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Optimizing irrigation scheduling using a drip system to enhance water use efficiency in tomato cultivation

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Abstract

Irrigation scheduling with drip irrigation is a crucial management technique for ensuring optimal soil moisture, thereby promoting plant growth, production, and economic return while enhancing water efficiency. Tomato crops, a mass consumer product grown worldwide, face significant challenges in the Sylhet region due to inefficient water management. To ascertain the best watering schedule for tomato crops based on evapotranspiration, a field experiment was carried out utilizing a randomized complete block design (RCBD) with six treatments and four replications. The six treatments include two irrigation frequencies (daily basis, F1 and every alternate day, F2) with three water doses W1, W2, W3 (i.e., 50%ETc, 75%ETc, 100%ETc). The Penman-Monteith method was used to estimate crop water requirements, and water for farming was applied according to designated schedules. Data analysis using SPSS 23 revealed that the impacts of irrigation frequency and water doses on plant growth, fruit yield, and water use efficiency were significant, except for stem diameter. The plant height, number of fruits, number of flowers, yield, and water use efficiency were increased with increasing water doses and decreased with decreasing water doses. The maximum yield was gained by increasing irrigation frequency at F_1 and water dosage at W_3, but the highest WUE was obtained at a lower irrigation frequency under the treatment F_2, with the highest water dose at W_3. The study concluded that the irrigation scheduling F_1W_3 was the best in balancing tomato productivity, fruit quality, and WUE in this study. The findings of this study will help local farmers make sustainable decisions about their irrigation methods.

Keywords: Irrigation scheduling, Drip irrigation, Water use efficiency, Tomato, Yield

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INTRODUCTION

Water is a priceless natural asset, a fundamental requirement for human existence, and a primary natural resource (Deka et al., 2023). Water scarcity is exacerbated by global warming, climate change, and population growth, leading to increased competition for freshwater resources (Junk, 2013). In many parts of the world, water is becoming a scarce economic resource, particularly in arid or semi-arid countries (Buttaro et al., 2015). Bangladesh struggles to provide water security for agricultural production, much as many other nations. Over the past few decades, there has already been an increase in the demand for water and competition for freshwater resources (Mancosu et al., 2015; Arfanuzzaman & Rahman, 2017). Due to its large water footprint and limited water supply, crop agriculture has significant challenges in ensuring sufficient water share (Allen et at., 1998). The primary consumer of Bangladesh's scarce water resources is agriculture (Chowdhury, 2010). Tomato is an essential agricultural crop in the Solanaceae family. Its primary uses are as a cash commodity and a food crop on a global scale (Gatahi, 2020). In Bangladesh, it is a significant crop for vegetable production. Around 6% of the region is now under tomato cultivation during both the summer and winter seasons (Karim et al., 2009). Tomato cultivation in Bangladesh is estimated to be around 4.4 million metric tons, ranking fourth after potato, onion, and brinjal (BBS, 2021). Local tomato growers overwater their plants to boost productivity, which exacerbates the imbalance between water supply and demand and produces wastewater (Li et al., 2017). The quality and storability of any fruit are impacted by numerous pre-harvest actions throughout production. One essential farming technique that impacts fruit and vegetable productivity and quality is irrigation (Agbemafle et al., 2014).

