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Irrigation Scheduling Strategies for High-Yield, Water-Efficient on Tomato Production under Drip Irrigation in Western Uttar Pradesh, India

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ABSTRACT

Drip irrigation is a highly efficient technology widely adopted in row crop agriculture, particularly in regions with limited freshwater resources. This controlled distribution minimizes the surface flow of water and percolation, enhancing insectpest management and salinity control. This study was carried out in the College of Agriculture Sciences and Engineering, IFTM University, Moradabad, Uttar Pradesh (India). The treatments of the study embraced different pairs of five drip irrigation levels T1 (1 hr in one-day intervals), T2 (2 hrs in two days intervals), T3 (3 hrs in three days intervals), T4 (4 hrs in four days intervals) and T5 (Furrow irrigation, i.e. Control). The result highest values i.e. plant height, growth, yield, Water use efficiency (WUE), benefit-cost ratio (B:C ratio) and economically in (T2), while in lowest values in (T5). The highest net return (189048 Rs/ha) was recorded in T2, while lowest in T5 (144765 Rs/ha), however the gross return was recorded to be the highest (291698 Rs/ha) in this treatment T2 and lowest in T5 (229765 Rs/ha). The benefit-cost ratio (BCR) values were recorded at higher levels of drip irrigation of T2 (4.28) and lowest T5 (3.79). The conclusion, drip irrigation, when combined with proper soil moisture management, significantly influences tomato growth, yield, and water use efficiency. This technology offers a promising solution for optimizing tomato production, conserving water resources, and enhancing profitability, particularly in regions facing water scarcity challenges.

Key words: *Drip irrigation, Tomato crop, Water use efficiency, Benefit-cost ratio, Soil characteristics*

Introduction

Drip irrigation is a high-efficiency watering technology that is frequently used in row crop agriculture. This clever technology includes precisely delivering water to the soil neighboring the plant's root zone using specific drip tubes. These tubes can be placed on the soil's surface (known as a surface drip) or placed a few centimeters below ground level (known as subsurface drip). Drip irrigation's exceptional benefits and efficiency have considerably boosted its adoption and utilization by farmers worldwide, particularly in arid and semi-arid countries where freshwater supplies are short (Olamide *et al.,* 2022). Due to its precise distribution of water directly to the root zone of crops without flooding the entire length of fields, drip irrigation stands out as a highly effective water-saving technique. Typically, only a small percentage of the soil surface gets hydrated by this method, ranging from 15% to 60% (Fanish *et al.,* 2011). Drop-by-drop water distribution is a crucial factor in reducing surface flow and percolation of water, which improves insectpest management and salinity control. Drip irrigation also has several additional benefits, including better crop quality, careful use of fertilizers and other chemicals, reduced weed growth, and the encouragement of improved agronomic practices (Wang, 2012).

Drip irrigation can help farmers to produce more food with less water, which is essential for sustainable agriculture. The cultivation of vegetable crops has seen a rise in the use of drip irrigation, a relatively new technology in Bangladesh. This interest has been inspired by the technology's ability to decrease water usage and possibly increase crop yields. Due to the systems precise and focused water distribution directly to the root zone, it has proven to be superior to conventional irrigation techniques, especially when used to irrigate fruit and vegetable crops (Biswas *et al.,* 2015). This strategy decreases the requirement for fertilizers while also conserving water. Additionally, it has the potential to raise agricultural yields even with minimal irrigation water application to field trials in the United States demonstrating the effectiveness of drip irrigation (Yohannes and Tadesse, 1998; Pruitt *et al.,* 1984).

