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Rosna P Shajan
Post Graduate Research Scholar, Department of Agronomy, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, Tamil Nadu, India

Jeyajothi R
Assistant Professor, Department of Agronomy, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, Tamil Nadu, India

Ramadass S
Assistant Professor & head, Department of Agronomy, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, Tamil Nadu, India

Rajasekar M
Assistant Professor, Department of Horticulture, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, Tamil Nadu, India

Corresponding Author:
Jeyajothi R
Assistant Professor, Department of Agronomy, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, Tamil Nadu, India

Effect of discharge rates on growth and yield parameters of bhendi (*Abelmoschus esculentus* L.) under drip irrigation

Rosna P Shajan, Jeyajothi R, Ramadass S and Rajasekar M

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Abstract
Bhendi (*Abelmoschus esculentus* L.), also known as lady's finger, is an important vegetable crop in tropical and subtropical regions, valued for its nutritional and economic significance. A field experiment was conducted from February to May 2025 at SRM College of Agricultural Sciences, Chengalpattu, Tamil Nadu, to evaluate the effect of different drip irrigation discharge rates on growth and yield performance of bhendi under clayey soil conditions. The experiment was laid out in a Randomized Block Design (RBD) comprising seven treatments with three replications. The treatments were set with two discharge rates (2 and 4 lph) and three irrigation levels (50%, 75%, and 100% ET_c) and T_7 - farmer's practice were also maintained for comparison. The TNAU Bhendi Hybrid CO4 variety was used, and standard agronomic practices were followed. Key parameters such as plant height, stem girth, leaf area index (LAI), crop growth rate (CGR), fruit length, fruit girth, average fruit weight, number of fruits per plant, and yield per hectare were recorded. Among the treatments, T_3 (2 lph @ 100% ET_c) significantly outperformed all others by recording the highest plant height (133.47 cm), LAI (3.51), CGR (12.53 g/m²/day), number of fruits per plant (24.00), and maximum yield (29.57 t/ha). T_6 (4 lph @ 100% ET_c) also performed on par with T_3. This was attributed to optimal and uniform moisture distribution around the root zone, enhancing nutrient uptake and reducing plant stress. Conversely, surface irrigation (T_7) resulted in the lowest growth and yield such as the lowest plant height (89.53 cm), LAI (2.09), CGR (10.02 g/m²/day), number of fruits per plant (12.00), and minimum yield (22.41 t/ha) due to irregular moisture availability. The study concludes that drip irrigation with 2 lph emitters at 100% ET_c is the most effective method for enhancing bhendi growth and productivity in clayey soils.

Keywords: Drip irrigation, bhendi, discharge rate, irrigation level, growth, and yield

Introduction
Bhendi (*Abelmoschus esculentus* L.), a widely cultivated crop in the Indian subcontinent, belongs to the Malvaceae family (Yasin *et al*., 2022) [12]. It is believed to have originated in Ethiopia and has since spread extensively across tropical, subtropical, and warm temperate regions worldwide. It holds significant nutritional value in the human diet, providing essential fats, proteins, carbohydrates, vitamins, and minerals (Benchasri *et al*., 2012) [1]. Bhendi is primarily grown in tropical and subtropical regions, particularly in warm climates with annual rainfall ranging from 900 to 1,000 mm and average temperatures between 18°C and 35°C. Well-drained sandy or clay loam soils with a pH of 6.0 to 6.8 are considered ideal for its cultivation (Uwiringiyimana *et al.*, 2024) [10]. It is susceptible to various abiotic stresses, including waterlogging, low temperatures, drought, and frost. As well as bhendi is sensitive to the soil moisture availability.

Drip irrigation is the best method of irrigation which can be adopted for better fruit yields in bhendi. A global meta-analysis revealed that under water-scarce conditions, drip irrigation is more effective in conserving water while maintaining crop yields compared to flooding, border, furrow, sprinkler, and micro-sprinkler irrigation methods. When applied at higher rates (100-120%), drip irrigation enhances crop yields by 28.92%, 14.55%, 8.03%, 2.32%, and 5.17% over flooding, border, furrow, sprinkler, and micro-sprinkler irrigation, respectively. In regions with adequate water availability, increasing drip irrigation levels further boosts crop production.

Additionally, researchers observed that drip irrigation helps minimize fertilizer leaching and reduces soil salinity (Yang *et al.,* 2023) [11]. Fertilizer input is also a very essential input in bhendi production. Conventional method of fertilizer application faces nutrient losses whereas, using water-soluble fertilizers through drip irrigation can be an effective strategy to minimize nutrient losses (Narendra *et al.,* 2017; Katyal *and* Randhawa, 2020) [, 4]. As a short-duration crop, growth and yield parameters of bhendi are highly responsive to proper irrigation and nutrient management practices (Thirunavukkarasu *et al.,* 2015) [9].

