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Research Paper

Impact of Micro Irrigation on the Growth and Yield of Tomatoes in Sandy Loam Soil

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ABSTRACT

A study was conducted to evaluate the efficacy of drip emitters and micro sprinklers under field conditions for cultivating tomatoes, with a focus on improving irrigation efficiency and minimizing field losses. The investigation involved assessing moisture distribution patterns for both micro-irrigation techniques. The data on moisture content before and after irrigation were scrutinized, and soil moisture contour maps for the longitudinal cross-section were created using the "Surfer" software. Results indicated that the drip system displayed a uniformity coefficient of 89.25% at 1.2 kg/cm^2, while the micro sprinkler system exhibited uniformity coefficients of 89.80% and 88.50% at 25cm and 50cm heights from the ground, respectively. The coefficient of manufacturing variation was low (0.048) in the drip irrigation system at 1.20 kg/cm^2. Regarding crop response, notable enhancements in growth parameters and tomato yield were observed under micro sprinkler irrigation compared to both drip and control treatments. The micro sprinkler treatment yielded the highest production at 54.3 t/ha, surpassing the drip (53.6 t/ha) and control (40 t/ha) treatments. Drip irrigation demonstrated the highest water use efficiency (245 kg/ha/mm), utilizing the least amount of water, including effective rainfall (350 mm). The benefit-cost (B-C) ratio increased for the micro sprinkler treatment (3.56) compared to drip (3.37) and control (3.07) treatments, indicating superior economic performance. In summary, the micro sprinkler treatment outperformed the drip plots in terms of yield and cost-effectiveness, despite the drip treatment exhibiting higher water use efficiency.

HIGHLIGHTS

- Assessment of Drip Emitters and Micro Sprinklers in Tomato Cultivation
- Investigation of Irrigation Efficiency and Moisture Distribution

Keywords: Drip, micro sprinkler, surface irrigation, crop growth, yield

In the context of climate change and degradation of natural resources, the agriculture confronts a tremendous challenge for increasing crop productivity with the resources available (Sairam *et al.* 2023). Water, often referred as the liquid gold, stands as a precious natural resource crucial for maximizing crop yields. The reliability of water supply for irrigation faces challenges as demand intensifies not only from non-agricultural sectors such as industries, households, and power but also due to the overarching impact of climate change and water shortages. The current allocation of 90% of water for agricultural purposes is anticipated to decrease to 75-80% in the coming decades due to escalating demands and the compounding effects of climate change (FAO, 2018; Maitra and Pine, 2020). To meet these dual challenges, there is a pressing need to optimize water usage in irrigation, with the

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goal of expanding irrigated areas and enhancing productivity. The judicious use of water is vital, especially as pressure on water resources continues to rise from various sectors, exacerbated by the increasingly erratic patterns induced by climate change. Efficient water management through scientific irrigation practices emerges as a critical tool in mitigating fluctuations in food production brought about by unpredictable weather patterns.

Conventional approaches to irrigation often lead to substantial water losses, ranging from 27 to 42%, contingent upon the soil type (Santosh and Maitra, 2022). Micro irrigation techniques, exemplified by drip and micro sprinkler systems, present effective solutions to mitigate water wastage and enhance water use efficiency by minimizing soil evaporation and drainage losses. These practices also contribute to sustaining favorable soil moisture conditions conducive to optimal crop growth. In essence, micro irrigation emerges as a key player in bolstering land productivity while grappling with the pressing issue of water scarcity (Santosh *et al.* 2021).

Drip and micro sprinkler systems are two prominent forms of micro irrigation. Drip irrigation involves the frequent application of water to plants in volumes approaching their consumptive use, thereby minimizing losses like deep percolation, runoff, and soil water evaporation (Santosh *et al.* 2022). On the other hand, micro sprinklers disperse water around plants, reducing potential runoff and erosion. While drip irrigation boasts a water use efficiency of approximately 90%, micro sprinkler systems achieve a commendable 70%. Beyond ensuring water economy through reduced evaporation and seepage losses, both drip and micro sprinkler irrigation methods establish an ideal moisture regime conducive to high yields in various crops (Santosh *et al.* 2022).