India boasts the largest irrigation network, but its irrigation efficiency remains below 60-70% due to the inappropriate utilization of available water resources (Imamsaheb *et al.,* 2014). Consequently, the prudent utilization of water resources through advanced drip irrigation methods becomes paramount. This approach can enhance water use efficiency and yield, ensuring the highest crop production per unit of water applied (Dunage *et al.,* 2009). In India, the majority of rainfall occurs during the monsoon season, from June to October. Hence, the adoption of modern irrigation methods such as pressurized irrigation (drip and sprinkler) is essential to meet the food demands of the growing population, especially during periods of water scarcity. In today's context, drip irrigation can effectively support crop production under conditions of water stress. Consequently, there is a pressing need to harness available water resources efficiently through the embracing of innovative irrigation technology.

Tomatoes are a widely cultivated vegetable globally, but they are particularly sensitive to soil water deficits, as noted by (Yang *et al.,* 2017; Hou *et al.,* 2020). Consequently, the selection of appropriate irrigation systems and the maintenance of optimal soil moisture levels are paramount for achieving higher yields and water efficiency in open-field tomato production. Studies have shown that tomato yield and water productivity are majorly influenced by soil moisture deficits, especially when the soil moisture is reduced to 50% of field capacity (FC), in comparison to maintaining them, as reported by Chakma *et al.* (2021) and Mukherjee *et al.* (2023). In furrow irrigation systems, less frequent irrigation can lead to rapid soil drying, surface cracking, and challenges for roots in accessing moisture and nutrients from the soil. In contrast, drip irrigation systems facilitate the even distribution and proper soaking of irrigation water within the root zone. The rising demand for diverse fresh vegetable crops, driven by crop diversification, has further underscored the importance of drip irrigation. This method has gained significant popularity among farmers as it allows for the cultivation of vegetable crops without the need to reduce agricultural land. It plays a vital role in achieving a balance between the growing demand for fresh vegetables and their supply in the market.

Materials and Methods

Experimental site

The research was carried out at the College of Agriculture Sciences and Engineering, IFTM University, located in Moradabad, Uttar Pradesh, with geographical coordinates of approximately 28.83°N latitude and 78.78°E longitude as shown in Fig.1. The site elevation was approximately 205.67 meters above mean sea level (MSL). The experimental durationis from November to Marchin the year (2018-2019). Agro-meteorological data for the year 2018-2019, including average temperature, sunshine duration, wind velocity, humidity, evaporation, and rainfall were gathered for analysis from the website www.accuweather.com. In May and June, the average maximum temperature consistently exceeded 32 ºC, while in December and January, minimum temperatures occasionally dropped below 1 ºC, with an average of 16 ºC. The annual mean rainfall measured 1024 mm. Specific weather conditions preva-

