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OPTIMIZING IRRIGATION SCHEDULES ON CHILLI CROPS UNDER DRIP IRRIGATION IN WESTERN UTTAR PRADESH, INDIA

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Abstract– This study conducted at the College of Agriculture Sciences and Engineering, IFTM University in Moradabad, Uttar Pradesh, India, investigated the impact of different drip irrigation levels on growth, yield, water use efficiency (WUE), and economic outcomes of Chilli crop. The study found that T2, involving 2 hours of drip irrigation every two days, yielded the best results across all parameters. T5, which utilized furrow irrigation, had the lowest values across all parameters. Specifically, T2 demonstrated the highest net return of 136,160 Rs/ha, while T5 had the lowest return of 81,080 Rs/ha. The benefit-cost ratio (BCR) was also highest at 2.30 for T2, indicating its economic viability, whereas T5 had the lowest BCR at 1.81. The study highlights that combining drip irrigation with effective soil moisture management significantly influences Chilli cultivation, leading to improved yield, water conservation, and profitability. This approach proves to be particularly valuable for regions grappling with water scarcity challenges. In simpler terms, the study found that watering tomato plants for 2 hours every two days using drip irrigation is the best way to grow tomatoes in terms of yield, water use efficiency, and economic returns. This approach is especially beneficial for regions with water scarcity.

INTRODUCTION

Drip irrigation is a water-efficient irrigation method that delivers water directly to the roots of plants. This is in contrast to surface and sprinkler irrigation, which water the entire soil profile (Olamide *et al.*, 2022). Drip irrigation saves water by only wetting the part of the soil where the roots are growing. However, this also means that plants grown with drip irrigation have less access to naturally available nutrients in the soil. Typically, only a small percentage of the soil surface gets hydrated in this method, ranging from 15% to 60%.

The growth and yields of crops under drip irrigation can be lower than those achieved through traditional methods if fertilizers are not adjusted to suit the needs of drip-irrigated crops (Miller *et al.*, 1976). This emphasizes the importance of finding the right fertigation strategy to supply the necessary nutrients in the correct amounts. Fertigation enhances the efficient use of water and fertilizers, leading to increased yields, improved product quality, and environmental conservation (Yohannes and Tadesse, 1998; Pruitt *et al.*, 1984). However, improper fertigation practices can diminish the expected yield advantages of crops irrigated using the drip method (Biswas *et al.*, 2015). Paraphrased text:

India has the biggest irrigation system in the world, but it does not use water very efficiently. This is because farmers do not always use water wisely. One way to improve water use efficiency is to use drip irrigation, which is a modern irrigation method. Drip irrigation delivers water directly to the roots of plants, which reduces water waste (Dunage *et al.*, 2009). Drip irrigation can also help to increase crop yields (Wang, 2012). In India, most of the rain falls during the monsoon season, which is from June to October. This means that there is often a shortage of water during the rest of the year. Modern irrigation methods such as drip irrigation can help to ensure that farmers have enough water to grow crops even during periods of water scarcity (Jain *et al.*, 2000).

Chilli is a major commercial crop in India, with India being the world's leading producer, consumer, and exporter of Chilli. India contributes to 50% of global Chilli production and exports 20% of its harvest. India's annual Chilli production is approximately 1.1 million tonnes, surpassing that of China, and Mexico. Chilli cultivation covers an area of 0.654 million hectares in India, with a productivity rate of 1551 kg/ha. The key Chilli-producing states in India are Andhra Pradesh (51%), Madhya Pradesh (11%), Karnataka (9%), Orissa (4%), Maharashtra (4%), Rajasthan (3%), and Tamil Nadu (3%) (Singh *et al.*, 2011; Singh *et al.*, 2016). Chilli cultivation is suited for tropical and sub-tropical regions, thriving in warm and humid climates. In other words, Chilli is a very important crop in India, both economically and culturally. India is the world's largest producer, consumer, and exporter of Chilli, and Chilli cultivation provides a livelihood for millions of farmers and farm workers in India (Kumar, 2010; Kumar *et al.*, 2013; Kumar *et al.*, 2014). Chilli is a tropical and sub-tropical crop that thrives in warm and humid climates. Studies have shown that tomato yield and water productivity are significantly influenced by soil moisture deficits, especially when the soil moisture is reduced to 50% of field capacity (FC), in comparison to maintaining as reported by Chakma *et al.*, (2021) and Mukherjee *et al.*, (2023).