Tomato (*Lycopersicon esculentum* Mill) holds a significant position as a vegetable crop with a rich cultivation history spanning 4000 years in India. It is widely recognized as one of the most crucial vegetable crops cultivated across the country, covering a total tomato cultivation area of 30,846 ha in Tamil Nadu and yielding approximately 3,25,006 t/ha (Kaur *et al.* 2020). Currently, the furrow irrigation method is employed for tomato cultivation, leading to substantial water loss through evaporation and deep percolation, resulting in decreased irrigation efficiency.

Under the current irrigation practices, the soil moisture content remains optimal for only a brief period during the irrigation interval. This causes significant fluctuations in the soil moisture regime, hindering the tomato crop's ability to achieve its full growth potential and yield (Mukherjee *et al.* 2023). The adoption of drip and micro sprinkler irrigation methods has the potential to sustain an optimum soil moisture regime consistently throughout the entire crop growth period. This study aims to assess the performance of drip and micro sprinklers in terms of irrigation and water use efficiency, seeking to enhance the overall cultivation process and yield outcomes.

MATERIALS AND METHODS

Field investigations were carried out at Centurion University of Technology and Management in Paralakhemundi, Odisha. The experimental farm is situated on level ground at 18°47′ N latitude, 84°06′ E longitude, and an elevation of 116 m above mean sea level. The soil in the experimental field is identified as red lateritic soil with a sandy loam texture. Paralakhemundi experiences a subtropical climate characterized by high humidity. Temperature fluctuations range from 18°C to 48°C, with hot and humid conditions prevailing in summer (April and May), a monsoon season from June to September, moderately hot and dry weather in autumn (October and November), cool and dry conditions in winter (December and January), and a moderate spring in February and March.

Climatic data, encompassing rainfall, maximum and minimum temperatures, relative humidity, and wind speed, were gathered over a three-year period (2018-2020) from the Meteorological Department at CUTM Paralakhemundi. The average monthly evaporation varies from 4.5 to 8.1 mm, while sunshine duration ranges from 3.4 to 8.6 hours per day. Irrigation is facilitated by a 3 HP centrifugal pump, supplying water as needed. The selected crop for the study in the experimental field is the NS-7531 variety of Tomato, with a duration of 120 days.

The study employed a randomized block design with three replications. Three distinct treatments were applied, maintaining a constant number of plants across all treatments. The details of the treatments were as follows:

- T1 = Micro sprinkler @ 2m spacing with plant spacing 45 × 60 cm and lateral spacing 2 m
- T2 = Drip system @ 60 cm with plant spacing 45 × 60 cm and lateral spacing 1 m
- T3 = Furrow irrigation with plant spacing 45 × 60 cm and lateral spacing 1.2 m (control)

Lateral lines consisting of 16 mm LLDPE pipes were utilized for the drip system, while 16 mm pipes were employed for the micro sprinkler system to irrigate the plots. The emitters used in the drip system had a capacity of 4 lph, and the average discharge for the micro sprinkler system was recorded at 36 lph, with a throw diameter of 3 m. To prevent obstructions caused by the height of the tomato crop, the initial height of the micro sprinkler, set at 25 cm, needed to be increased to 50 cm.

The micro sprinkler treatments (T1) covered a total area of 96 m^2, the drip irrigation treatment (T2) covered the same area of 96 m^2, and T3 represented the control treatment with an identical area of 96 m^2. Biometric observations were recorded at 15-day intervals from the date of transplanting, focusing on various parameters such as plant height, number of leaves, root distribution, and the yield of the tomato crop.

The discharge rate of drippers was measured at emitter points selected randomly on the 1st, 5th, 10^{th}, 15^{th}, 20^{th}, and the last one on each lateral, in order to assess the uniformity of the drip system following the procedure outlined by Larry G. James (1988). The uniformity coefficient was then calculated using the following formula.

$$Eu = 100\left[1.0 - \frac{1.27}{\sqrt{Ne}}Cv\right]\frac{W_{\min}}{Q_{avg}}$$

Where,

Eu = Emission uniformity in per cent,

Ne = number of point source segments,

Cv = the manufacturer's coefficient rate in the system in lph,

Q_{min} = the minimum discharge rate,

Q_{avg} = the average rate in lph.