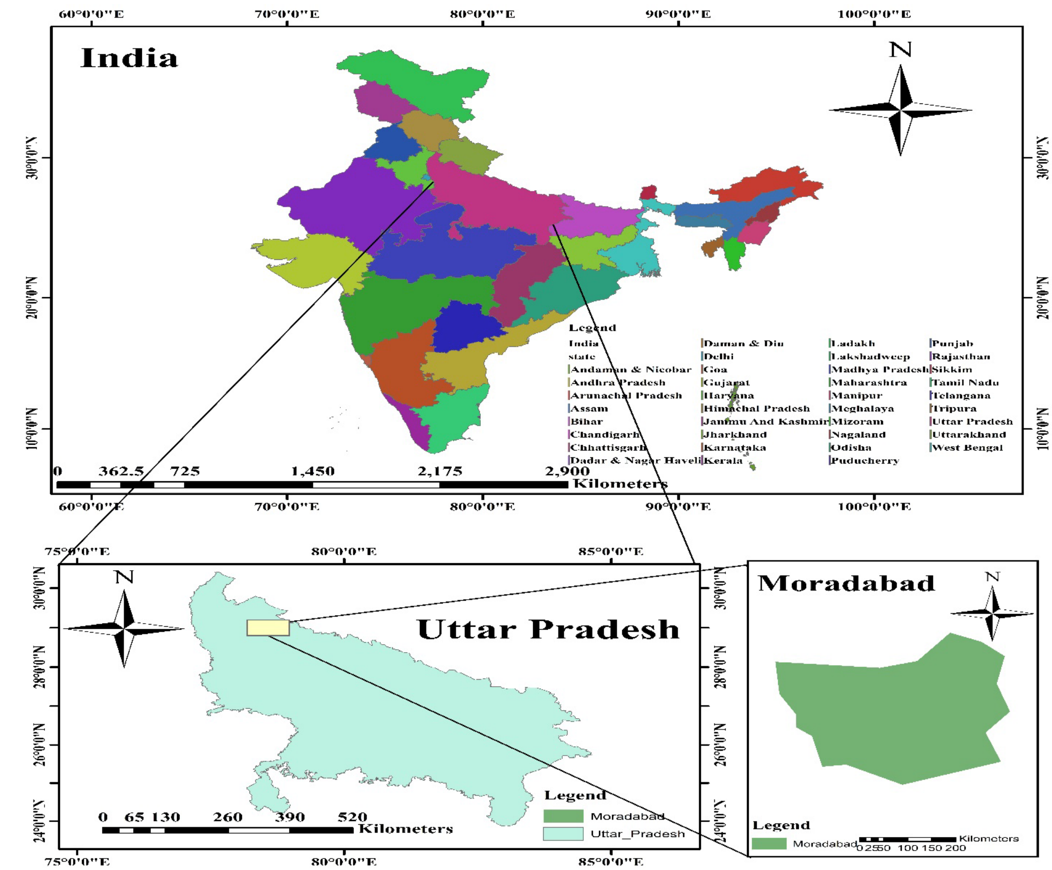

Fig. 1. Study area of map

lent during the crop season were obtained from the meteorological observatory. During the crop season, the total recorded rainfall amounted to 285 mm, with the highest rainfall occurring in July. Relative humidity levels ranged from 87% in July to 80% in December during the period of crop growth.

Layout and Design of drip irrigation system

The experimental setup consists of several components, including a screen filter, main, sub mains, laterals, dripper, and various other accessories for drip irrigation. These components were installed on a 60 m^2 experimental land area as shown in Fig. 2. To create the main pipeline for drip irrigation, PVC pipes with a 50 mm diameter were used, while the sub-main pipelines employed 25 mm diameter PVC pipes. Linear Low-Density Polyethylene (LLDPE) pipes with a 12 mm diameter were utilized for the laterals associated with each treatment shown in Plate 1. To regulate the flow rate of water, drippers with a flow rate of 1.46 liters per hour (lph) were placed at 70 cm intervals along the laterals within

Plate 2. Layout of drip irrigation system

the plot. Additionally, small valves located at the start of each treatment enabled control and switching as needed.

Treatment details

In this research on determining the water requirements for tomato crops through drip irrigation, we took into account various aspects when designing the system. For the design of the drip irrigation system as well as the experimental particulars for the test plots, we installed 15 laterals, each having a 12 mm diameter, with a spacing of 70 cm between rows and 50 cm between individual plants. In each row, a single plant was transplanted at a depth ranging from 3 to 4 cm. The different irrigation scheduling treatments were implemented as follows: T1 (1 hr in one-day intervals), T2 (2 hrs in two days intervals), T3 (3 hrs in three days intervals), T4 (4 hrs in four days intervals) and T5 (Furrow irrigation, i.e. Control). The 'Hybrid NS-524' variety of commercial tomato (*Lycopersicon esculentum L.*) has been selected for conducting trial and details of crop specification are given in Table 2. The selected crop was planted in November and harvested in March.

Plant growth parameters

In a plant experiment, five plants were randomly selected and labelled for each treatment group. The height of these plants was measured at 30, 60, and 90 days after transplanting (DAT), from the base to the tip of the main stem. The number of primary branches per plant was also counted for each treatment group.

