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Assessing water use efficiency, nutrient use efficiency and yield of Bhendi with 19:19:19 water-soluble fertilizer under drip irrigation

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Abstract

This study examines the effects of different fertilization treatments on the yield, water use efficiency (WUE) and nutrient use efficiency (NUE) of Bhendi. Field experiments were conducted at the Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, during the Rabi season of December 2023 to March 2024 because Bhendi thrives in warm temperatures and requires precise water management. Drip irrigation provides optimal growth conditions even in the cooler Rabi weather while minimizing water waste, especially in areas with limited water availability. The treatments included soil-based fertilizers and water-soluble fertilizers (WSF), applied alone or in combination with recommended doses of fertilizer (RDF). Among the treatments, T8, which applied 120 kg/ha of TNAU water-soluble fertilizer 19:19:19 with an additional 25 % RDF proved to be the most effective. It achieved the highest yield, WUE and NUE, demonstrating superior crop productivity and resource efficiency. In contrast, the absolute control treatment (T1), which received no fertilizer, resulted in the lowest yield, highlighting the importance of fertilization in enhancing crop performance. Treatment T5, which used 120 kg/ha of WSF, also showed high yield and good WUE but did not match the efficiency levels of T8. The study concludes that integrating high doses of water-soluble fertilizers with additional RDF through drip fertigation is the most effective strategy for optimizing yield and resource efficiency in Bhendi cultivation.

Keywords

bhendi; drip irrigation; fertigation; Water use efficiency (WUE); Fertilizer use efficiency (FUE); water-soluble fertilizer (19:19:19); crop productivity

Introduction

Bhendi (*Abelmoschus esculentus* L. Moench) commonly known as okra or ladies' finger is a vital vegetable crop belonging to the Malvaceae family. Originating from tropical Africa, Bhendi is an herbaceous annual plant that is economically significant in tropical and sub-tropical regions. Often referred to as the "queen of vegetables"(1). It provides essential nutrients, including carbohydrates, proteins, minerals, vitamins and fats, which are often lacking in staple foods (2).

India leads the world in Bhendi production, with a cultivated area of 5.19 million ha and an annual production of 6.37 million metric tons, achieving a productivity of 12 tonnes per ha. During the 2021-2022 agricultural year, Tamil Nadu alone cultivated 555000 ha of Bhendi, producing 6819000 metric tons (3).

In water-limited areas, drip fertigation is gaining popularity, saving up to 30 % of water and 70 % of fertilizer while maintaining crop yields. It improves nutrient absorption, reduces waste and is crucial in India, where irrigation efficiency is limited (4).

In vegetable production, drip fertigation minimizes fertilizer and nitrate loss by supplying small doses of fertilizer directly to the plant's root zone. This approach not only enhances yield but also reduces fertilizer expenses (5). Applying 75 % of the recommended fertilizer dose under drip fertigation resulted in the highest ascorbic acid content in Bhendi. Additionally, increasing the fertilizer dose further improved overall fruit quality (6).

The crude protein, crude fiber, ascorbic acid and mucilage content of Bhendi were significantly higher when irrigated at 100 % and fertigated with 150 % RDF using water-soluble fertilizers (WSF). This improvement in quality is expected because the recommended fertilizer doses supplied the necessary nutrients in a balanced manner. This balanced nutrition likely enhanced chlorophyll levels and photosynthetic activity, resulting in increased sugar content, as well as higher levels of mucilage, protein, starch and ascorbic acid (7). These factors can significantly impact the size, shape, texture and nutritional content of the fruits, ultimately leading to higher market value.

Given that water is a crucial but limited resource, its effective management is critical for successful crop production (8). Drip irrigation at 100 % pan evaporation (PE) enhances water use efficiency and yields, while drip fertigation with 150 % of the recommended fertilizer dose, using water-soluble phosphorus, boosts nutrient uptake, improving both the quality and yield of Bhendi (6).