Implementing water-efficient irrigation systems may result in enhanced yields, better fruit quality, and improved efficiency of water use. To conserve water, a range of techniques have been applied to tomato cultivation, such as deficit irrigation, mulching, and trickle irrigation. Drip irrigation (DI) is a water-saving technique in which water is supplied directly to the root zone at small, frequent intervals, resulting in a significant reduction in overall water use. In contrast to conventional irrigation methods, drip irrigation has the potential to conserve water by 45–50% while sustaining an acceptable reduction in yield (Marino et al., 2014). In tomatoes and other commodities, numerous studies comparing sprinkler or furrow irrigation with DI have demonstrated that DI ultimately increased WUE and crop yields (Biswas et al., 2015). A prudent assessment of the crop water requirements is vital to scheduling irrigation and planning of agricultural irrigation systems (Mushtaq et al., 2020). For the improvement of WUE, scientists and academics are now very concerned about this (Derib et al., 2011; Eshete et al., 2020). Irrigation scheduling is the amount and frequency of water supplied to a crop; it is crucial to prevent over- or under-irrigation since this can lower crop quality, yield, and water use efficiency (WUE) (Pardossi & Incrocci, 2011). Diverse irrigation scheduling methods exist, including those that rely on plant-based sensing (Jones, 2004), soil moisture sensors (e.g., volumetric, soil moisture tension) (Ganjegunte et al., 2012) and meteorological conditions (e.g., FAO Penman–Monteith, evaporation pans) (Pardossi & Incrocci, 2011). An alternative method involves creating a daily water balance to determine ETc and plan irrigation times based on projected crop water extraction and the effective soil water storage capacity. These irrigation scheduling techniques can be highly effective (Mohammad et al., 2013). Tracking ETc losses and additions from irrigation and precipitation is the basic strategy for the ET-based method, which aims to maintain the balance of SM available to the plant at any given time (Nouri et al., 2016). For many years, the Penman–Monteith approach has been a popular choice for scientific studies (Farooque et al., 2021). Nevertheless, very few have tried to explain the Penman-Monteith model's operation in a way that farmers may utilize to help with irrigation scheduling (Her et al., 2019).

Although there exist more precise techniques for optimizing irrigation schedules (Linker, 2021) still, there is a dearth of research on irrigation scheduling in tomatoes. The impact of water levels and irrigation frequency on tomato crops has been the focus of several investigations, although most of these investigations examined both variables in isolation. Hence, to enhance both the quantity and quality of agricultural output as well as optimize irrigation efficiency, it would be advantageous to research irrigation scheduling. The goal of this study is to determine the best watering schedule for tomato crops that will maximize fruit quality and WUE while lowering production costs and water usage. We anticipate that the outcomes will equip local farmers with the necessary knowledge to make sustainable decisions about their irrigation methods.

MATERIALS AND METHODS

Site description

The study was carried out in the Sylhet Agricultural University research field (35 meters above sea level, latitude 24.89°N and longitude 91.87°E) from December 2023 to February 2024. The site is in the subtropical climate zone (BARC, 2022). Two manual soil samples were taken, covering the targeted area, following normal soil sampling procedures. Soil analysis was performed using the laboratory of the soil science department at Sylhet Agricultural University. The soil sample had a sandy loam texture with 25% field capacity.

Experimental design

The experiment was conducted in a randomized complete block design (RCBD) with six treatments and four replications. Plots and blocks were separated by 0.3 m, and each plot was 1.21 m by 1.06 m. For tomato plants, the spacing is 50 cm between plants and 60 cm between rows. The treatments are as follows:

T_1 : Evapotranspiration - Once a day (F_1), 50% of ETc (W_1)
T_2 : Evapotranspiration - Once a day (F_1), 75% of ETc (W_2)
T_3 : Evapotranspiration - Once a day (F_1), 100% of ETc (W_3)
T_4 : Evapotranspiration - Once in every alternate day (F_2), 50% of ETc (W_1)
T_5 : Evapotranspiration - Once in every alternate day (F_2), 75% of ETc (W_2)
T_6 : Evapotranspiration - Once in every alternate day (F_2), 100% of ETc (W_3)

Irrigation Setup

The drip irrigation system was designed to deliver water and fertilizers to the crops efficiently. It utilized a 0.5 HP pump connected to a 500-liter tank to ensure an ample water supply for crop needs. A filtration system was installed to avoid clogging of the drippers and other components due to the impurities of irrigation water. A venturi connected to the pump created a vacuum, enabling the mixing of fertilizers with the water flow. The drip irrigation system's water flow was controlled, and the pressure was adjusted using flow control and pressure regulating valves. A main line of 25 mm diameter served as the primary conduit, delivering water from the pump to lateral pipes. These lateral pipes, with a diameter of 14 mm, distributed water from the main line to individual plants. Adjustable drippers were fixed to the lateral pipes, supplying water and fertilizer directly to the root zone of each plant.