Yield and yield attributes

The number of fruits harvested from five plants was counted on each picking. The total number of fruits harvested across all pickings was then divided by five to find the average number of fruits harvested per plant. These fruits were then weighed using an electronic balance. To determine the weight of each fruit, we divided the total weight of fruits collected from each plot by the total number of fruits obtained. The total marketable fruit yield was determined by combining the yields from all picking sessions and expressing it in quintals per hectare. The total unmarketable yield was calculated by identifying and separating fruits that were infected with borers, rotting, or of unmarketable size in each picking session. The yields from each picking were recorded and then summed to determine the overall unmarketable yield in quintals per hectare. The total yield was calculated by weighing all the fruits harvested from every picking session, including both marketable and unmarketable fruits, and expressing it in quintals per hectare.

Water Use Efficiency

Water use efficiency (WUE) is a measure of fruit yield produced per unit of irrigation water used. It is calculated by dividing the fruit yield per hectare by the irrigation water per hectare.

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

$$WUE = \frac{Y}{WR} \quad ..\ (2)$$

where, Y = Weight of marketable produce of the crop (kg/ha) and WR=Depth of water used (cm)

Economic Analysis

The expenses from preparing the field to harvesting were calculated and presented in terms of rupees per hectare. The yield of green tomatoes per hectare was determined, and the total income was calculated using the minimum market rate that was currently in effect. The net returns were then derived by separating the cultivation costs from the gross returns. The cost of installing a drip irrigation system for one hectare was determined based on the prevailing market prices. It was assumed that the drip system would have a lifespan of 5 years.

The benefit-cost ratio (BCR) was worked out by using the formula suggested by Palaniappan (1985).

$$BCR = \frac{\text{Gross return (q ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs.ha}^{-1}\text{)}} \quad ..\ (3)$$

Statistical Analysis

In this research, a one-way analysis of variance (ANOVA) was conducted using a Randomized Block Design (RBD) with three replications. The threshold for identifying statistically significant differences was set at an LSD level with a significance level of $P < 0.05$.

Results and Discussion

Growth parameters

After 30, 60, and 90 days of transplanting, the height of tomato plants with various irrigation levels was measured as shown in Fig. 3. The results showed that the plant height increased progressively with the day after transplanting (DAT). The plant height of tomato plants at different growth stages also varied significantly due to different treatments. At 30 DAT, the maximum plant height was observed in T2 (37.23 cm), followed by T1, T3, T4, and T5 (34.53, 33.33, 30.53, and 26.33 cm), respectively. At 60 days after transplanting, the tomato plants in treatment T2 had the tallest average height (51.57 cm), followed by those in treatments T1, T3, T4, and T5 (48.53, 47.33, 44.33, and 41.33 cm, respectively. Similarly, trends following as among the five treatments, the tomato plants in treatment T2 (59.90 cm) had the tallest average height at 60 days after transplanting. The average height of the plants in the other treatments was slightly lower, with treatment T5 (48.33 cm) having the shortest plants. The differences in plant height between the treatments were statistically significant. In other words, the treatment T resulted in the tallest plants, followed by T1, T3, T4, and T5. The plants in T1 were significantly taller than the plants in T5 at 30, 60 and 90 DAT. The results of this experiment suggest that the different treatments had a significant impact on the plant height of tomato plants.

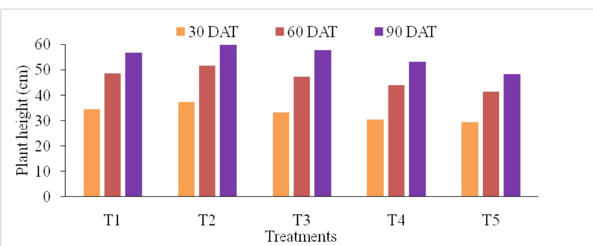

Fig. 3. Effect of irrigation scheduling on plant height and number of branches per plant in drip irrigation