Overall, the text argues that India needs to adopt modern irrigation methods such as drip irrigation to improve water use efficiency and crop yields. This is especially important given the country's growing population and the increasing frequency of droughts.

MATERIALS AND METHODS

Experimental Site

The experimental site was located at the College of Agriculture Sciences and Engineering, IFTM University, located in Moradabad, Uttar Pradesh, with geographical coordinates of approximately in a semiarid region at 28.83°N latitude and 78.78°E longitude (Fig. 1). Experiment was conducted from January to May 2017-2018. During the experiment, various weather parameters such as maximum and minimum temperature (5 and 45 ^{o}C), and rainfall (mm) for daily scale and Soil samples were collected from the field at depths of 0-15 cm for this analysis. The experimental site was divided into small plots, which were protected from animals with wire mesh. The researchers recorded weather data and measured the chemical and physical properties of the soil at different depths. They also analyzed the soil texture, which is the amount of sand, silt, and clay in the soil.

Layout and Design of drip irrigation system

The experimental setup consisted of various components, such as a screen filter, main, sub-mains and laterals, drippers, and other accessories for drip irrigation. These components were installed on a 60 m^2 experimental area. The main drip irrigation pipeline was constructed using PVC pipes with a 50 mm diameter, while sub-main pipelines were made using PVC pipes with a 25 mm diameter. Linear low-density polyethene (LLDPE) pipes with a 12 mm diameter were used for the laterals associated with each treatment shown in Fig. 2. Drippers, with a flow rate of 1.46 liters per hour (lph), were placed at intervals of 70 cm along the laterals to regulate the water flow. Additionally, small valves at the beginning of each treatment allowed for control and adjustment as necessary.

Treatment details

This study focused on determining the water requirements for tomato crops through drip irrigation, we carefully considered various factors during the system design and experimental planning. The drip irrigation setup consisted of 15 laterals, each with a 12 mm diameter, spaced 70 cm apart between rows and 50 cm apart between individual plants. One plant was transplanted in each row at a depth ranging from 3 to 4 cm. We implemented different irrigation schedules: T1 (1 hour daily), T2 (2 hours every two days), T3 (3 hours every three days), T4 (4 hours every four days), and T5 (Control, using furrow irrigation). For the trial, we chose the 'Pant Chilli-1' variety of commercial tomatoes (*Capsicum annuum* L.), and specific details about the crop can be found in Table 2. Planting took

