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RESEARCH PAPER

Effect of different irrigation regimes and fertigation strategies on maize (*Zea mays* L.) yield and water productivity under drip irrigation

Muli Devi Parihar • Sushil Kumar Singh • Hardeep Singh Sheoran • Seema Sheoran • M. K. Sharma

Abstract A field experiment was conducted during the *rabi* season of 2022–23 at CCS Haryana Agricultural University, Hisar, India, to study the effect of different irrigation levels and fertigation strategies on the growth, yield, and water productivity of maize (*Zea mays* L.) under drip irrigation. The experiment was laid out in a split plot design with three replications. The main plot treatments included three irrigation regimes based on pan evaporation (Epan) viz., D_1: 100% Epan, D_2: 80% Epan and D_3: 60% Epan. The sub-plot treatments comprised five fertigation schedules (T_1–T_5) integrating various combinations of organic and inorganic NPK sources applied as basal and through fertigation. The results indicated that irrigation applied at 100% Epan recoded higher cob weight (122.0 g), cob girth (14.5 cm), grain weight per cob (99.8 g), number of grains per cob (450.0), and 100-grain weight (24.1 g), whereas D_3 (60% PE) achieved the highest irrigation water productivity (3.3 kg m^{-3}) and total water productivity (2.9 kg m^{-3}). Among the different fertigation treatments, T_5 (25% NPK from organic + 25% inorganic as basal + 50% through fertigation) significantly increased the cob weight (130.1 g), grain weight per cob (103.8 g), number of grains per cob (454.7), and 100-grain weight (24.5 g), grain yield (63.7 q ha^{-1}) and biological yield (193.4 q ha^{-1}). Similar results were recorded for irrigation water productivity (2.8 kg m^{-3}) and total water productivity (2.6 kg m^{-3}). The results of the study revealed that combining irrigation at 80 per cent of pan evaporation with integrated nutrient management (T_5) offers an efficient and sustainable approach for improving maize productivity and water use efficiency under drip irrigation systems in water-limited regions.

Keywords: Maize • Drip irrigation • Fertigation • Irrigation level • Water productivity

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Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops globally, known for its high yield potential, wide adaptability, and diverse uses in food, feed, fodder, and industrial applications. In India, maize has emerged as the third most important cereal crop after rice and wheat, contributing significantly to food security and farm income (Dass *et al.,* 2010). However, the challenge of maintaining high productivity in maize cultivation under conditions of limited water resources persists as a critical concern across numerous maize-growing regions.

Agriculture is a primary water consumer; therefore, it is crucial to develop an optimal and effective irrigation management strategy that is adapted to different regions and farmers to increase crop yield (Gheysari *et al.,* 2009). Effective farm water management practices significantly affect crop production in irrigated agriculture, especially in arid and semiarid regions (Dough and Boujelben, 2011). The inefficient use and mismanagement of water and nutrients not only compromise crop productivity but also contribute to groundwater depletion, nutrient leaching, and environmental degradation (Singh and Panda, 2013). With only 4 per cent of the world's freshwater resources to support 17 per cent of the global population, there is a need to improve the efficiency of agricultural water use to ensure future food and water security in India (GOI, 2020). Addressing these issues requires an integrated approach to soil-water-plant nutrient management at the plant-rooting zone.

Drip irrigation has gained attention as an efficient water application technique, especially in arid and semi-arid regions. Integrating fertilizer application with drip irrigation leads to significant water and nutrient conservation when compared to traditional irrigation practices. By delivering water directly to the root zone, drip irrigation minimizes water loss through evaporation and deep percolation, thereby increasing water use efficiency (Seema *et al.,* 2023). In combination with fertigation, wherein nutrients are supplied through the irrigation system. This system synchronizing nutrient application with crop requirements, improves nutrient use efficiency and reduces wastage. This system allows precise and timely delivery of nutrients in synchrony with crop demand and thereby improving nutrient uptake and reducing losses (Hebbar *et al.,* 2004). The integration of organic and inorganic nutrient sources can further enhance soil health and crop productivity. Integrating organic and inorganic nutrient sources under fertigation not only supports sustainable nutrient supply but also improves soil structure, microbial activity, and long-term fertility. The use of organic amendments such as farmyard manure, compost, or vermicompost in conjunction with chemical fertilizers has been shown to enhance nutrient use efficiency and crop yield while minimizing environmental impacts (Sharma and Mittra, 1991; Singh *et al.,* 2011).