Materials and Methods

A field experiment was carried out from February to May 2025 at the SRM College of Agricultural Sciences, SRMIST, Chengalpattu, located at 12°N latitude and 79°E longitude with an elevation of 68 meters above mean sea level. The region receives an average annual rainfall of 1400 mm. The study aimed to assess the effect of different drip irrigation discharge rates on the growth and yield of bhendi using the TNAU Bhendi Hybrid CO4, which recorded a 90% germination rate. Seeds were treated with *Trichoderma viride* at 4 g/kg and sown in a paired row system with a spacing of 45 cm between rows and 30 cm between plants. The experimental soil was silty clay loam in texture with low available nitrogen (128.8 kg/ha), high phosphorus (7 kg/ha), medium potassium (280 kg/ha), and an organic carbon content of 0.66%. The experiment was laid out in a Randomized Block Design (RBD) comprising seven treatments replicated three times. The treatments are imposed as, T_1: Drip irrigation with 2 lph @ 50% ET_c, T_2: Drip irrigation with 2 lph @ 75% ET_c, T_3: Drip irrigation with 2 lph @ 100% ET_c, T_4: Drip irrigation with 4 lph @ 50% ET_c, T_5: Drip irrigation with 4 lph @ 75% ET_c, T_6: Drip irrigation with 4 lph @ 100% ET_c and T_7: Surface irrigation (Farmers' practice).

Each plot measured 24.3 m², and the drip system was installed on 90 cm wide raised beds with 30 cm furrows, allowing for adequate aeration and crop establishment. Inline laterals (16 mm LLDPE) with emitters spaced at 60 cm were laid out at 1.2 m intervals. A 7.5 HP submersible motor pumped filtered water through a sand filter and distributed it using 63 mm PVC sub-mains and 90 mm mainlines. Drip irrigation was scheduled once in three days based on ETc, and fertigation was given once in six days starting from 10 DAS to 90 DAS. Control plots were irrigated once in every 7 days, and fertilizers were applied based on the recommended dose of 200:100:100 NPK kg/ha, with nitrogen split into two equal doses-one as basal and the other at 30 DAS. The crop matured by 45 DAS, and harvesting began thereafter. A total of 28 harvests were done at alternate days, and data were collected on plant height, stem girth, leaf area index (LAI), crop growth rate (CGR), fruit length, fruit girth, average fruit weight, number of fruits per plant, and fruit yield per hectare. Statistical analysis of the collected data was performed using GRAPES (Gopinath *et al.,* 2021) [3] and RStudio.

Results and Discussion

1. Plant height (cm)

The influence of discharge rates and irrigation levels on bhendi growth parameters was found to be significant (Table 1.1). The plant height responded significantly with different irrigation levels of drip irrigation. The maximum plant height was observed in T_3: Drip irrigation with 2 lph @ 100% ET_c (133.47 cm) followed by T_6 (125.23 cm) and the minimum plant height was in T_7 (89.53 cm). The findings exhibited a significant variation in terms of plant height. The plants under drip irrigation system with lower discharge rate is more attributable to uniform moisture availability in the root zone minimizing stress when compared with wetting of surface irrigation. This results in better plant height of bhendi plants in drip irrigated plots with low discharge rate when compared to surface irrigated crop which undergoes low moisture stress and high moisture stress between the irrigation intervals (Thirumalaikumar *et al.,* 2014) [8].

2. Stem girth (cm)

The influence of discharge rates and irrigation levels on stem girth of bhendi was found to be non-significant (Table 1.1). The comparatively higher stem girth was observed in T_3: Drip irrigation with 2 lph @ 100% ET_c (3.42 cm) which was at par with T_6 (3.21 cm) and the minimum stem girth was in T_7 (2.57 cm). The discharge rates have no significant influence on stem girth in bhendi, even though a slight increase can be observed in drip irrigated plants compared to surface irrigation (farmers' practice). This is due to more consistent soil moisture and nutrient availability in the root zone. Farhan *et al.,* 2023 [2] also reported similar findings such as drip irrigation methods enhanced growth parameters including stem girth by ensuring uniform wetting, reducing stress, and improving fertilizer use efficiency.

