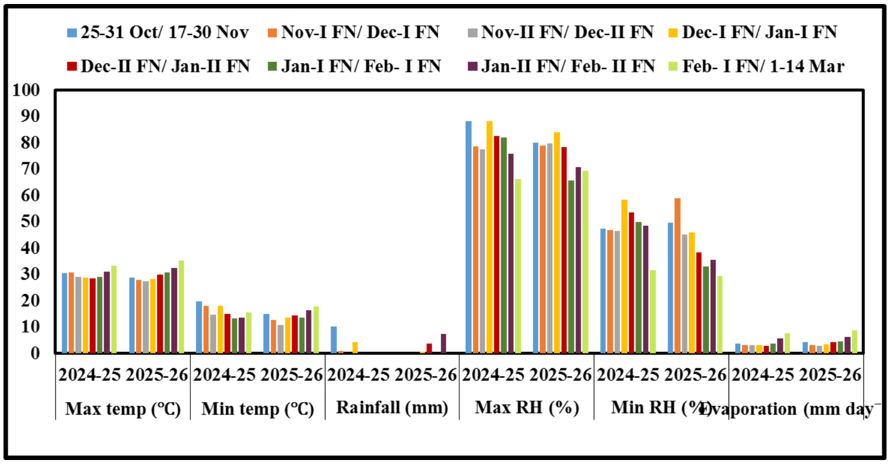

Fig. 1 : Mean meteorological data for the experimental year 2024-25 and 2025-26 during maize growing season at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad

Drip irrigation scheduling at 5-day intervals was based on crop evapotranspiration (ETc). The ETc was estimated in two steps. First, the reference evapotranspiration (ETo; mm) was calculated using the modified Penman–Monteith approach based on pan evaporation (Equation 1).

$$ETo = Ep \times Kp \qquad (1)$$

where, *Ep* is the daily pan evaporation (mm) and *Kp* is the pan coefficient (0.75).

Daily pan evaporation data were recorded using a Class A open pan evaporimeter installed at the Agrometeorological observatory, MARS, Dharwad. The average daily pan evaporation during the crop growth period was 4.1 mm in 2024-25 and 4.7 mm in 2025-26. Subsequently, crop evapotranspiration (ETc) was estimated using the reference evapotranspiration and crop coefficient (Kc) values as given by Allen *et al.* (1998) follows (Equation 2):

$$ETc = ETo \times Kc \qquad (2)$$

where, *Kc* is the crop coefficient of maize.

Table 2 : Crop coefficient values used during maize growth period

Crop growth stage	Duration (days)	Crop coefficient (Kc)
Seedling/ initial stage	20	0.40
Vegetative / crop development stage	35	0.80
Reproductive / mid season stage	40	1.15
Late season stage	30	0.70

The application rate of the drip system/total water applied and duration of irrigation were done based on following equation

$$\text{Duration of irrigation (minutes)} = \frac{\text{Total water applied (1)} \times 60}{\text{No. of emitters} \times \text{emitter discharge (1 per hr)}}$$

Water productivity was calculated by using the following formula and expressed in kilogram per cubic meter

$$\text{Water productivity (kg m}^{-3}\text{)} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Water applied (m}^{3}\text{)}}$$

Further, five representative plants were randomly selected and tagged in each net plot for recording various growth and yield attributes. The experimental data were compiled and subjected to statistical analysis following Fisher's method of analysis of variance (ANOVA) and treatment means were tested at the 5% level of significance using the critical difference (CD) test (Gomez and Gomez 1984). The mean values of vertical strip, horizontal strip and their interactions were further compared using Duncan's Multiple Range Test (DMRT) with the corresponding error mean square and degrees of freedom was carried out using the OPSTAT statistical package.