Although several studies have independently reported the benefits of drip irrigation and fertigation, limited research is available on their interactive effects, particularly under varying irrigation regimes. Understanding the combined impact of different irrigation regimes and fertigation strategies is vital to developing integrated water–nutrient management systems tailored for water-scarce environments.

Therefore, the present study was carried out to evaluate the combined effects of varying irrigation levels and fertigation schedules based on the integration of organic and inorganic nutrient sources on the growth, yield, and water productivity of maize under drip irrigation during the *rabi* season. This research aims to develop integrated water and nutrient management strategies that can enhance maize productivity while conserving critical water resources in semi-arid environments.

Materials and methods

The field experiment was carried out during *rabi* season of 2022-23 at Soil Research Farm, Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana, India. It is located in Indo-Gangetic plains of India at 29°10′ N latitude, 75°46′ E longitude and at an altitude of 215.2 meter above mean sea level in the western region of Haryana. The average rainfall in the area fluctuates between 350 to 450 mm with considerable variation in total rainfall and its distribution. The mean weekly maximum and minimum temperature ranges were 38.1–14.6°C and 19.7–3.6°C, respectively recorded during the crop season. Mean morning relative humidity was between 100 and 50.0 per cent, while evening relative humidity was between 85.2 and 16.9 per cent. Total rainfall of 29.5 mm was recorded during crop season. During the crop season weekly mean wind velocity range was 1.2- 6.0 km hr^{-1}, with the range nearly rising in magnitude as the crop season progressed. The brightest week during the crop season was the 15^{th} week, with 8.8 sunshine hours per day, and the least bright week was the 2^{nd} week, with 2.3 hours per day. The highest evaporative demand was 6.8 mm per day during the 16^{th} standard week, while the lowest open pan evaporation was recorded during the 1^{st} standard week with 0.86 mm per day. Weekly meteorological data from the Department of Agricultural Meteorology at CCS Haryana Agricultural University in Hisar throughout the experimental crop season (*rabi* 2022-23) is provided in Figure 1.

Experiment was laid out in split plot design with 18 treatment combinations consisting of three irrigation levels in the main plot viz., 100% Epan, 80% Epan and 60% Epan and five fertigation levels in the subplots (T_1: 50% N and 100% P K as basal and 50% N in 2 splits through top dressing, T_2: 50% N P K inorganic as basal + 50% through fertigation, T_3: 25% N P K (organic) + 50% N P K (inorganic) as basal + 25% through fertigation T_4: 25% N P K inorganic + 75% through fertigation, T_5: 25% N P K (organic) + 25% inorganic as basal + 50% through fertigation), replicated thrice. The maize hybrid was sown in first week of November in *rabi* 2022-23 on flat bed. In each plot crop was sown at 60 cm and 20 cm distance between and within rows, respectively. The thinning and gap filling were accomplished in order to maintain optimum and uniform plant population. Weed control was achieved through a pre-emergence application of Atrazine (50WP)