Reference Evapotranspiration (ET_0) Calculation

Transpiration, the loss of water from a plant's surface and evaporation, and the loss of water from the soil surface happen simultaneously. Together, they are termed evapotranspiration (ET). The rate of ET from an imaginary crop, assuming a height of 0.12 meters, an albedo of 0.23, and a constant canopy resistance of 70 sm^{-1}, is known as reference evapotranspiration (Allen et al., 1998). The reference crop evapotranspiration ET_0 was determined using the Penman-Monteith technique (Allen et al., 1998; Boltana et al., 2023). The Bangladesh Meteorological Department (BMD) provided the hourly minimum and maximum temperature, radiation, sunlight hours, wind speed, latitude, and elevation of the field, which were used to compute the ET_0.

$$ET_0 = \frac{0.408(Rn-G)+\gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma(1+0.34u2)}$$

Where,

ET_0 = reference crop evapotranspiration (mm/day),

R_n = net radiation at crop surface (MJ/m^2/day),

G = soil heat flux (MJ/m^2/day),

T = average temperature (°C),

U_2 = wind speed measured at 2 m above ground (m/s),

e_s-e_a = vapor pressure deficit(kpa)

Δ = slope vapor pressure curve (kPa/°C),

γ = psychometric constant (kPa/°C),

900 = conversion factor.

Crop Water Requirement Determination

The crop water requirement represents the quantity of water equivalent to the loss from a cultivated area due to evapotranspiration (ET), typically expressed as a rate in millimeters per day. Determining the crop water requirement involves estimating crop evapotranspiration (ETc), which can be computed using the following formula (Pereira et al., 2015)

ETc = Kc * ET_0

The amount of rainfall was collected from the Bangladesh Meteorological Department (BMD) and adjusted with crop evapotranspiration (ETc) during the experimental period.

Net irrigation requirement (NIR) = ETc – Rainfall

The volumetric water requirement for a tomato plant was computed by the following equation (Biswas et al., 2015);

V = NIR * A

The duration of operation (RT) of the drip irrigation system is dependent on the volume of water required, dripper discharge, and dripper discharge rate. In this experiment, adjustable drippers were used, and the dripper discharge rate was adjusted manually. As all the treatments were different based on the irrigation schedule, the time of operation was also different from each other. The running time (RT) of the drip irrigation system was calculated using the Equation (Simić et al., 2023);

$$RT = \frac{\textit{the volume of water applied}}{\text{number of drippers} \times \textit{dripper discharge rate}}$$

The volume of water applied was in m^3, and the dripper discharge rate was in m^3/s.

Where, ET_0 = reference evapotranspiration (mm/day)

ETc = Crop Evapotranspiration (mm/day)

A = wetted area (m^2)

Kc = the crop coefficient.

Crop coefficient (Kc) adjustment

This factor represents the ratio of crop evapotranspiration (ETc) to reference evapotranspiration (ET_0), encapsulating the impact of four key characteristics that distinguish the crop from reference grass. These factors include the crop-soil surface reflectance (albedo), crop height, canopy resistance, and soil evaporation. As crop ETc varies across growth stages, the crop coefficient (Kc) fluctuates throughout its developmental phases, typically categorized into four stages: initial, crop development, mid-season, and late season (Allen et al., 1998; Ewaid et al., 2019). The adjustment of the k_c value (Table 1) was carried out in compliance with the guidelines provided by the FAO (FAO Irrigation and Drainage Paper, 2006).