Though fertigation involves additional costs due to the use of water-soluble fertilizers, these costs are largely offset by higher net returns from increased yields and improved crop quality. For instance, drip fertigation with 150 % RDF provided the highest yields and net returns in various field experiments (9). Moreover, these low-cost technologies, by saving significant amounts of water and nutrients, are accessible to resource-poor farmers, especially in regions like the Gangetic alluvial plain of Eastern India (10).

Fertilizer application enhances both crop yield and nutrient content, boosting diet-quality enhancing nutrients by 11.9 %, a key factor for food security, defined by the FAO as access to sufficient, safe and nutritious food for a healthy life (11). Advanced practices like drip fertigation with water-soluble fertilizers further improve nutrient use efficiency and crop quality. This study examines the impact of different fertilizer levels on water and nutrient use efficiency, productivity, and economic returns in Bhendi hybrid CO 4 under drip fertigation, with a focus on the effectiveness of 19:19:19 water-soluble fertilizer in enhancing yield and efficiency.

Materials and Methods

Experimental Site:

The field experiment was conducted at the Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai during the Rabi season of December, 2023 to March, 2024. The experimental site was situated at 9° 96' N latitude and 78°20' E longitude, at an elevation of 147 meters above mean sea level (MSL). The soil of the experimental field was sandy clay loam in texture, with an initial nutrient status of low available nitrogen (245.5 kg/ha), high available phosphorus (26.3 kg/ha) and medium available potassium (235.2 kg/ha) and a soil organic carbon content of 3.6 kg/ha.

Treatment details:

T_1: Absolute control

T_2: Soil application of STCR RDF (200:100:100 kg N, P_2O_5, K_2O ha^{-1})

T_3: TNAU water-soluble fertilizer 19:19:19 at 80 kg/ha

T_4: TNAU water-soluble fertilizer 19:19:19 at 100 kg/ha

T_5: TNAU water-soluble fertilizer 19:19:19 at 120 kg/ha

T_6: T3 + 25 % RDF

T_7: T4 + 25 % RDF

T_8: T5 + 25 % RDF

Experimental Design:

The experiment was laid out in a Randomized Block Design (RBD) were statistically analysed by three way ANOVA using AGRES software with 8 treatments, each replicated 3 times across 24 plots. Each plot measured 10 m x 1.2 m (12 m^2), with a plant spacing of 60 cm x 30 cm (Fig. 1 and 2).

Cultural Operation:

Preparation of Experimental plot:

The land was prepared by ploughing it 5 times to achieve proper soil texture and aeration (Fig. 3). During the preparation,

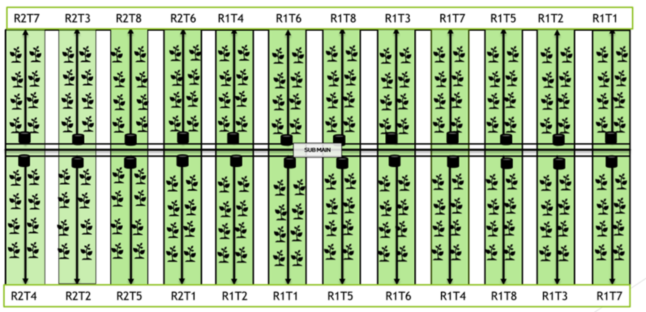

Fig. 1. Field layout of drip-fertigation system for crop growth.

Fig. 2. Optimizing crop growth through drip fertigation in field trials.

Fig. 3. Field preparation using rotary tillers with ridge attachments.

well-decomposed farmyard manure (FYM) was applied at a rate of 25 tons per ha to enrich the soil. Additionally, neem cake and poultry manure were incorporated to further improve plant growth and yield. Ridges and furrows were then formed at 45 cm apart.

Crop details:

The Bhendi hybrid CO 4, purchased from the Horticulture College and Research Institute in Trichy, was subjected to a germination test, achieving a 90 % germination rate. After the test, the seeds were sown. The seeds were treated with ***Trichoderma viride*** at 4 g/kg or ***Pseudomonas fluorescens*** at 10 g/kg of seeds. Additionally, 400 g of ***Azospirillum*** was applied using starch as an adhesive and the treated seeds were left to dry in the shade for 20 min. For sowing, 3 seeds were placed per hill at a spacing of 30 cm and after 10 days, the seedlings were thinned to 2 plants per hill to ensure optimal growth.