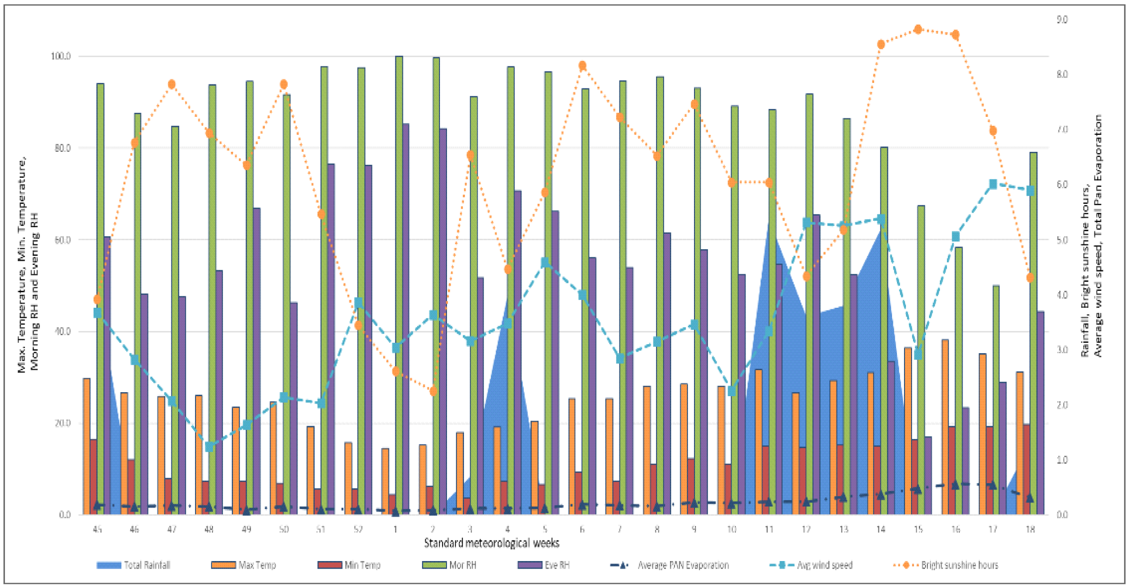

Figure 1. Monthly mean weather data during *rabi* (2022-23)

at 1.25 kg ha^{-1} in 500 L of water and supplemented with two manual weeding during the later stages of crop growth.

In fertigation conventional fertilizers viz., Urea (46% N), single super phosphate (16% P) and MOP (60% K) were used as inorganic sources while farmyard manure (FYM) was used as organic nutrient source. Random sample of FYM, was collected from the bulk, air-dried, ground, sieved and then analyzed for total N (0.75%), total P (0.52%), and total K (1.25%) (Chapman and Pratt 1961).

Irrigation scheduling

Irrigation was scheduled based on cumulative pan evaporation (CPE) using data from a Class-A pan evaporimeter installed near experimental site. Three irrigation levels were followed: 100, 80, and 60 per cent of CPE. Water was applied through a surface drip irrigation system, with laterals laid out at 60 cm spacing and emitters spaced 40 cm apart along the lateral lines. Each dripper had a discharge rate of 4 liters per hour (lph), ensuring uniform water delivery. The volume of water applied was calculated using the formula:

$$\text{Volume (L)} = \text{Epan} \times \text{Kp} \times \text{A} \times \text{f}$$

Where, Epan is the cumulative pan evaporation (mm), Kp is the pan coefficient (0.8), A is the area to be irrigated (m²), and f is the fraction of Epan (1.0, 0.8, or 0.6 depending on the treatment). Irrigation was applied when the accumulated CPE reached the target level for each treatment.

The irrigation water volume was adjusted and uniformly applied to all the plots based on their respective treatment schedules.

Irrigation water productivity

Irrigation water productivity (IWP) was calculated to assess the efficiency of water use under different irrigation and fertigation treatments. It was computed as the ratio of grain yield to the total volume of irrigation water applied during the crop season, and expressed in kg m^{-3}. The formula used was:

$$\text{IWP (kg m}^{-3}) = \frac{\text{Total irrigation water applied (m}^{3}\text{ ha}^{-1})}{\text{Grain yield (kg ha}^{-1})}$$

Total water productivity

Total water productivity (TWP) was calculated to evaluate the overall efficiency of water use, including both irrigation and effective rainfall, in relation to crop yield. It was expressed as the ratio of grain yield to the total volume of water supplied (irrigation + effective rainfall) during the crop growing season, and expressed in kg m^{-3}. The formula used was:

$$\text{TWP (kg m}^{-3}) = \frac{\text{Total water applied (m}^{3}\text{ ha}^{-1})}{\text{Grain yield (kg ha}^{-1})}$$

Total water input was estimated by summing the total volume of irrigation water applied and total rainfall received during the crop season. TWP provides a comprehensive measure of water use efficiency.