The number of branches per plant of tomato plants under different irrigation treatments was measured at 30, 60, and 90 (DAT) graphically represented in Fig. 4. The results showed that the number of branches per plant increased with age, regardless of treatment. However, there were significant differences in plant number of branches per plant between treatments at each growth stage. At 30 (DAT), treatment T2 had the number of branches per plant (6.3), followed by T1, T3, T4, and T5 (5.3, 5, 4.6 and 4.3, respectively). At 60 days after transplanting, treatment T2 again had the maximum observed number of branches per plant (13.33), followed by T1, T3, T4, and T5 (11.33, 10.67, 10 and 9.67, respectively). The same trend continued 90 days after transplanting, with T2 having the tallest plants (11.33) and T5 having the shortest plants (8.0). The variances in number of branches per plant between treatments were statistically significant. In other words, treatment T2 resulted in the maximum number of branches per plant followed by T1, T3, T4, and T5. According to (Hundal *et al.,* 2000; Zhang *et al.,* 2005; and Biswas et al., 2015), greater plant growth in T2 could be attributed to sufficient soil water supply near the root zone, minimal evaporation loss about the optimum water regime, right temperature control due to the presence of mulch, better nutrient utilisation, and excellent soil-water-plant relationships.

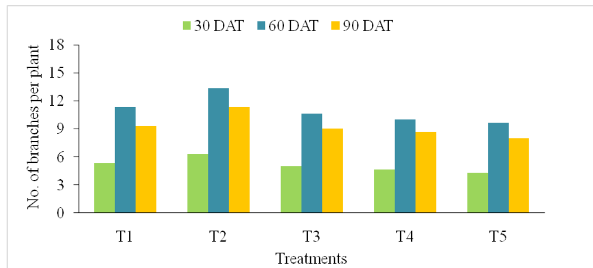

Fig. 4. Effect of irrigation scheduling on the number of branches per plant in drip irrigation

Yield Parameters

The quantity of water through the drip irrigation system (irrigation scheduling) was found to have a significant effect on the number of fruits per plant Among the irrigation level, the highest number of fruits per plant (32.33) was observed at T2, which were statistically difference of T1, T3 T4 and T5 (28.8, 26.6, 25.0 and 17.6, respectively. The least count of fruits per plant (17.6) was recorded at T5, shown in Fig. 5. The outcomes of this experiment suggest that tomato growers can increase the number of fruits per plant by using T2 of irrigation scheduling such as (2 hrs in two-day intervals).

The study revealed that the quantity of water managed through the drip irrigation system, known as irrigation scheduling, had a notable impact on fruit weight. Among the various irrigation levels, the highest fruit weight, measuring 83.67 (g) was observed at T2. This weight was statistically different from the fruit weights at T1, T3, T4, and T5, which were 72.33, 69.33, 68.68 and 56.67 (g), respectively. The low fruit weight of 56.67 (g) was logged at T5, shown in Fig. 5.

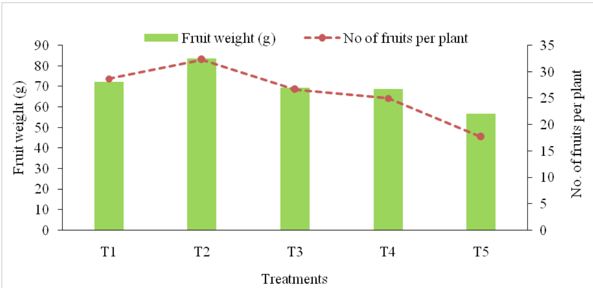

Fig. 5. Effect of irrigation scheduling on fruit weight and No. fruits per plant in drip irrigation

The different irrigation water frequencies had a significant impact on yield. Fig. 5 shows that the highest yield (583.40 q/ha) was obtained at T2, while the lowest yield (459.53 q/ha) was obtained at T5. The yields at T1 (575.87 q/ha), T3 (567.74 q/ha) and T4 (565.13 q/ha), respectively were statistically different using the irrigation scheduling such as (2 hrs in two days intervals). It is more significant to take into account the other factors that can affect total yields, such as tomato variety, climate, and additional agronomic practices.