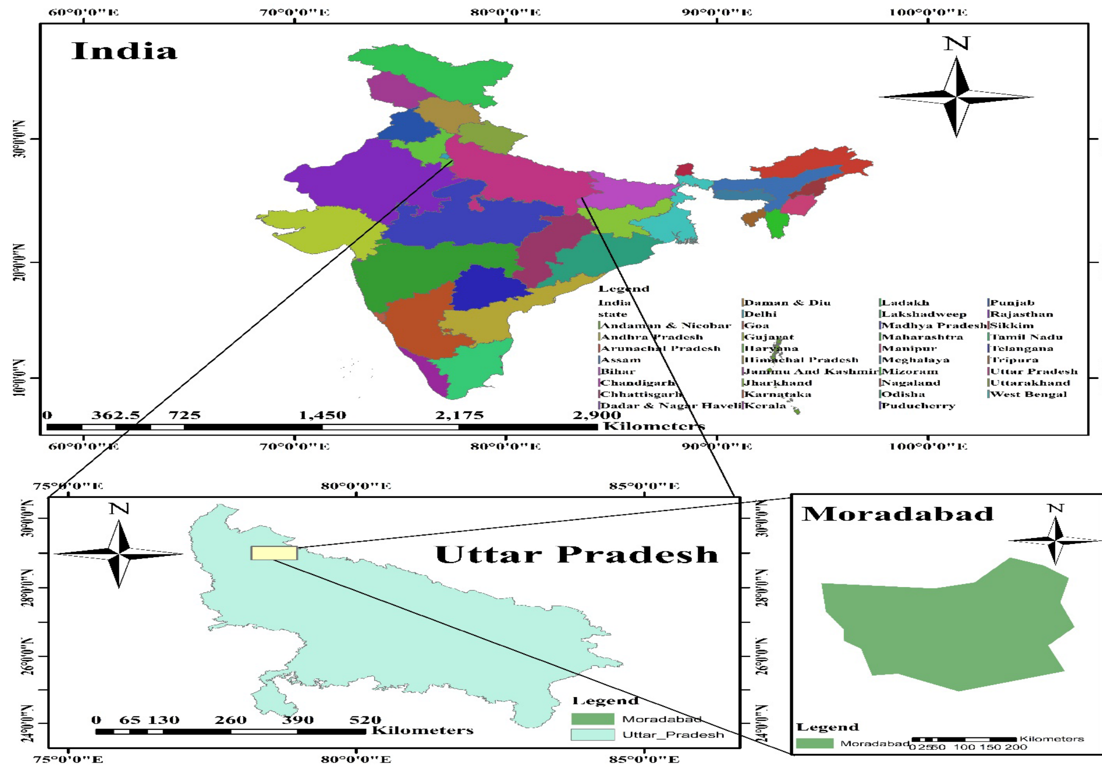

Fig. 1. Study area map

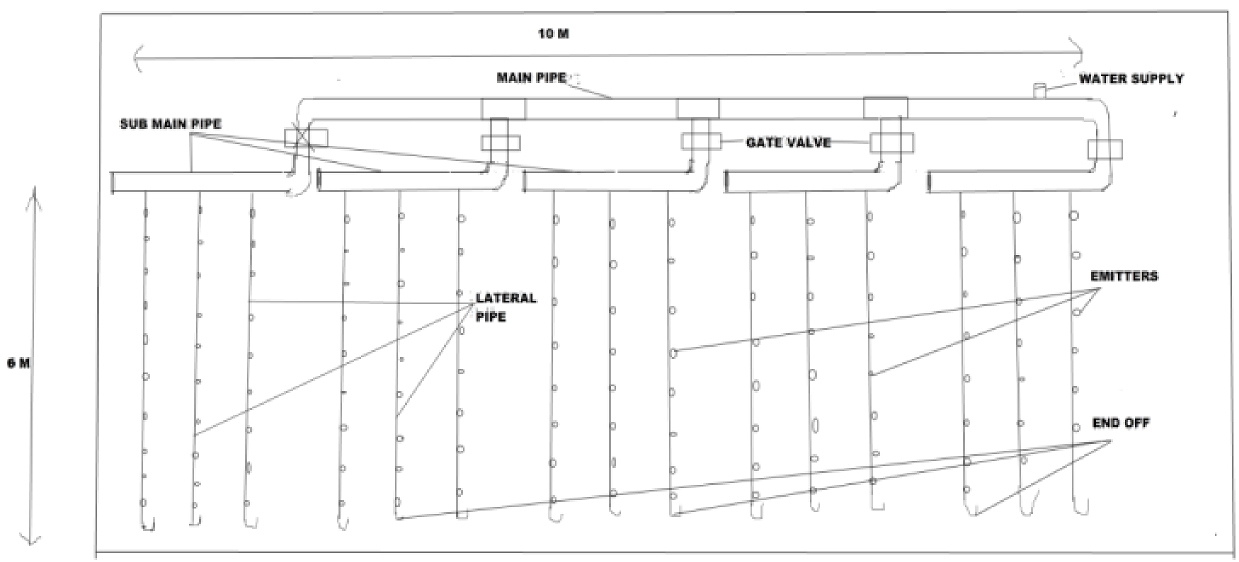

Fig. 2. Layout of drip irrigation system

place in November, and harvesting occurred in March.