The statistical analysis of the soil and plant experiment data was done using analysis of variance by split plot design and OPSTAT statistical software package created by the Department of Statistics at the CCS Haryana Agricultural University (Sheoran *et al.,* 1998). The test of significance was carried out at 5% level of significance by referring to 'F' table values.

Results and discussion

Yield attributes

Effect of irrigation levels

Yield attributing traits of maize were significantly influenced by irrigation levels (Table 1). Among different irrigation treatments, D_1 (100% pan evaporation) recorded the highest cob weight (122.0 g), cob girth (14.5 cm), grain weight per cob (99.8 g), number of grains per cob (450.0), and 100-grain weight (24.1 g), all significantly superior to D_3 (60% PE), which recorded the lowest values for these traits. The improvement in yield parameters under D_1 can be attributed to the consistent soil moisture conditions throughout the crop growth period, especially during tasseling and grain filling stages. These results align with Jat *et al.* (2019) and Kumar *et al.* (2018), who reported that full irrigation schedules maintained under drip systems optimize photosynthetic activity, enhance kernel development, and lead to superior cob traits.

Effect of fertigation schedules

Among the different fertigation treatments, T_5 (25% NPK organic + 25% inorganic as basal + 50% through fertigation) exhibited the highest values across all yield attributes–cob weight (130.1 g), cob girth (14.7 cm), grain weight per cob (103.8 g), number of grains per cob (454.7), and 100-grain weight (24.5 g). These were significantly higher than the control (T_1), which recorded the lowest values (e.g., cob weight: 101.4 g; grain weight per cob: 84.3 g; 100-grain weight: 19.8 g). The superior performance of T_5 may be attributed to balanced and timely nutrient supply through both organic and inorganic sources, which likely improved root development, nutrient uptake, and enzymatic activity during critical reproductive stages. This is supported by the findings of Singh *et al.* (2020) and Tripathi *et al.* (2019), who noted enhanced yield attributes under integrated nutrient management combined with fertigation.

Table 1. Effect of different irrigation and fertigation schedules on yield attributes of maize

Treatments	Cob weight (g)	Cob girth (cm)	Grain weight /cob (g)	No. of grains per cob	100-grain weight (g)
Irrigation levels					
D_1: Optimum Irrigation (100% of Pan Evaporaton)	122.0	14.5	99.8	450.0	24.1
D_2: Optimum Irrigation (80% of Pan Evaporaton)	118.7	14.1	97.9	435.1	23.4
D_3: Optimum Irrigation (60% of Pan Evaporaton)	108.9	13.3	91.0	370.2	20.2
SEm+	1.2	0.1	1.2	6.7	0.6
CD (p<0.05)	5.0	0.6	4.6	27.1	2.4
Fertigation schedule					
T_1: Control (50 % N and 100 % PK as basal and 50 % N in 2 splits through Top dressing)	101.4	12.9	84.3	371.6	19.8
T_2: 50% NPK as basal + 50% through fertigation inorganic	110.2	13.8	93.6	395.8	22.3
T_3: 25% NPK (Organic) + 50% NPK (Inorganic) as basal+ 25% through fertigation (Inorganic)	116.7	13.9	97.0	420.7	22.5
T_4: 25% NPK as basal+ 75% through fertigation (inorganic)	124.2	14.6	102.3	449.3	23.8
T_5: 25% NPK (Organic) +25% Inorganic as basal+ 50% through fertigation	130.1	14.7	103.8	454.7	24.5
SEm+	2.3	0.2	1.5	7.3	0.2
CD (p<0.05)	6.9	0.6	4.4	21.5	0.6