In micro sprinkler the uniformity coefficient was calculated by first collecting water in the catch cans placed at grid points of the overlapped area and then using Christiansen's equation of uniformity coefficient.

$$Cu = \frac{100\left[1.0 - \sum X\right]}{MN}$$

Where,

Cu – Coefficient of uniformity in per cent

X – Numerical deviation of individual observations from the average application rate, mm

M – Average value of all observations, mm

N – Total number of observation points

To assess the uniformity of the system, the discharge rates were recorded at various segments. The depth of irrigation was calculated by dividing the volume of water discharged from the emitters by the area of the plot corresponding to each treatment.

RESULTS AND DISCUSSION

Observations from the experiment revealed significant differences in the emission uniformity of point-source emitters in drip-irrigated plots at varying pressures. The highest uniformity (89.25%) was noted at a pressure of 1.2 kg/cm^2, followed by 88.80% at 1 kg/cm^2. The emission uniformity coefficient increased up to 1.2 kg/cm^2 and subsequently decreased. The optimal operating pressure for achieving the maximum uniformity coefficient in the point-source emitter drip irrigation system was determined to be 1.2 kg/cm^2. The flow rate also exhibited variations with changing pressure. Mhaske *et al.* (2014) reported a tomato uniformity coefficient of 90.6%, aligning with the results obtained in this study.

The performance of micro sprinklers was investigated to assess the impact of pressure (ranging from 0.5 kg/cm^2 to 1.5 kg/cm^2) on discharge. The highest discharge, reaching 36 lph, was recorded at a pressure of 1.5 kg/cm^2. Optimal uniformity was achieved at 1.5 kg/cm^2, with a recorded value of 89.80% for a micro sprinkler stake height of 25 cm, while it was slightly lower at 88.50% for a 50 cm stake height. Additionally, it was observed that the emission uniformity coefficient increased with the rise in operating pressure for both micro sprinkler stake heights of 25 cm and 50 cm.

The analysis of the soil moisture profile revealed that the profile was not continuous up to the base of the stakes; instead, it predominantly existed in the outer half of the radius of throw for all pressures. This observation indicates that, due to an overlapping of less than 100% of the radius of throw, dry spots were present near the stake, leading to poor uniformity coefficients. Notably, the profile of micro sprinklers did not align with any of the sprinkler profiles outlined by Christiansen equation. Consequently, the overlapping percentage of the diameter of throw recommended by Christiansen would not be applicable for micro sprinklers. Therefore, it is recommended that the spacing of micro sprinklers along laterals and the spacing of laterals along the main/sub-main should be equal to the radius of throw at design pressures.

Soil moisture levels were examined in all treatments both before and after irrigation, as depicted in Figs. 1.a to 1.c. For drip and micro sprinkler treatments, the moisture content was observed at specific points: near the micro sprinkler and drip emitter (E1), at one-fourth the distance between two micro sprinklers and drip emitters (E2), and in the middle of the two micro sprinklers and drip emitters (E3) at depths of 15cm, 30cm, 45cm, and 60cm, denoted as D1, D2, D3, and D4, respectively. The moisture content was determined on a percentage weight basis. In the conventional system, moisture content was randomly observed at various points (G1, G2, G3, G4) and depths (15cm, 30cm, 45cm, and 60cm).

Differences in the height of the tomato crop were evident among various treatments, as detailed in Table 1. Initially, no significant distinctions were observed, but variations became apparent on the 60th day after transplanting. Notably, on the 90th day after transplanting, treatment T1 exhibited the highest plant height at 94.90cm, followed by T2 (93.80cm) and T3 (87.25cm). The micro sprinkler treatment (T2) displayed a mean height of 69.53cm, whereas the drip (T1) and control (T3) treatments had mean heights of 66.98cm and 62.57cm, respectively. A reduced irrigation level causing water deficit may induce anatomical changes in plant cells, such as a decrease in cell size and intercellular spaces, thereby limiting cell division and elongation, leading to an overall decrease in plant growth. Similar increases in plant height have been reported by Tripathi *et al*. (2014) and Tripathi *et al*. (2016). The mean data analysis indicated that, among the treatments tested, treatment T1 resulted in the maximum plant height, while the lowest plant height was observed in treatment T3.