Results

Growth parameters

The pooled data of two years revealed that growth of maize differed significantly due to irrigation levels (Table 3). Furrow irrigation at 1.0 IW/CPE ratio recorded significantly higher growth parameters like plant height (215.3 cm) and total dry matter production (253.1 g plant^{-1}) at harvest, leaf area (61.59 dm^{2} plant^{-1}) and stem girth (7.13 cm) at 60 DAS and this treatment was on par with drip irrigation at 1.0 ETc with plant height of 199.9 cm and total dry matter production of 243.6 g plant^{-1} at harvest, leaf area of 58.55 dm^2 plant^{-1} and stem girth of 6.95 cm at 60 DAS. when compared to the drip irrigation at 0.9 ETc and 0.8 ETc. Among the osmoregulants sprays, foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS recorded significantly higher growth parameters such as like plant height (200.0 cm) and total dry matter production (240.6 g plant^{-1}) at harvest, leaf area (57.78 dm^2 plant^{-1}) and stem girth (7.08 cm) at 60 DAS and this treatment was found on par with foliar spray of KNO_3 @ 0.5 per cent at 30 and 60 DAS with plant height of 194.2 cm and total dry matter production of 234.1 g plant^{-1} at harvest, leaf area of 56.33 dm^2 plant^{-1} and stem girth of 6.90 cm at 60 DAS over that of other foliar spray treatment. The interaction effect of irrigation levels and osmoregulant sprays was found significant (Table 3). Furrow irrigation at 1.0 IW/CPE ratio with foliar application of glycine betaine @ 0.3% at 30 and 60 DAS recorded significantly higher growth parameters *viz.*, plant height (221.8 cm) and total dry matter production (260.3 g plant^{-1}) at harvest, leaf area (63.66 dm^2 plant^{-1}) and stem girth (7.42 cm) at 60 DAS. However, it remained statistically on par with furrow irrigation at 1.0 IW/CPE ratio with KNO_3 @ 0.5% spray at 30 and 60 DAS, hydrated aluminium silicate @ 0.5 per cent spray at 30 and 60 DAS and no foliar spray, drip irrigation at 1.0 ETc with foliar spray of glycine betaine @ 0.3% at 30 and 60 DAS and KNO_3 @ 0.5% spray at 30 and 60 DAS.

Yield parameters and yield

The pooled data from the experiment conducted for two years revealed that irrigation levels had significant effect on yield parameters and yield of maize (Table 3). Furrow irrigation at 1.0 IW/CPE ratio recorded significantly higher cob length (17.0 cm), cob diameter (4.79 cm), number of grain per cob (554.7), cob weight (184.4 g plant^{-1}) and grain yield (99.2 q ha^{-1}), this treatment was found on par with drip irrigation at 1.0 ETc (16.2 cm, 4.68 cm, 506.7, 165.1 g plant^{-1}, 93.8 q ha^{-1}, respectively) over other irrigation levels. Similarly, foliar spray of osmoregulants had significant influence on yield parameters and yield of maize. Significantly higher yield parameters and yield of maize *viz.*, cob length (15.9 cm), cob diameter (4.61 cm), number of grain per cob (487.8), cob weight (159.5 g plant^{-1}) and grain yield (88.2 q ha^{-1}) was recorded with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS and this treatment was noticed on par with foliar spray of KNO_3 @ 0.5 per cent at 30 and 60 DAS (15.5 cm, 4.55 cm, 463.3, 151.3 g plant^{-1}, 83.8 q ha^{-1}, respectively) over other treatments. The interaction effect of irrigation levels and foliar spray of osmoregulants showed significant influence on yield parameters and yield of maize. Furrow irrigation at 1.0 IW/CPE ratio with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS recorded significantly highest cob length (17.7 cm), cob diameter (4.84 cm), number of grain per cob (582.4), cob weight (198.0 g plant^{-1}) and grain yield (103.8 q ha^{-1}) and this treatment was registered on par results with furrow irrigation at 1.0 IW/CPE ratio with KNO_3 @ 0.5% spray at 30 and 60 DAS, hydrated aluminium silicate @ 0.5 per cent spray at 30 and 60 DAS and no foliar spray, drip irrigation at 1.0 ETc with foliar spray of glycine betaine @ 0.3% at 30 and 60 DAS and KNO_3 at 0.5% spray at 30 and 60 DAS.

Water productivity

Different deficit irrigation treatments noticed significant influence. The drip irrigation at 1.0 ETc saved 15.9 to 24.2 per cent water over furrow irrigation (Table 1). Similarly, significantly the highest water productivity (2.57 kg m^{-3}) was recorded with drip irrigation at 1.0 ETc over furrow irrigation at 1.0 IW/CPE ratio (2.19 kg m^{-3}) (Table 4). Among the foliar spray of osmorgeulants, the highest water productivity was recorded with foliar spray of glycine betaine @ 0.3 per cent at 30 DAS and 60 DAS (2.37 kg ha^{-1}) and it was on par with KNO_3 @ 0.5 per cent spray at 30 and 60 DAS (2.25 kg ha^{-1}). Whereas, the lowest water productivity (1.97 kg ha^{-1}) was recorded in no foliar spray. The interaction effect of irrigation levels and foliar spray of osmorgeulants showed a significant effect on water productivity. Drip irrigation at 1.0 ETc with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS recorded significantly higher water productivity (2.77 kg m^{-3}) and it remained on par with drip irrigation at 1.0 ETc with KNO_3 @ 0.5 per cent spray (2.58 kg m^{-3}), hydrated aluminium silicate @ 0.5 per cent spray (2.51 kg m^{-3}) and drip irrigation at 0.9 ETc with glycine betaine @ 0.3 per cent spray at 30 and 60 DAS (2.56 kg m^{-3}) as compared to other treatment combinations. However, drip irrigation at 0.8 ETc with no foliar spray of osmoregulants recorded significantly lowest water productivity (1.45 kg m^{-3}).