Grain yield

Significant variation in grain yield was observed under different irrigation levels (Table 2). The highest grain yield (61.9 q ha^{-1}) was obtained with the treatment D_1 (Optimum irrigation at 100% of pan evaporation), followed by D_2 (80% PE) with 60.3 q ha^{-1}. The lowest yield (55.5 q ha^{-1}) was recorded in D_3 (60% PE), which was significantly lower than D_1 and D_2. The decline in yield under sub-optimal irrigation may be attributed to reduced photosynthate production and impaired grain filling due to moisture stress during critical stages. Kumar *et al.* (2018) reported that yield reduction under deficit irrigation can be attributed to limited moisture availability during critical crop stages, which adversely affected assimilate partitioning towards the grain. Similar trends have been reported by Jat *et al.* (2019), who observed that maintaining optimal soil moisture through drip irrigation enhanced photosynthesis and kernel development, thereby improving grain yield.

These findings also align with the results reported by Patel and Rajput (2007) and Singh *et al.* (2019), who observed that optimum irrigation under drip systems enhances growth by maintaining favorable soil moisture, leading to improved nutrient uptake and translocation. Drip irrigation at full crop evapotranspiration also prevents water stress, which otherwise limits cell expansion and reduces assimilate partitioning to reproductive parts (Shruthi *et al.,* 2018).

Among the different fertigation schedules, T_5 (25% NPK from organic + 25% inorganic as basal + 50% through fertigation) recorded the highest grain yield (63.7 q ha^{-1}), which was significantly superior to all other treatments. It was followed by T_4 (62.2 q ha^{-1}) and T_3 (59.8 q ha^{-1}). The lowest yield was observed in T_1 (conventional fertilization) with 54.5 q ha^{-1}. Improved yield performance under T_5 could be due to enhanced nutrient availability throughout the crop growth period and better synchrony of nutrient release and uptake, as supported by findings of Singh *et al.* (2020) and Patel *et al.* (2022). They emphasized that integrating organic and inorganic nutrient sources under fertigation ensures balanced nutrition, improves soil health, and enhances nutrient use efficiency. Similar improvements in maize performance with integrated nutrient management have been also reported by Patra *et al.* (2021), who emphasized that organic sources improve soil microbial activity and root proliferation, while fertigation enhances nutrient use efficiency through precise and timely application. Furthermore, Bar-Yosef (1999) and Reddy *et al.* (1980) confirmed that fertigation promotes better vegetative growth and reproductive success due to improved nutrient solubility and root zone concentration. In contrast, T_1 treatment, which followed conventional basal application

Table 2. Effect of irrigation and fertigation on yield and harvest index of *Rabi* maize

Treatments	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Irrigation levels				
D_1: Optimum Irrigation (100% of Pan Evaporaton)	61.9	126.2	188.1	32.9
D_2: Sub-Optimum Irrigation (80% of Pan Evaporaton)	60.3	123.5	183.8	32.8
D_3: Sub-Optimum Irrigation (60% of Pan Evaporaton)	55.5	114.9	170.4	32.5
SEm+	0.6	1.5	2.3	0.1
CD ($p<0.05$)	2.6	6.1	9.3	NS
Fertigation schedule				
T_1: Control (50 % N and 100 % PK as basal and 50 % N in 2 splits through Top dressing)	54.5	113.3	167.6	32.5
T_2: 50% NPK as basal + 50% through fertigation inorganic	56.0	115.1	171.1	32.7
T_3: 25% NPK (Organic) + 50% NPK (Inorganic) as basal+ 25% through fertigation (Inorganic)	59.8	122.6	182.4	32.8
T_4: 25% NPK as basal+ 75% through fertigation (inorganic)	62.2	127.1	189.3	32.8
T_5: 25% NPK (Organic) +25% Inorganic as basal+ 50% through fertigation	63.7	129.6	193.4	32.9
SEm+	0.7	1.2	1.7	0.2
CD ($p<0.05$)	1.9	3.6	4.8	NS

and top dressing, recorded the lowest yield (49.2 q ha^{-1}) which may be attributed due to inefficient nutrient use and temporal mismatches in crop nutrient demand and supply (Singh *et al.,* 2019). These observations clearly support the synergistic effect of combining organic amendments with fertigation in enhancing maize productivity under semi-arid conditions.