Weed growth in the experimental tomato field was monitored, revealing significant differences among treatments. In the early stages of plant growth, weed growth was more pronounced compared to later stages. On the 30th day after transplanting, the micro sprinkler treatment exhibited lower weed weight at 546.78 kg/ha, followed by the drip treatment at 598.64 kg/ha. The conventional plot had a higher weed weight at 633.43 kg/ha on the 30th day after transplanting, surpassing all other treatments. Weed growth was more prominent in the initial 30 days post-transplanting for all treatments. However, on the 60th and 90th days after transplanting, weed growth decreased. Moisture distribution was more

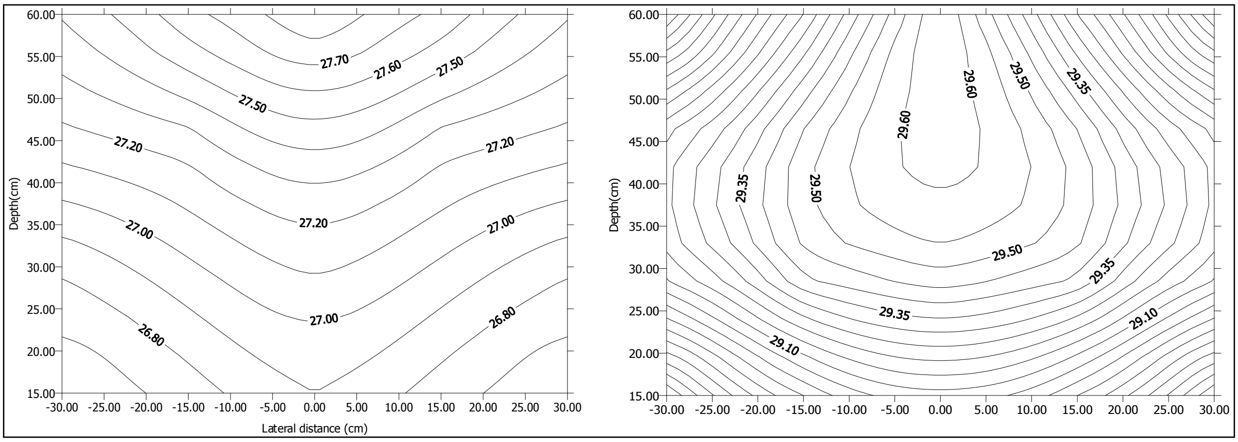

Fig. 1(a): Soil moisture distribution in drip plot before and after irrigation

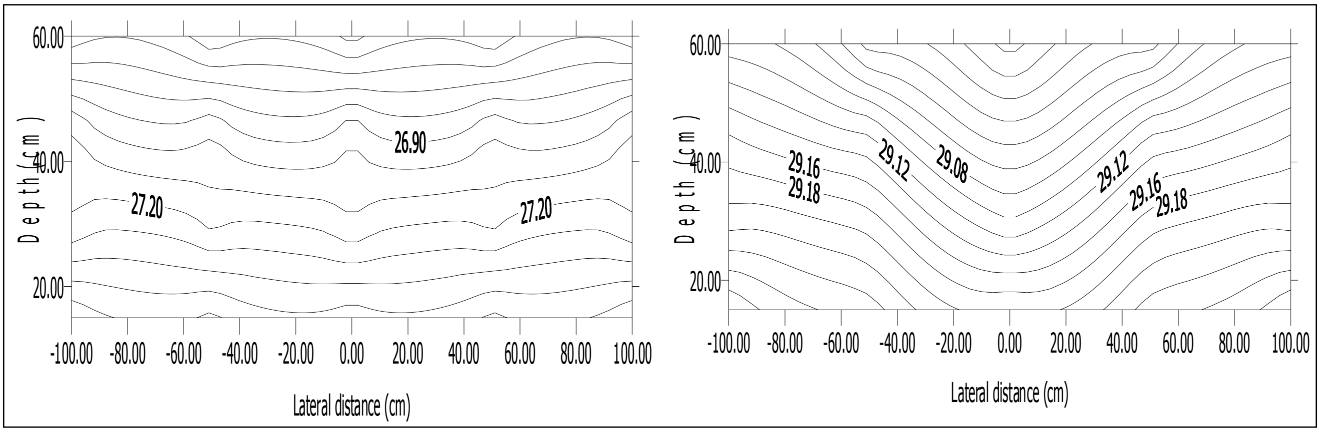

Fig. 1(b): Soil moisture distribution in micro sprinkler treated plot before and after irrigation