Economics of maize

The economics data (Table 4) depicted that, cost of cultivation (considered 90 % subsidy for drip irrigation) increased with increase in irrigation amount under drip irrigation and highest was with drip irrigation at 1.0 ETc (Rs. 69491/ ha). Whereas, the lowest cost of cultivation was observed under drip irrigation at 0.8 ETc (Rs. 66616/ha) and furrow irrigation at 1.0 IW/CPE ratio (Rs. 67271/ha). Further, furrow irrigation at 1.0 IW/CPE ratio (Rs. 218499 ha^{-1}, Rs. 1,51,227 ha^{-1} and 3.27) and drip irrigation at 1.0

ETc (Rs. 206847 ha^{-1}, Rs. 1,37,356 ha^{-1} and 3.00) were on par with each other, but recorded significantly higher gross returns, net returns and B-C ratio, respectively when compared to other irrigation levels. Among the tested osmoregulants, the maximum cost of cultivation was recorded with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS (Rs. 78507 ha^{-1}) whereas, no foliar spray recorded minimum cost of cultivation (Rs. 62212 ha^{-1}). Foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS (Rs. 194540 ha^{-1}) recorded higher gross returns and it was on par with foliar spray of KNO_3 @ 0.5 per cent spray at 30 and 60 DAS (Rs. 185157 ha^{-1}). However, foliar spray of KNO_3 @ 0.5 per cent spray at 30 and 60 DAS to recorded highest net returns (Rs. 118854 ha^{-1}) and benefit cost ratio (2.80) and it was found on par with glycine betaine @ 0.3 per cent at 30 and 60 DAS with respect to net returns (Rs. 116033 ha^{-1}).

Among interaction treatments the highest cost of cultivation was recorded with drip irrigation at 1.0 ETc with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS (Rs. 80090/ha). Furrow irrigation at 1.0 IW/CPE ratio with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS recorded significantly higher gross returns (Rs. 2,28,491 ha^{-1}) as compared to other treatment combinations and was on par with furrow irrigation at 1.0 IW/CPE ratio with foliar spray KNO_3 @ 0.5 per cent (Rs. 2,22,572 ha^{-1}) and hydrated aluminium silicate @ 0.5 per cent spray (Rs. 2,17,227 ha^{-1}) and drip irrigation at 1.0 ETc with glycine betaine @ 0.3 per cent spray (Rs. 2,22,092 ha^{-1}), KNO_3 @ 0.5 per cent spray (Rs. 2,07,168 ha^{-1}) at 30 and 60 DAS. However, furrow irrigation at 1.0 IW/CPE ratio with foliar spray of KNO_3 @ 0.5 per cent at 30 and 60 DAS recorded significantly higher net returns (Rs. 1,56,942 ha^{-1}) and B-C ratio (3.40) and it was found on par with furrow irrigation at 1.0 IW/CPE ratio with foliar spray of hydrated aluminium silicate @ 0.5 per cent spray, glycine betaine @ 0.3 per cent spray and with no foliar spray and drip irrigation at 1.0 ETc with glycine betaine @ 0.3 per cent spray, KNO_3 @ 0.5 per cent spray at 30 and 60 DAS. Whereas, drip irrigation at 0.8 ETc with no foliar spray of osmorgeulants recorded significantly the lowest net returns.

Discussion

From the present the study, the higher growth parameters under furrow irrigation at 1.0 IW/CPE ratio with foliar spray of osmoregulants and drip irrigation at 1.0 ETc with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS and KNO_3 @ 0.5 per cent at 30 and 60 DAS due to the optimum availability of soil moisture in root zone coupled with improved physiological efficiency imparted by foliar applied osmoprotectants might have enhanced nutrient uptake and promoted synthesis of nucleic acids, amino acids and amide compounds in vegetative meristematic tissues, which ultimately increased cell division and elongation, resulted in higher plant height. Similar findings have been reported by Youseef and Hozayenb (2019) and Elmasry and El-Rady (2024). This further, strengthened source-sink activity which increased the synthesis, translocation of structural carbohydrates and assimilates in plant tissues, which ultimately contributed towards higher total dry matter production (Bayat and sepehri, 2012, Shafiq *et al.,* 2021 and Kathwal *et al*., 2022).