Irrigation and Fertigation Setup:

The raised bed system, featuring 90 cm wide beds with 30 cm furrows, optimizes space, drainage and air circulation. Two plant rows are spaced 20 cm apart, ensuring ideal conditions for efficient crop production in intensive agricultural systems.

The water source for the experiment was supplied through a 7.5 HP submersible motor, conveyed to the field using 90 mm diameter PVC pipes. The water was filtered through a sand filter before being distributed through 63 mm diameter PVC sub-mains. Inline laterals (12 mm Linear Low-Density Polyethylene) were spaced 1.2 m apart, with emitters fixed at 60 cm intervals, delivering water at a discharge rate of 4 LPH (Fig. 5). Drip irrigation was scheduled at 3 days intervals.

Treatment wise fertilizers applied (Kg/ha) under fertigation for Bhendi Hybrid:

Macro nutrients were applied as water-soluble fertilizers through the fertigation system using a dosmatic pump. The crop duration was 110 days and fertigation was scheduled in 4 splits. Fertilizer applications were made from the 10th day after planting until the 90th day, at regular intervals during the crop period (Table 1).

Data Collection and Calculations:

Water and Fertilizer Use Efficiency of Bhendi (Okra) under Drip Irrigation (Table 2)

Water Use Efficiency (WUE):

WUE was calculated as the yield per unit of water used (kg/ha/mm), using the following formula

$$\text{WUE} = \frac{\text{Economic yield of crop (kg ha}^{-1}\text{)}}{\text{Total water used (mm)}}$$

Table 1. Treatment wise fertilizers applied (Kg/ha) under fertigation for Bhendi hybrid.

Symbols	Treatment details	Urea (kg/ha)	SSP (kg/ha) (Basal dose)	MOP (kg/ha)	19:19:19 (kg/ha)
T_1	Absolute control	-	-	-	-
T_2	Soil application of STCR RDF (200:100:100 kg N, P_2O_5, K_2O ha^{-1})	434.78	625	166.67	-
T_3	TNAU water-soluble fertilizer 19:19:19 at 80 kg/ha	-	-	-	80
T_4	TNAU water-soluble fertilizer 19:19:19 at 100 kg/ha	-	-	-	100
T_5	TNAU water-soluble fertilizer 19:19:19 at 120 kg/ha	-	-	-	120
T_6	T3 + 25 % RDF	108.7	156.25	41.66	80
T_7	T4 + 25 % RDF	108.7	156.25	41.66	100
T_8	T5 + 25 % RDF	108.7	156.25	41.66	120

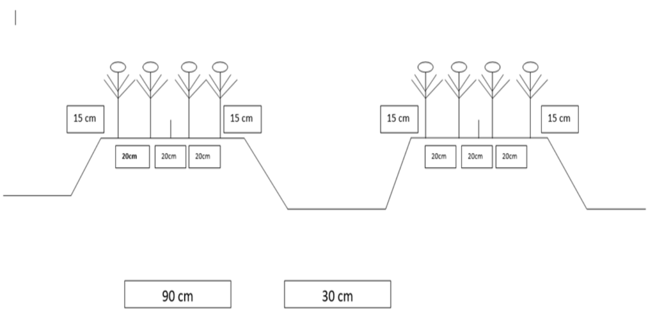

Fig. 4. Drip and crop layout in single bed.

Fig. 5. Irrigation and fertigation setup.

Water Productivity (WP):

WP was calculated as the yield per cubic meter of water used (kg/m^3), using the formula:

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

Fertilizer Use Efficiency (FUE):

FUE was calculated as the increase in yield per unit of fertilizer applied, relative to the control.

$$\text{Fertilizer Use Efficiency} = \frac{\text{Yield with fertilizer - yield without fertilizer}}{\text{Amount of nutrient applied (kg/ha)}}$$

Yield:

Harvesting of the crop was done treatment wise after attaining maturity. After the first harvest, other harvests were done at an interval of 2 days. The first yield was taken 30th day after planting. Total of the 23 harvests gave the total yield (Fig. 4).