3. Leaf area index (LAI)

The influence of discharge rates and irrigation levels on leaf area index of bhendi was found to be slightly significant (Table 1.1). The maximum leaf area index was observed in T_3: Drip irrigation with 2 lph @ 100% ET_c (3.51) followed by T_6 (3.24) and the minimum leaf area index was observed in T_7 (2.09). Studies on bhendi have shown that drip irrigation both surface and drip irrigation generally maintains or slightly improves LAI by ensuring a steady moisture supply, whereas surface systems often result in fluctuating wet-dry cycles that can limit optimal leaf expansion (Merin *et al.,* 2021) [6].

4. Crop growth rate (CGR)

The influence of discharge rates and irrigation levels on leaf area index of bhendi was found to significant (Table 1.1). The maximum crop growth rate was observed in T_3: Drip irrigation with 2 lph @ 100% ET_c (12.53 g/m^2/day) followed by T_6 (12.82 g/m^2/day) and the minimum crop growth rate was in T_7 (10.02 g/m^2/day). The findings exhibited a significant variation in terms of crop growth rate. More consistent and higher CGR are maintained in drip irrigated bhendi due to the continuous moisture and nutrient availability in the rhizosphere, where stress cycles are reduced compared to surface irrigation (Sharma *et al.,* 2016) [7].

Table 1: Effect of discharge rates on growth parameters of Bhendi

Treatment	Plant height (cm)	Stem girth (cm)	LAI	CGR (g/m^2/day)
T_1: Drip irrigation with 2 lph @ 50% ET_c	100.97	2.91	2.79	13.29
T_2: Drip irrigation with 2 lph @ 75% ET_c	116.41	3.14	3.06	13.73
T_3: Drip irrigation with 2 lph @ 100% ET_c	133.47	3.42	3.51	12.53
T_4: Drip irrigation with 4 lph @ 50% ET_c	102.51	2.84	2.66	11.55
T_5: Drip irrigation with 4 lph @ 75% ET_c	115.67	3.02	2.91	13.58
T_6: Drip irrigation with 4 lph @ 100% ET_c	125.23	3.21	3.24	12.82
T_7: Surface irrigation (Farmers' practice)	89.53	2.57	2.09	10.02
SEd	5.82	0.25	0.16	0.92
CD (P=0.05)	12.67	NS	0.34	1.99

5. Fruit length (cm)

The influence of discharge rates and irrigation levels on bhendi yield parameters was found to be significant (Table 1.2). The maximum fruit length was observed in T_3: Drip irrigation with 2 lph @ 100% ET_c (13.50 cm) followed by T_6 (11.60 cm) and the minimum fruit length was in T_7 (8.10 cm). The findings exhibited a significant variation in terms of fruit length. The effect of low irrigation conditions could be attributed to limited access to water and nutrients leads to minimum fruit length.

6. Fruit girth (cm)

The maximum fruit girth was recorded in T_7 (6.10 cm) followed by T_4 (5.50 cm) and the minimum (4.00 cm) was recorded in T_3: Drip irrigation with 2 lph @ 100% ET_c. The fruit length and fruit girth have an indirectly proportional relationship between them. So, the T_3 fruits are long and thin whereas, T_7 has the thicker and short fruits.

7. Average fruit weight (g)

The highest average fruit weight was observed in T_3: Drip irrigation with 2 lph @ 100% ET_c (22.30 g) followed by T_6 (20.80 g) and the lowest (15.10 g) was in T_7. The treatments exhibited a significant variation in terms of average fruit weight, with a correlation between irrigation level and increase in fruit weight as indicated by data in Table 1.1. The water availability had an inevitable impact on fruit weight, leading to overall healthy crop (Najafabadi *et al.*, 2023).

8. No. of fruits per plant

The maximum number of fruits per plant was noted in T_3: Drip irrigation with 2 lph @ 100% ET_c (24.00) followed by T_6 (22.00) and the minimum (12.00) was in T_7. The different irrigation levels can also impact on number of fruits per plant. The high moisture availability in the soil resulted in a higher number of fruits per plant. In this soil type, 2 lph was observed as the best emitter discharge rate which provides higher moisture availability than 4 lph and even more than the conventional method of irrigation.

***9.* Yield (t/ha)**

The yield data revealed significant differences among the treatments, and statistical analysis confirmed that the variation in yield per hectare in tons was statistically significant (Fig.1). The maximum fruit yield per hectare (29.57 t/ha) was recorded in T_3: Drip irrigation with 2 lph @ 100% ET_c which was at par with T_6 (28.63.13 t/ha) and the minimum (22.41 t/ha) yield per hectare was in T_7. These results showed that the adequate irrigation level and discharge rate can positively influence the nutrient and water uptake which in turn leads to the healthy plant growth, maximum fruit production and ultimately, higher yields. The previous studies in this context also confirms these findings.