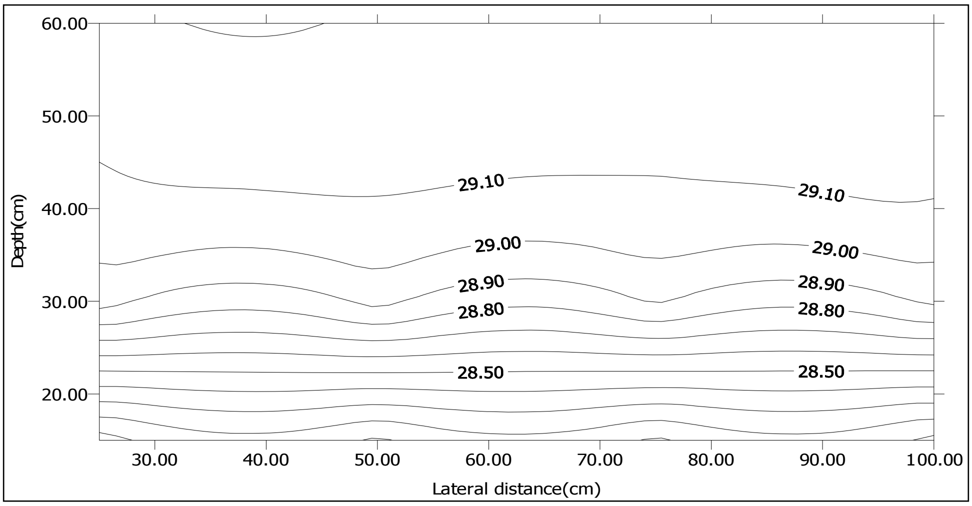

Fig. 1(c): Soil moisture distribution in control plot after irrigation

Table 1: The height of tomato plants under various treatments

Treatments	**Days after transplanting**						
	15	**30**	**45**	**60**	**75**	**90**	**Mean**
T1	34.53	48.72	62.75	84.26	92.03	94.90	69.53
T2	33.24	46.94	59.42	78.58	89.42	93.80	66.98
T3	31.59	40.54	57.01	76.59	82.46	87.25	62.57
Mean	33.12	45.40	59.83	79.81	87.97	92.01	79.81

	SED	**CD (0.05)**
Days	0.368	0.749
Treatment	0.521	1.060
Interaction	0.903	1.836

efficient in the drip treatment compared to the micro sprinkler treatment, possibly contributing to reduced weed growth in the micro sprinkler plot. Conversely, the conventional plot exhibited greater weed growth, attributed to the application of a higher water volume across the entire area.

As depicted in Fig. 2, the drip treatment produced an elongated taproot measuring 19 cm, followed by the micro sprinkler treatment with 18.20 cm and the control treatment with 16.30 cm. Drip irrigation promoted the development of denser and longer roots compared to the other treatments.