Leaf area and stem girth were also significantly improved under higher irrigation levels *i.e.,* furrow irrigation at 1.0 IW/CPE ratio and drip irrigation at 1.0 ETc combined with glycine betaine and KNO_3 application. Maintenance of adequate plant water status promoted leaf expansion, chlorophyll retention and photosynthetic activity, while efficient uptake and transport of water and mineral nutrients through the xylem supported vigorous vegetative growth. Improved assimilate translocation through the phloem further contributed to stem thickening and overall crop vigour. These results are consistent with earlier reports of Shemi *et al*. (2021), Sivakumar *et al*. (2023) and Ishfaq *et al*. (2024).

In this study, the increase in yield parameters and yield under treatment furrow irrigation at 1.0 IW/CPE ratio with foliar spray of osmoregulants and drip irrigation at 1.0 ETc with foliar spray of glycine betaine @ 0.3 per cent at 30 and 60 DAS and KNO_3 @ 0.5 per cent at 30 and 60 DAS attributed to enhanced physiological activity during the reproductive phase (Abdelgalil, 2022 and Morsy, and Mehanna, 2022). Adequate moisture availability maintained favourable plant water relations, while foliar-applied osmoregulants improved osmotic regulation, stomatal function and photosynthetic efficiency under varying moisture conditions. These responses likely enhanced pollen viability, fertilization, kernel set and assimilate partitioning towards developing grains, resulted in superior cob characteristics and grain yield. These findings are in close conformity with the observations of Noreen *et al.* (2017) and Salih and Aissa (2023).

The larger wetted soil volume under drip irrigation at 1.0 ETc was mainly attributed to the higher quantity and frequent application of irrigation water which enhanced lateral and vertical water movement within the soil profile. Owing to the expanded wetted zone and water supply was maintained in the crop root zone. Although furrow irrigation produced grain yields comparable with drip irrigation at 1.0 ETc, drip irrigation achieved substantially higher water productivity by reducing the total quantity of irrigation water applied. Frequent application of smaller quantities of water through the drip system maintained optimum soil moisture within the effective root zone while minimizing evaporation, runoff and deep percolation losses. Consequently, a greater proportion of the applied water was converted into economic yield. In contrast, the relatively lower water productivity under furrow irrigation can be attributed to higher application losses despite comparable grain yield. These findings are in agreement with earlier reports on efficient water use under drip irrigation systems by Ibrahim *et al.*, (2016) and Priya *et al.* (2018). Foliar application of glycine betaine and KNO_3 further enhanced water productivity under drip irrigation. Osmoregulants enhance osmotic adjustment, membrane stability and stomatal regulation under moisture-limited conditions. These physiological responses improve root activity, nutrient uptake, photosynthetic carbon assimilation and assimilate translocation, thereby increased grain production per unit of water consumed. Similar responses have been reported by Ashraf and Foolad (2007) and Farooq *et al.* (2009).

Economic analysis revealed that cultivation costs increased under drip irrigation owing to the additional expenditure associated with the irrigation system, while glycine betaine incurred the highest cost among the osmoregulants. Nevertheless, drip irrigation at 1.0 ETc combined with foliar application of glycine betaine or KNO_3 produced net returns comparable to those obtained under conventional furrow irrigation because of its higher productivity and efficient water utilization. Among the osmoregulants, KNO_3 produced economic returns similar to glycine betaine with a comparatively lower input cost, making it a more cost-effective option for farmers. These findings are in agreement with earlier reports of Wairagade *et al.* (2020) and Vinita (2023).