Stover yield

Stover yield followed a trend similar to grain yield across irrigation and fertigation treatments. The maximum stover yield (126.2 q ha^{-1}) was recorded under D_1, followed by D_2 (123.5 q ha^{-1}), and the minimum (114.9 q ha^{-1}) under D_3. Adequate water supply supports vegetative growth, leading to higher stover accumulation (Ramesh *et al.*, 2017). Among different fertigation treatments, T_5 again resulted in the highest stover yield (129.6 q ha^{-1}), followed by T_4 (127.1 q ha^{-1}), while the control (T_1) showed the least (113.3 q ha^{-1}). These results arein agreement with Tripathi *et al.* (2019), who reported that combined organic-inorganic nutrient management under fertigation significantly enhanced vegetative biomass in maize.

Biological yield

Biological yield was significantly affected by both irrigation and fertigation practices. The highest biological yield (188.1 q ha^{-1}) was obtained under treatment D_1, followed by D_2 (183.8 q ha^{-1}), and the lowest (170.4 q ha^{-1}) under D_3. Similar findings were reported by Yadav *et al.* (2021), where optimal irrigation contributed to greater total dry matter accumulation in maize. Among fertigation schedules, T_5 recorded the highest biological yield (193.4 q ha^{-1}), followed by T_4 (189.3 q ha^{-1}), and T_3 (182.4 q ha^{-1}). The lowest (167.6 q ha^{-1}) was recorded under T_1. These findings align with the results of Choudhary *et al.* (2020), who concluded that fertigation ensures efficient nutrient delivery and improved biomass production.

Harvest index

Harvest index (HI) ranged from 32.5 per cent to 32.9 per cent across treatments and remained statistically unaffected by either irrigation or fertigation schedules. This indicates that the proportion of economic yield to total biomass was stable despite changes in input management. Similar stability in HI under varied irrigation and fertigation conditions was reported by Meena *et al.* (2018), suggesting that both reproductive and vegetative growth respond proportionately to nutrient and water availability in maize.

Water productivity

Effect of irrigation levels

Water productivity (WP) was significantly influenced by irrigation levels (Table 3). The highest irrigation water productivity (3.3 kg m^{-3}) and total water productivity (2.9 kg m^{-3}) were recorded under D_3 (60% pan evaporation), which also used the least amount of irrigation water (168.1 mm). However, this treatment produced the lowest grain yield (55.5 q ha^{-1}).

In contrast, D_1 (100% PE) recorded the lowest irrigation water productivity (2.2 kg m^{-3}) and total water productivity (2.0 kg m^{-3}) due to the highest volume of irrigation water applied (280.2 mm), despite yielding the highest grain output (61.9 q ha^{-1}). These results suggest a trade-off between maximizing yield and optimizing water use efficiency. Similar findings were reported by Jat *et al.* (2019), who observed that deficit irrigation improves water productivity but may reduce overall grain yield. The treatment D_2 (80% PE) have a balanced outcome with moderate water use (224.7 mm) and a grain yield (60.3 q ha^{-1}) statistically at par with D_1. It achieved better irrigation (2.7 kg m^{-3}) and total water productivity (2.4 kg m^{-3}) than D_1, suggesting that slight deficit irrigation can enhance efficiency without compromising yield significantly. This aligns with the recommendations of Kumar *et al.* (2018), advocating sub-optimal irrigation for sustainable maize production under limited water resources.