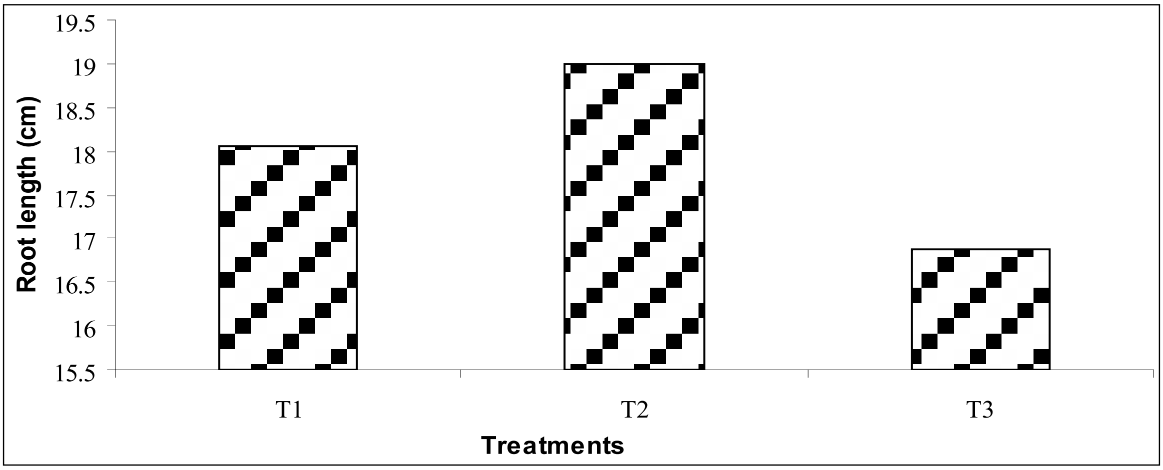

Fig. 2: Effect of tap root length under different treatments

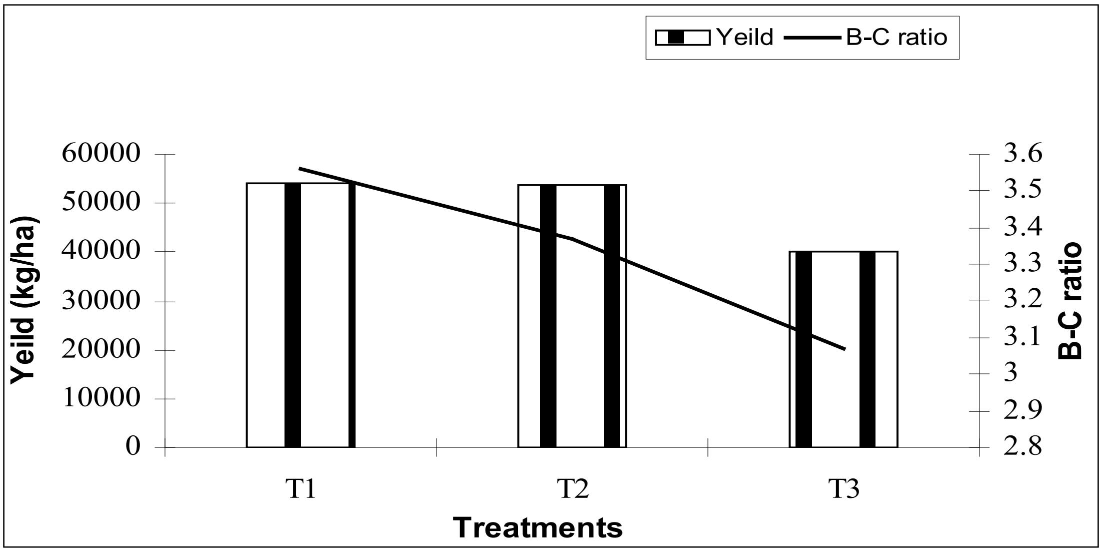

Fig. 3: Yield and benefit cost ratio for tomato crop

The extended taproots in the drip treatment were attributed to more effective moisture distribution within the soil, consequently enhancing root activities. The irrigation levels exerted a significant influence on both the mean length and density of the roots.

The yield data is displayed in Table 2, indicating that the highest yield for the tomato crop was achieved in the micro sprinkler treatment (54.2 t/ha), followed closely by the drip treatment (53.6 t/ha). The control treatment recorded the lowest yield at 40.0 t/ha. Notably, the tomatoes in the micro sprinkler plot exhibited comparatively larger fruit sizes, and the visual observation revealed salt deposition on the tomatoes due to water spraying.

The total water consumption, including effective rainfall, for the tomato crop is detailed in Table 2. It is evident that the control treatment utilized the most water for the tomato crop (550 mm), followed by the micro sprinkler treatment (470 mm) and the drip treatment (350 mm). The reduced water quantity utilized in the drip treatment was attributed to lower evaporation losses. The highest water use efficiency was observed in the drip treatment (153.14 kg/ha/mm), followed by the micro sprinkler treatment (115.131 kg/ha/mm). Conversely, the control treatment exhibited the least water use efficiency at 72.72 kg/ha/mm. Similar increases in water use efficiency have been reported by Attia *et al.* (2017). Comparatively, the drip treatment demonstrated higher water use efficiency than the micro sprinkler treatment. Fig. 3 illustrates the relationship between water applied and the water use efficiency of the tomato crop. The

Table 2: Crop yield and water utilization efficiency across various treatments in tomato cultivation