Table 3 : Response of deficit irrigation levels and foliar spray of osmoregulants on growth and yield parameters, yield of *rabi* maize

Treatments	Growth parameters				Yield parameters and yield				
	At harvest		At 60 DAS						
	Plant height (cm)	TDMP (g plant^{-1})	Leaf area/ plant (dm^2)	Stem girth (cm)	Cob length (cm)	Cob diameter (cm)	No. of grains per cob	Cob weight (g/plant)	Grain yield (q/ha)
Irrigation levels (I)									
I_1	168.5^{b}	205.1^{c}	48.43^{c}	6.18^{b}	13.3^{c}	4.11^{c}	337.0^{c}	105.7^{c}	53.7^{c}
I_2	182.7^{b}	225.5^{b}	53.61^{bc}	6.71^{ab}	14.8^{b}	4.45^{b}	420.0^{b}	133.8^{b}	79.2^{b}
I_3	199.9^{a}	243.6^{a}	58.55^{ab}	6.95^{ab}	16.2^{a}	4.68^{a}	506.7^{a}	165.1^{a}	93.8^{a}
I_4	215.3^{a}	253.1^{a}	61.59^{a}	7.13^{a}	17.0^{a}	4.79^{a}	554.7^{a}	184.4^{a}	99.2^{a}
Osmorgulants spray (S)									
S_1	194.2^{ab}	234.1^{ab}	56.33^{a}	6.90^{ab}	15.5^{ab}	4.55^{ab}	463.3^{ab}	151.3^{ab}	83.8^{ab}
S_2	188.6^{ab}	229.0^{bc}	54.49^{b}	6.64^{bc}	15.1^{bc}	4.48^{b}	443.8^{bc}	142.6^{bc}	79.8^{bc}
S_3	200.0^{a}	240.6^{a}	57.78^{a}	7.08^{a}	15.9^{a}	4.61^{a}	487.8^{a}	159.5^{a}	88.2^{a}
S_4	183.6^{b}	223.7^{c}	53.57^{b}	6.35^{c}	14.7^{c}	4.39^{c}	423.6^{c}	135.5^{c}	74.1^{c}
Interaction (I x S)									
I_1S_1	170.4^{f-h}	207.3^{hi}	49.43^{ef}	6.40^{a-c}	13.6^{h-j}	4.20^{hi}	346.6^{h-j}	108.5^{ij}	55.6^{gh}
I_1S_2	167.2^{gh}	202.0^{i}	47.40^{f}	6.11^{bc}	13.2^{ij}	4.12^{i}	326.7^{ij}	102.5^{ij}	52.4^{gh}
I_1S_3	173.8^{f-h}	213.9^{gh}	50.46^{ef}	6.59^{a-c}	13.9^{g-i}	4.26^{gh}	368.8^{g-j}	115.2^{h-j}	60.1^{fg}
I_1S_4	162.7^{h}	197.0^{i}	46.45^{f}	5.62^{c}	12.5^{j}	3.87^{j}	305.9^{j}	96.6^{j}	46.9^{h}
I_2S_1	185.3^{d-g}	228.2^{ef}	54.30^{b-f}	6.90^{ab}	15.0^{e-g}	4.48^{ef}	431.0^{eg}	140.2^{e-h}	84.8^{de}
I_2S_2	180.3^{e-h}	222.8^{fg}	52.60^{c-f}	6.57^{a-c}	14.6^{f-h}	4.41^{f}	405.3^{f-h}	128.5^{f-i}	77.1^{e}
I_2S_3	189.8^{c-f}	234.0^{de}	55.78^{a-e}	7.06^{ab}	15.4^{d-f}	4.57^{de}	457.2^{d-f}	146.2^{d-g}	88.1^{d}
I_2S_4	175.4^{e-h}	217.2^{g}	51.76^{d-f}	6.30^{a-c}	14.1^{g-i}	4.35^{fg}	386.4^{g-i}	120.3^{g-j}	67.0^{f}
I_3S_1	203.0^{a-d}	245.2^{bc}	59.46^{a-d}	7.09^{ab}	16.4^{a-d}	4.71^{a-c}	512.6^{a-d}	168.8^{a-e}	93.9^{a-d}
I_3S_2	194.2^{b-e}	240.1^{cd}	57.30^{a-e}	6.84^{a-c}	16.0^{b-e}	4.64^{b-d}	493.8^{b-e}	160.1^{b-e}	91.3^{b-d}
I_3S_3	214.4^{a}	254.0^{ab}	61.24^{ab}	7.26^{ab}	16.9^{a-c}	4.77^{ab}	542.6^{a-c}	178.6^{a-c}	100.8^{ab}
I_3S_4	187.8^{d-f}	235.1^{de}	56.21^{a-e}	6.62^{a-c}	15.7^{c-f}	4.60^{c-e}	477.7^{c-e}	152.8^{c-f}	89.2^{cd}
I_4S_1	218.0^{a}	255.7^{a}	62.14^{ab}	7.20^{ab}	17.1^{ab}	4.80^{a}	563.1^{ab}	187.7^{ab}	101.0^{ab}
I_4S_2	212.6^{ab}	250.9^{ab}	60.68^{a-c}	7.03^{ab}	16.7^{a-d}	4.76^{ab}	549.1^{ab}	179.3^{a-c}	98.6^{a-c}
I_4S_3	221.8^{a}	260.3^{a}	63.66^{a}	7.42^{a}	17.7^{a}	4.84^{a}	582.4^{a}	198.0^{a}	103.8^{a}
I_4S_4	208.6^{a-c}	245.6^{bc}	59.88^{a-d}	6.89^{ab}	16.5^{a-d}	4.73^{a-c}	524.2^{a-d}	172.4^{a-d}	93.3^{b-d}