Plant growth and yield parameters

Five plants were selected at random and tagged for each treatment group in a plant experiment. Every 30 days, the plant height was measured from the top point to the root shoot at 30, 60, 90 and 120 days after transplanting (DAT). For each treatment group, the number of primary branches per plant was also counted. The weight, length, thickness, number, and yield of Chilli fruits were measured and recorded at each harvest. The weight of each fruit was measured in grams and recorded. The average fruit weight was calculated by taking the mean of all the weights. The length and thickness of each fruit were measured and recorded. The average length and thickness were calculated for each treatment the number of fruits harvested from each treatment at each harvest was counted and recorded. The yield of fruits harvested from each treatment at each harvest was weighed and recorded. The data collected in this study can be used to assess the growth and productivity of Chilli plants under different conditions. The researchers could compare the fruit weight, length, thickness, number, and yield of plants that received different treatments, such as different types of fertilizer or different irrigation schedules in drip irrigation (Mukherjee *et al.,* 2023). This information could then be used to develop better management practices for Chilligrowers.

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 them 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 how well crops use water. It is calculated by dividing the crop yield by the amount of irrigation water applied. In the study, the researchers calculated WUE for different treatments by dividing the fruit yield per hectare by the amount of water used per hectare. This allowed them to compare how efficient different treatments were at using water to produce fruit.

$$\text{WUE} = \frac{\text{Chilli yield (q ha}^{-1}\text{)}}{\text{Amount of water applied (mm)}} \quad .. (1)$$

The higher the WUE, the more efficient the crop is at using water. It means, that if two treatments produce the same amount of fruit, but one treatment uses more water than the other, then the treatment that uses less water will have a higher WUE. WUE is an important measure of agricultural sustainability. By improving WUE, farmers can reduce their water use and costs, while also maintaining or increasing their crop yields.

Economic Analysis

The researchers calculated the costs of growing Chilli per hectare, from field preparation to harvesting. They also measured the yield of green Chilli per hectare and calculated the total income using the current minimum market rate. Net returns were calculated by subtracting the cultivation costs from the gross returns. The researchers also calculated the cost of installing a drip irrigation system for one hectare, based on current market prices and assuming a lifespan of 5 years. Finally, they calculated the benefit-cost ratio (BCR) using the following formula.

$$\text{BCR} = \frac{\text{Gross return (Rs.ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs.ha}^{-1}\text{)}} \quad .. (2)$$

Statistical Analysis

This research used a statistical test called one-way analysis of variance (ANOVA) to compare the effects of different treatments on the yield of tomatoes. They used a randomized block design (RBD) to control for variation within the groups. To determine which treatments were significantly different, the researchers used the least significant difference (LSD) test at a significance level of $P < 0.05$. This means that the researchers were willing to accept a 5% chance of making a Type I error, which is the error of rejecting the null hypothesis when it is true.

RESULTS AND DISCUSSION

Growth parameters

The average plant height for each treatment is shown in Fig. 3. Plant height was measured at 30, 60, 90, and 120 days after transplanting (DAT). The average plant height values for different treatments.