Effect of fertigation schedules

Water productivity also improved significantly with different fertigation schedules. The highest irrigation water productivity (2.8 kg m^{-3}) and total water productivity (2.6 kg m^{-3}) were achieved under T_5 (25% organic + 25% inorganic as basal + 50% through fertigation), which also recorded the highest grain yield (63.7 q ha^{-1}). This was followed by T_4 (25% basal + 75% fertigation) with 2.8

Table 3. Effect of different moisture regimes and fertigation levels on water productivity (kg m^{-3}) of Maize

Treatments	Effective rainfall (mm)	Irrigation water (mm)	Total water (mm)	Grain yield (q ha^{-1})	Water productivity (kg m^{-3})	
					Irrigation water	Total water
Irrigation levels						
D_1: Optimum Irrigation (100% of Pan Evaporaton)	22.7	280.2	302.9	61.9	2.2	2.0
D_2: Sub-Optimum Irrigation (80% of Pan Evaporaton)	22.7	224.7	246.9	60.3	2.7	2.4
D_3: Sub-Optimum Irrigation (60% of Pan Evaporaton)	22.7	168.1	190.8	55.5	3.3	2,9
SEm+	-	-	-	0.6	-	-
CD (p<0.05)	-	-	-	2.6	-	-
Fertigation schedule						
T_1: Control (50% N and 100% PK as basal and 50% N in 2 splits through Top dressing)	22.7	224.7	246.9	54.5	2.4	2.2
T_2: 50% NPK as basal + 50% through fertigation inorganic	22.7	224.7	246.9	56.0	2.5	2.3
T_3: 25% NPK (Organic) + 50% NPK (Inorganic) as basal + 25% through fertigation (Inorganic)	22.7	224.7	246.9	59.8	2.7	2.4
T_4: 25% NPK as basal+ 75% through fertigation (inorganic)	22.7	224.7	246.9	62.2	2.8	2.5
T_5: 25% NPK (Organic) +25% Inorganic as basal+ 50% through fertigation	22.7	224.7	246.9	63.7	2.8	2.6
SEm+	-	-	-	0.7	-	-
CD (p<0.05)	-	-	-	1.9	-	-

and 2.5 kg m^{-3} for irrigation and total water productivity, respectively. The improved water productivity under fertigation treatments, especially T_5, may be attributed to more efficient nutrient uptake and root zone moisture management, which enhanced crop water use efficiency (Singh *et al.*, 2020; Patel *et al.*, 2022). Since irrigation amounts were the same across all fertigation treatments (224.7 mm), the differences in productivity reflect the positive impact of nutrient placement and timing, particularly under combined organic and inorganic sources. Shruthi *et al.* (2018), highlighted that fertigation enhances nutrient availability at the root zone, thereby optimizing nutrient uptake and water use simultaneously. Integrated nutrient management involving organic and inorganic sources has also been shown to improve soil structure and microbial activity, leading to improved water retention and efficient nutrient release (Patra *et al.,* 2021), further explaining the superior performance of T_5. The control treatment T_1, recorded the lowest water productivity, both in terms of irrigation water productivity (2.4 kg m^{-3}) and total water productivity (2.2 kg m^{-3}), due to conventional nutrient application methods leading to lower synchronization with crop nutrient demand, resulting in reduced nutrient use efficiency and ultimately, lower yields (Reddy *et al.,* 1980; Singh *et al.,* 2019).

Conclusion

Drip irrigation at 100% Epan ensured the optimum growth and yield of maize, while deficit irrigation (60% Epan) led to significantly improved water productivity. Fertigation schedule T7E integrating 50% fertigation with 25% organic and 25% inorganic basal nutrients, significantly enhanced growth, yield, and water productivity. Therefore, the study suggests that combining optimum irrigation levels with integrated fertigation is a sustainable strategy for increasing maize productivity and resource use efficiency under semi-arid regions.

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