Results and Discussion

Water use efficiency:

The yield, total water used, water use efficiency (WUE) and water productivity of Bhendi (okra) under various treatments is detailed in Table 2. The yield significantly varied, ranging from 7930 kg/ha in the control treatment (T1) to 21130 kg/ha in T8. All treatments used the same total water amount of 310.2 mm, enabling a direct comparison of WUE and water productivity.

T8, which involved drip fertigation with 19:19:19 water -soluble fertilizer at 120 kg/ha + 25 % of the Recommended Dose of Fertilizer (RDF), recorded the highest yield of 21130 kg/ha. It also had the highest WUE (68.13 kg/ha/mm) and water productivity (6.81 kg/m^3), showing that the highest fertilizer dose, when combined with drip fertigation, maximized yield and optimized water use.

T7 and T6 followed, with yields of 18270 kg/ha and 18030 kg/ha respectively. Their WUE and water productivity were also high (58.89 kg/ha/mm and 5.89 kg/m^3 for T7; 58.11 kg/ha/mm and 5.81 kg/m^3 for T6). This indicates that slightly reducing the fertilizer dose still delivers strong yields and water efficiency, making them nearly as effective as T8.

In contrast, the control (T1) recorded the lowest yield of 7930 kg/ha, with the lowest WUE (25.56 kg/ha/mm) and water productivity (2.56 kg/m^3), highlighting the crucial role of nutrient management in enhancing crop performance under drip fertigation.

Nutrient use efficiency:

The nutrient use efficiency (FUE) of Bhendi (okra) under different treatments, along with yield data, is detailed in Table 2. FUE reflects how efficiently the applied fertilizers were utilized by the crop to produce yield.

Analysis reveals that treatment T5, with 120 kg/ha of 19:19:19 water-soluble fertilizer, recorded the highest FUE at 75.66, corresponding to a yield of 14830 kg/ha. This suggests that T5 provided an optimal balance between fertilizer application and crop yield, resulting in the most efficient nutrient use.

Treatments T4 and T3 followed, with FUE values of 59.74 and 51.64 and corresponding yields of 12470 kg/ha and 11070 kg/ha respectively. These moderate fertilizer rates effectively enhanced crop nutrient use, leading to high nutrient use efficiency.

Interestingly, treatments T6, T7 and T8, which produced the highest yields (18030 kg/ha, 18270 kg/ha and 21130 kg/ha respectively), had lower FUE values at 38.72, 37.46 and 45.32. This suggests that while these treatments maximized yield, they did so with less efficient nutrient use, possibly due to higher fertilizer inputs diluting efficiency.

The control treatment (T1), with no fertilizer, recorded an FUE of 0, while T2, with soil application of the recommended dose, had an FUE of 1.175, reflecting baseline nutrient uptake.

Overall, T5 stands out for achieving a balance between high yield and nutrient use efficiency, underscoring the importance of optimizing fertilizer application rates for both yield and efficiency in crop production.

Fig. 6. Bhendi yield under drip fertigation.

Table 2. Water and fertilizer use efficiency of Bhendi (Okra) under drip irrigation.

Treatment	Yield (kg/ha)	Total water used (mm)	Water use efficiency (kg/ha/mm)	Water productivity (kg/m^3)	FUE
T1	7930	310.2	25.56	2.56	0
T2	8870	310.2	28.60	2.86	1.175
T3	11070	310.2	35.69	3.57	51.64
T4	12470	310.2	40.19	4.02	59.74
T5	14830	310.2	47.81	4.78	75.66
T6	18030	310.2	58.11	5.81	38.72
T7	18270	310.2	58.89	5.89	37.46
T8	21130	310.2	68.13	6.81	45.32

Yield:

The field experiments revealed the significant impact of various fertilizer applications on Bhendi (okra) yield. Treatment T8, which involved applying TNAU water-soluble fertilizer (19:19:19) at 120 kg/ha with an additional 25 % of the recommended dose of fertilizer (RDF), achieved the highest yield of 21130 kg/ha. This demonstrates that combining high levels of water-soluble fertilizers with supplementary nutrients can significantly enhance crop productivity. In contrast, the Absolute Control (T1), which received no fertilizer, had the lowest yield of 7930 kg/ha, underscoring the crucial role of fertilization in improving crop yields. Treatment T2, involving soil application of Soil Test Crop Response (STCR) - Recommended Dose of Fertilizer (RDF), produced a higher yield of 8870 kg/ha compared to the control but remained substantially lower than treatments with TNAU water-soluble fertilizers. Treatments T3 and T4, which applied intermediate levels of these fertilizers, resulted in yields of 11,070 kg/ha and 12470 kg/ha respectively, reflecting incremental improvements as fertilizer rates increased. Adding 25 % RDF to the fertilizer treatments (T6, T7 and T8) further boosted yields, with T8 delivering the highest yield. These results highlight the importance of precise nutrient management, showing that the optimal combination of high fertilizer rates and supplementary RDF leads to the most significant yield gains.

When comparing water use efficiency (WUE), fertilizer use efficiency (FUE) and yield across treatments, significant variations were evident. Treatment T8 achieved not only the highest yield but also the highest WUE of 68.13 kg/ha/mm and an FUE of 45.32. This indicates that the combination of high fertilizer rates and additional RDF led to superior water and nutrient use efficiencies. In contrast, the Absolute Control (T1) recorded the lowest yield of 7930 kg/ha, the lowest WUE of 25.56 kg/ha/mm and zero FUE, demonstrating the negative effects of insufficient fertilization. Treatment T5, which applied TNAU water-soluble fertilizer at 120 kg/ha, achieved a yield of 14830 kg/ha with a WUE of 47.81 kg/ha/mm but a higher FUE of 75.66. While T5 performed well, it did not reach the efficiency levels of T8, which emerged as the best treatment for maximizing yield, WUE and FUE in Bhendi cultivation.

Conclusion

Traditional irrigation methods often yield approximately 12 tons per ha but face significant challenges with inefficient water and nutrient usage, which limits overall productivity and resource utilization. Drip irrigation technology has emerged as a viable tool to rectify the water exploration and achieve sustainable development goal, offering multiple benefits, such as a yield increase ranging from 13 % to 37 % and a significant improvement in water use efficiency (WUE) by 30 % to 50 % compared to conventional methods like flood or furrow irrigation. This precision irrigation technique not only ensures better water distribution to the root zone but also minimizes water loss through evaporation and deep percolation, making it a sustainable practice for improving agricultural output, particularly in water-scarce regions.

The study focused to depict the optimal integration of TNAU water-soluble fertilizer (19:19:19) applied at a rate of 120 kg/ha, along with an additional 25 % of the recommended dose of fertilizer (RDF), produced the highest recorded yield of 21130 kg/ha. This treatment also demonstrated superior WUE of 68.13 kg/ha/mm and a fertilizer use efficiency (FUE) of 45.32, showcasing the effectiveness of precise nutrient application in maximizing both yield and resource use efficiency. In stark contrast, the control treatment without any fertilizer input resulted in a much lower yield of only 7930 kg/ha, with the lowest WUE of 25.56 kg/ha/mm and an FUE of zero, underscoring the critical role that effective nutrient management plays in optimizing crop performance and sustainability.

To further improve outcomes for this study, the future research should explore the combined effects of different nutrient mixes, including micronutrients, biofertilizers and water-soluble fertilizers, to enhance productivity and optimize resource use. Expanding the number of treatments and incorporating advanced monitoring tools like sensor-based fertigation systems could fine-tune nutrient application schedules to meet real-time crop needs, ultimately leading to more resilient and sustainable agricultural practices. Such comprehensive studies would provide a holistic understanding of how to optimize nutrient use efficiency, water use efficiency and yield in varied agro-climatic conditions, paving the way for broader adaptability and adoption of precision fertigation strategies in diverse cropping systems in sustainable manner.

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Authors' contributions

SAP - Write the frame work of this research article; SS and SS -Editing and compilation of the research article; MA, PS and PP - Reviewing and editing the article.

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