For drip irrigation treatments (T1, T2, T3, and T4), plant heights ranged from 27.59 cm, 28.75 cm, 26.38 and 25.52 cm, respectively) at 30 DAT. In contrast, furrow irrigation in treatment T5 had a different water application method, and the corresponding plant height was recorded (23.76 cm). Notably, at 30 DAT, plant height in treatment T2 was greater than that in treatment T5. After 60 days of transplanting, Chilli plants in treatment T2 exhibited the highest average height 45.56 cm. In comparison, plants in treatments T1, T3, T4, and T5 had average heights of 43.10 cm, 41.90 cm, 39.65 cm, and 37.43 cm, respectively. AT 90 DAT, the tallest plant height was obtained in T2 (60.67 cm), followed by T1 (58.02 cm), T2 (55.67 cm), T3 (54.28 cm) and T5 (53.12 cm), respectively. Similarly, the trend followed, at120 DAT, the highest plant height was found in T2 (58.15 cm) compared to the lowest in T5 (50.78 cm).

Number of branches per plant under different irrigation treatments at 30, 60, 90 and 120 DAT graphically represented in Fig. 4. At 30 DAT, treatment T2 had the maximum number of branches per plant was observed (5.3), followed by treatments T1, T3, T4, and T5 (4.2, 3.7, 3.3, and 2.7) branches per plant, respectively). At 60 DAT, the highest branches per plant were recorded (6.7), followed by treatments T1, T3, T4, and T5 (8.6, 7.7, 6.7, 6.3, respectively). This trend continued at 90 and 120 DAT, with treatment T2 having the most branches per plant (9.7 and 8.6) and treatment T5 having the fewest branches per plant (7.6 and 6.3).These differences in the number of branches between the treatments were statistically significant.

Yield Parameters

The study revealed a significant impact of drip irrigation and irrigation scheduling on the number of fruit lengths. Among the different irrigation levels, treatment T2 showed the highest weight of fruit length (11.50 cm), which was statistically different from T1, T3, T4, and T5 (10.67 cm, 9.33 cm, 8.67 cm, and 8.33 cm, respectively). Conversely, the lowest weight of fruits per plant (8.33 cm) was observed in T5, as shown in Fig. 5.

Different irrigation frequencies significantly influenced the crop yield, as depicted in Fig. 4. Treatment T2 yielded the highest (120.58 q/ha), while the lowest yield (90.94 q/ha) was observed in T5. Yields for T1 (110.31 q/ha), T3 (105.59 q/ha), and T4 (100.23 q/ha) werestatistically different due to the specific irrigation scheduling employed (2 hours every two days). It's crucial to consider various

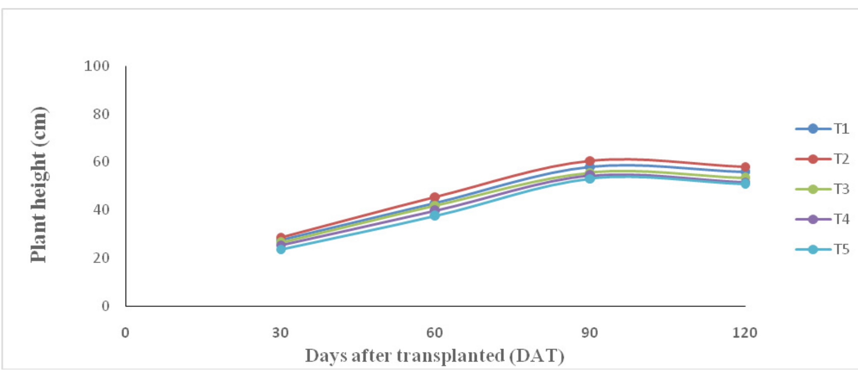

Fig. 3. Effect of irrigation scheduling on plant height and number of branches per plant in drip irrigation of Chilli crop

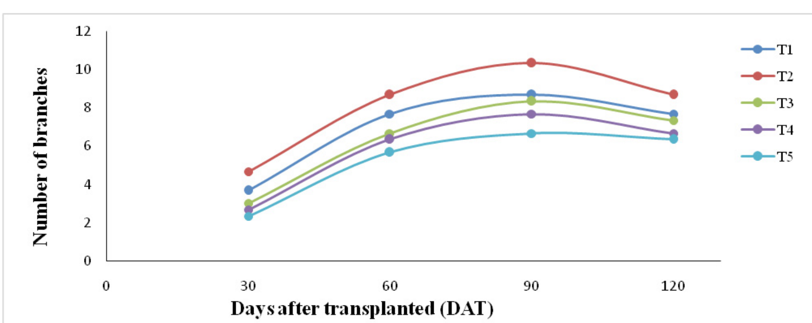

Fig. 4. Effect of irrigation scheduling on the number of branches per plant in drip irrigation of Chilli crop