Table 2: Effect of discharge rates on yield parameters of Bhendi

Treatment	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	No. of fruits/plant	Fruit yield (t/ha)
T_1: Drip irrigation with 2 lph @ 50% ET_c	10.50	5.30	18.10	18.00	24.62
T_2: Drip irrigation with 2 lph @ 75% ET_c	11.20	4.80	20.30	21.00	25.57
T_3: Drip irrigation with 2 lph @ 100% ET_c	13.50	4.00	22.30	24.00	29.57
T_4: Drip irrigation with 4 lph @ 50% ET_c	10.00	5.50	17.20	17.00	24.45
T_5: Drip irrigation with 4 lph @ 75% ET_c	10.90	4.84	19.20	20.00	25.18
T_6: Drip irrigation with 4 lph @ 100% ET_c	11.60	4.74	20.80	22.00	28.63
T_7: Surface irrigation (Farmers' practice)	8.10	6.10	15.10	12.00	22.41
CD	1.23	0.63	0.67	2.02	3.63
SE(d)	0.56	0.29	0.31	0.93	1.67

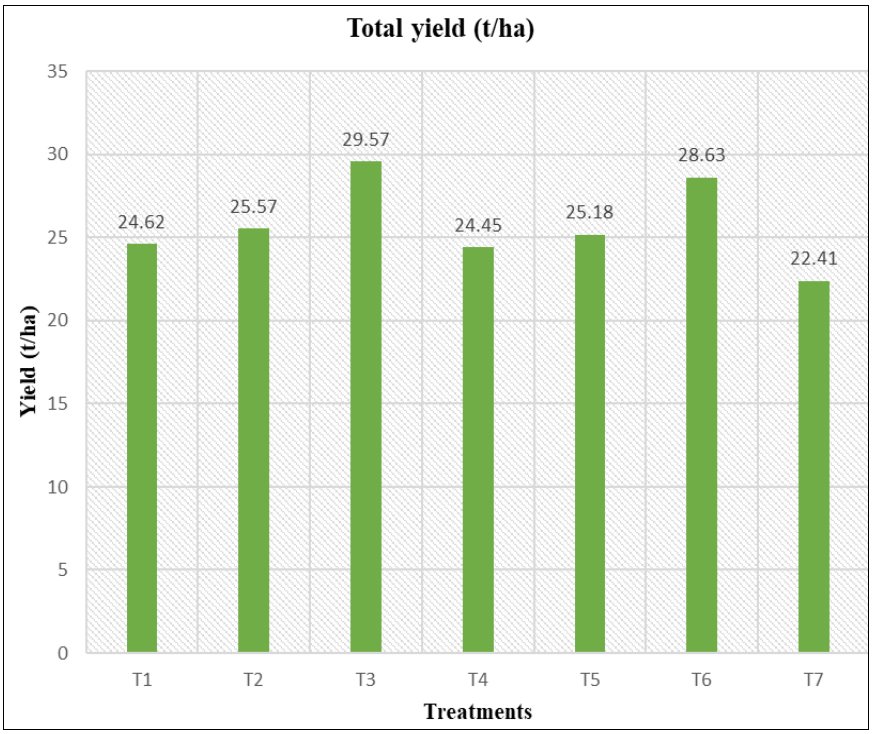

Fig 1: Effect of different discharge rates and irrigation levels on yield (tons/ha)

Conclusion

The present study demonstrated that drip irrigation significantly enhances the growth and yield of bhendi compared to conventional surface irrigation methods. Among the treatments, T_3 (Drip irrigation with 2 lph @ 100% ETc) consistently produced superior results in terms of plant height, LAI, crop growth rate, fruit length, average fruit weight, number of fruits per plant, and overall yield (29.57 t/ha). T_6 also performed on par with T_3. These improvements are attributed to the precise and consistent moisture and nutrient availability at the root zone, which minimizes plant stress and promotes vigorous growth. Based on the findings, it is strongly recommended that farmers, especially those cultivating bhendi in clayey soils under similar agro-climatic conditions, adopt drip irrigation with a 2 lph discharge rate at 100% ET_c or drip irrigation with 4 lph discharge rate at 100% ET_c. This approaches not only ensures better crop performance and higher returns but also promotes water use efficiency and sustainable farming practices.

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Conflict of Interest

The authors affirm that there are no conflicts of interest associated with this publication.

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