Treatment	Water applied (mm)	Effective rainfall (mm)	Total water used (mm)	Yield (t/ha)	Water use efficiency (kg/ha/mm)
T1	370	100	470	54.2	115.31
T2	250	100	350	53.6	153.14
T3	450	100	550	40.0	72.72
Mean				49. 3	
SED				7.54	
CD (0.05)				20.94	

Table 3: Economic analysis of the cost for implementing drip and micro sprinkler irrigation systems for one hectare of tomato cultivation

Sl. No.	Description	T_1	T_2	T_3
1	Fixed cost (₹/ha)	91,225	1,01,891	
(a)	Life (years)	10	10	
(b)	Depreciation	9122.5	10189.1	
(c)	Interest @ 12 % (₹)	10,947	12,226.92	
(d)	Repair and maintenance	1824.5	2037.82	
(e)	Total cost (b+c+d)	20,981.75	24,453.82	
2	Cost of cultivation	55,000	55,000	65,000
3	Seasonal total cost (2+e) (₹)	75,981.75	79,453.82	
4	Water used (mm)	470	350	550
5	Yield of produce (t/ha)	54.20	53.60	40.00
6	Selling price (₹/t)	5000	5000	5000
7	Income from produce (5×6) ₹/ha	2,71,000	2,68,000	2,00,000
8	Net seasonal Income (7-3) (₹)	1,95,018	1,88,546.18	
9	Gross benefit – cost ratio (7/3)	3.56	3.37	3.07

enhanced water use efficiency in the drip treatment was attributed to reduced losses in drainage, canopy interception, and improved water utilization. Excessive water usage beyond the optimum level resulted in lower water use efficiency for the tomato crop.

Relative humidity details were collected for the experimental field on different days. Notably, higher relative humidity levels were observed in the micro sprinkler treatment at both 8 a.m (73.16%) and 2 p.m (56.50%), followed by the drip treatment (71.55% and 54.33%) and the control treatment (69.88% and 53.30%) at the same times. The microclimate in the experimental field underwent changes when irrigated with micro sprinklers. The spray effect of micro sprinklers induced a cooling effect within the canopy, contributing to the higher relative humidity observed in the micro sprinkler plot.

Table 3 presents data on the cost of cultivation, fixed costs, gross and net income, and water usage for different treatments in tomato crop cultivation. The pipe materials' lifespan was assumed to be ten years. To determine the cost economics, interest at twelve percent of the fixed cost and repair and maintenance costs at two percent of the fixed cost were taken into account. The micro sprinkler irrigation system demonstrated a higher yield and a higher gross benefit ratio compared to drip irrigation. In the case of drip treatment, it was evident that the installation cost of the drip system was substantial (₹ 1,03,810), resulting in a lower yield and gross benefit ratio compared to the micro sprinkler treatment. The micro sprinkler irrigation system yielded more with lower costs compared to the drip irrigation system. Figure 3 illustrates that the benefit-cost (B-C) ratio was higher in the micro sprinkler treatment (3.56) compared to drip (3.37) and control treatment (3.07).

CONCLUSION

In the micro sprinkler plot, moisture distribution was more pronounced over the surface at the midpoint between two micro sprinklers compared to the drip plot. In the drip plot, moisture was evenly distributed below the emitter and diminished with an increase in radial distance from the emitter. The micro sprinkler treatment exhibited the highest plant height of 94 cm, resulting in a mean height of 69.53 cm for the crop. The taproot length of the tomato crop reached its maximum at 19 cm in the drip treatment. The highest yield, significantly superior to all other treatments, was observed in the micro sprinkler treatment at 54,200 kg/ha. The drip treatment yielded less at 53,600 kg/ha compared to the micro sprinkler treatment. The control treatment recorded the lowest yield at 40,000 kg/ha.

Water application was 470 mm for the micro sprinkler treatment, which was lower than the control treatment (550 mm). The drip treatment had the lowest water application at 350 mm. The highest water use efficiency of 153.14 kg/ha/mm was achieved with drip irrigation, surpassing the micro sprinkler treatment's efficiency at 115.31 kg/ha/mm. The benefit-cost ratio was higher at 3.96 for the micro sprinkler treatment compared to the drip (3.37) and control (3.07) treatments. Additionally, it was observed that the micro sprinkler irrigation system outperformed the drip irrigation system in terms of yield, plant height, and reduced cost, but the water use efficiency was higher in the drip treatment.

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