Water use efficiency (WUE)

According to the data presented in Fig. 6, the highest water use efficiency (WUE) was achieved with treatment T2, which involved irrigating for 2 hours every 2 days. This treatment resulted in a WUE of 300.63 kg/ha-mm in treatment (T2). The lowest WUE was achieved with treatment T5, which involved furrow irrigation (the control treatment). This treatment (T5) resulted in a WUE of 169.88 kg/ha-mm. The other treatments (T1, T3, and T4) resulted in WUE values of 296.75 kg/ha-mm, 292.56 kg/ha-mm, and 291.22 kg/ha-mm, respectively. The enhanced water use efficiency (WUE) and reduced irrigation water consumption observed in drip irrigation can be attributed to minimal losses of water through initial and later abstraction. In this approach, water is supplied near the plant root periphery in the precise amount needed, which significantly minimizes wastage. This discovery aligns with previous research on tomato cultivation using drip irrigation, as reported by (Devi *et al.*, 2020; Singnadhupe *et al.*, 2003; Mukherjee, 2010).

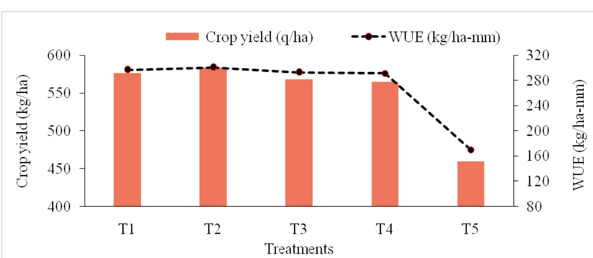

Fig. 6. Effect of irrigation scheduling on crop yield and WUE in drip irrigation

Economic analysis

The highest net return (189048Rs/ha) was recorded in T2, while the lowest was in T5 (144765Rs/ha). In the case of treatments (T1, T2, T3 and T4),the same irrigation regime and cost of cultivation are also sane, these returns were T1 (185285 Rs/ha), T3 (181222 Rs/ha) and T4 (179917 Rs/ha), respectively, however the gross outcome was recorded to be the highest (291698 Rs/ha) in this treatment T2 and lowest in T5 (229765Rs/ha) presented in Table 1. Incremental benefit-cost ratio (BCR) values were documentedat higher levels of drip irrigation of T2 (2.84) followed by T1 (2.81), T3 (2.77), T4 (2.75) and T5 (2.70), respectively.

Conclusion

- The growth, yield, and water usage of tomatoes were considerably impacted by the soil moisture regime and drip irrigation technology.
- Farmers can use this information to choose the best irrigation treatment for their crops to maximize plant height and number of branches per plant. Drip irrigation was the most profitable irrigation regime for the given scenario, as it had

Table 1. Economics of tomato as influenced by irrigation scheduling and drip irrigation levels

Treatments	Crop yield (kg/ha)	Gross return (Rs/ha)	Total cost (Rs/ha)	Net return (Rs/ha)	BCR
T1	575.87	287935	102650	185285	2.81
T2	583.40	291698	102650	189048	2.84
T3	567.74	283872	102650	181222	2.77
T4	565.13	282567	102650	179917	2.75
T5	459.53	229765	85000	144765	2.70

the highest gross return, net return and the highest BCR value. It is recommended to use drip irrigation for maximum profitability.

- Drip irrigation is a way to water plants by delivering water directly to their roots. This is a more efficient way to water plants than traditional methods, such as furrow irrigation.
- Potential benefits of drip irrigation with reduced soil moisture regimes for tomato production such as increased tomato yields, improved water use efficiency, reduced water consumption, reduced runoff and evaporation., improved plant growth and development and reduced risk of root rot and other problems associated with overwatering. Overall, drip irrigation with reduced soil moisture regimes is a promising approach for improving tomato production, especially in zones where additional water for irrigation is scarce.

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