Table 1. Economics of Chilli as influenced by irrigation scheduling in drip irrigation

Treatments	Crop yield (kg/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	BCR
T1	110.31	220620	115620	2.10
T2	120.58	241160	136160	2.30
T3	105.59	211180	106180	2.01
T4	100.23	200460	95460	1.91
T5	90.54	181080	81080	1.81

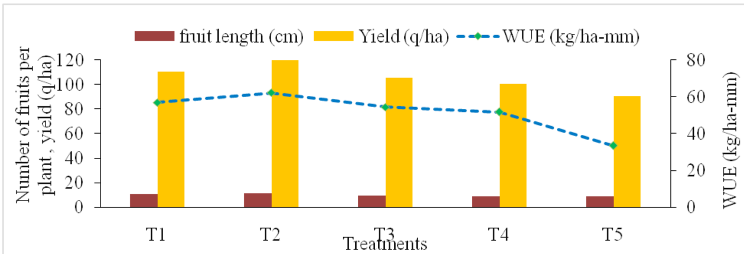

Fig. 5. Effect of irrigation scheduling on fruit length, crop yieldand WUE in drip irrigation of Chilli crop

factors impacting total yield, including the tomato variety, climate conditions, and other agricultural practices.

Water Use Efficiency (WUE)

As shown in Fig. 4, treatment T2, which involved 2 hours of irrigation every 2 days, had the highest water usage efficiency (WUE) 62.84 kg/ha-mmTreatment T5, which used furrow irrigation (the control treatment), had the lowest WUE, resulting in a WUE of 33.47 kg/ha-mm. WUE values for treatments T1, T3, and T4 were 56.14 kg/ha-mm, 54.41 kg/ha-mm, and 51.65 kg/ha-mm, respectively. The lower irrigation water consumption and enhanced WUE of drip irrigation can be ascribed to minimal losses due to percolation, runoff, seepage, and soil evaporation. This technology accurately provides water to the crop's root zone, considerably reducing waste.

Economic analysis

The highest net return was recorded by T2 (136160Rs/ha), while the lowest was recorded by T5 (81080 Rs/ha). When the irrigation regime and cultivation costs were the same, the returns for treatments T1 (115620 Rs/ha), T3 (106180 Rs/ha) and T4 (95460 Rs/ha), respectively. The gross return was highest in T2(241160 Rs/ha) and lowest in T5 (181080 Rs/ha), as indicated in Table 1. Additionally, T2 (2.30) showed better incremental benefit-cost ratio (BCR) values for drip irrigation than T1 (2.10), followed by T3 (2.01) T4 (1.91), and T5 (1.81), respectively expressed in Table 1.

CONCLUSION

Drip irrigation methods significantly impact on growth, yield, water use efficiency, and economic outcomes of Chilli cultivation. Among the various irrigation levels tested, the study revealed that watering Chilli plants for 2 hours every two days using drip irrigation (T2) resulted in the most favourable outcomes. This approach not only led to higher yields but also proved to be economically viable, as indicated by the highest net return of 136,160 Rs/ha and a benefit-cost ratio of 2.30. On the contrary, furrow irrigation (T5) exhibited inferior results across all parameters, emphasizing the importance of adopting efficient irrigation techniques. The significance of combining drip irrigation with effective soil moisture management practices. This combination not only enhances Chilli cultivation but also contributes to water conservation efforts and increased profitability. Particularly in regions facing water scarcity challenges, the implementation of this approach holds immense value, offering a sustainable and economically feasible solution for Chilli farmers.

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