Table 4 : Response of deficit irrigation levels and foliar spray of osmoregulants on water productivity and economics of *rabi* maize

Treatments	Water productivity (kg m^{-3})	Economics			
		Cost of cultivation (Rs./ha)	Gross income (Rs./ha)	Net income (Rs./ha)	B-C ratio
Irrigation levels (I)					
I_1	1.66^{d}	66616	119148^{c}	52532^{c}	1.80^{c}
I_2	2.30^{b}	68309	175125^{b}	106815^{b}	2.57^{b}
I_3	2.57^{a}	69491	206847^{a}	137356^{a}	3.00^{a}
I_4	2.19^{c}	67271	218499^{a}	151227^{a}	3.27^{a}
Osmorgulants spray (S)					
S_1	2.25^{ab}	66303	185157^{ab}	118854^{a}	2.80^{a}
S_2	2.13^{b}	64666	176285^{bc}	111620^{b}	2.73^{ab}
S_3	2.37^{a}	78507	194540^{a}	116033^{ab}	2.48^{c}
S_4	1.97^{c}	62212	163636^{c}	101424^{c}	2.63^{b}
Interaction (I x S)					
I_1S_1	1.72^{h-j}	64972	123312^{gh}	58339^{g}	1.90^{f}
I_1S_2	1.62^{ij}	63373	116233^{gh}	52860^{g}	1.84^{f}
I_1S_3	1.86^{g-i}	77187	133082^{fg}	55895^{g}	1.73^{f}
I_1S_4	1.45^{j}	60933	103966^{h}	43033^{g}	1.71^{f}
I_2S_1	2.47^{b-d}	66842	187579de	120737de	2.81^{b-d}
I_2S_2	2.24^{de}	65030	170367^{e}	105337^{e}	2.63^{c-e}
I_2S_3	2.56^{a-c}	78992	194494^{d}	115502^{e}	2.47^{de}
I_2S_4	1.94^{f-h}	62372	148059^{f}	85686^{f}	2.38^{e}
I_3S_1	2.58^{ab}	67769	207168^{a-d}	139399^{a-c}	3.06^{ab}
I_3S_2	2.51^{a-d}	66194	201315^{b-d}	135121^{b-d}	3.05^{ab}
I_3S_3	2.77^{a}	80090	222092^{ab}	142002^{a-c}	2.78^{b-d}
I_3S_4	2.45^{b-d}	63911	196814^{cd}	132904^{cd}	3.09^{ab}
I_4S_1	2.23^{de}	65630	222572^{ab}	156942^{a}	3.40^{a}
I_4S_2	2.17^{ef}	64065	217227^{a-c}	153161^{ab}	3.40^{a}
I_4S_3	2.29^{c-e}	77759	228491^{a}	150733^{a-c}	2.94^{bc}
I_4S_4	2.06^{e-g}	61631	205705^{b-d}	144074^{a-c}	3.35^{a}

Conclusion

Drip irrigation at 1.0 ETc with either foliar spray of glycine betaine @ 0.3% at 30 and 60 DAS or KNO_3 @ 0.5% spray at 30 and 60 DAS found effective in maximizing the productive use of available water and sustaining maize yield with better economic returns. However, drip irrigation at 1.0 ETc with KNO_3 spray is more economical due to the higher cost of glycine betaine.

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Authors contribution

The first author was responsible for conceptualizing and designing the study, conducting the research, collecting and analyzing the data, interpreting the results and drafting the manuscript. The second author supervised the research, provided guidance on the study design and methodology, reviewed the literature and critically revised the manuscript for important intellectual content. The third and subsequent authors provided the necessary laboratory and field facilities required for conducting the experiments and analyses, offered technical support during the research and reviewed and corrected the manuscript to improve its scientific quality and presentation. All authors contributed to the revision of the manuscript, read and approved the final version for publication.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

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