Table 1. Kc values for tomato used in the experiment.

Growth stage	Days after transplant	Standard value of kc (FAO)	Adjusted value of kc
Initial	1 -7	0.60	0.395
Development	8 - 29	0.60 – 1.3225	0.395 – 1.0285
Mid stage	30 - 51	1.3225	1.0285 – 1.2285
Late stage	52 - 82	0.8	1.0859 – 0.8

Agronomic Variables

Tomato seedlings were transplanted to the experimental field on 02 December 2023, 28 days after sowing, when they reached a height of 10 cm with 3 true leaves. After transplanting the seedlings, a variety of intercultural practices were undertaken to enhance the growth and development of the plants. Bamboo sticks were used to support each plant once they were firmly established. Weeding was carried out at 15, 30, 50, and 70 days after transplanting (DAT) to maintain weed-free conditions in the field and promote optimal crop establishment. The recommended doses of manures and fertilizers, such as well-decomposed cow dung, urea, TSP, and MOP, respectively, were applied (DAE). 50% cow dung and 50% TSP were applied during the final land preparation. The rest of the cow dung and TSP were applied in the pit before transplanting the seedlings. Urea and MoP were applied in two equal installments. The first half was applied 20 DAT, and the second half was applied 35 DAT. During the experiment, plant growth and physiological characteristics (such as plant height, stem diameter, number of branches, number of flowers, and number of fruits) were measured for all treatments. Fruits were picked while they were ripening and mature. Crop maturity was evaluated by the presence of red coloring on the fruits. It was possible to collect a total of five crops during the harvesting stages. The fruit parameters (fruit length, fruit weight, fruit diameter, total yield) were measured after harvesting.

Water Use Efficiency

Water use efficiency is defined as the ratio of grain yield to the total amount of irrigation water applied during the whole growing season. It was calculated by the following equation (Vikas Sharma et al., 2021);

$$WUE = \frac{Total\ yield\ (kg)}{the\ amount\ of\ water\ applied\ (m3)} \times 100$$

Statistical Analysis

The data was analyzed using SPSS 23.0 statistical software (SPSS Inc., Chicago, II, USA). The effects of various interventions were evaluated using a general linear model and descriptive and homogeneity tests in SPSSA P-value of less than 0.05 for the Duncan test indicated that differences between treatments were significant. Origin Pro software (OriginLab Corporation, MA, USA) was employed to generate analytical graphical representations of the data. The final report and the result were compiled utilizing the data that had been analyzed.

RESULTS

Weather data in the experiment

Figure 1 shows the data observed during the experiment. In daily meteorological observation, the average minimum air temperature ranged from 20.29°C to 20.10°C, while the highest air temperature ranged from 21.47°C to 21.48°C. The average relative humidity ranged from 85.50% to 69.64%, while ET_0 varied from 2.48 mm to 2.11 mm.

In every other day of weather observation, the average relative humidity ranged from 84.88% to 68.49%, and ET_0 ranged from 2.68 mm to 2.04 mm. The average minimum air temperature ranged from 20.45°C to 20.09°C, while the highest temperature ranged from 21.67°C to 21.67°C. Evapotranspiration (ETc) was highly variable since the meteorological circumstances in the research area changed dramatically day by day. Figure 1 represents how the value of ETc fluctuated with water doses with daily and every alternate day irrigation.

Crop Water Requirement

Water requirements for crops are the amount of water (or depth) required to replenish the amount gone via evapotranspiration (ETc). After transplantation, irrigation treatment started on 10 December 2023 and closed on 20 December 2023. A total of 73 irrigations and 36 irrigations were done daily and alternate-basis irrigation, respectively. No rainfall occurred during the experimental period. The amount of irrigation water that is required for various water doses and irrigation frequencies is outlined in Table 2. In the experiment, the amount of irrigation water was increased with increased water doses and with the highest irrigation frequency. It was shown that the F_1W_3 treatment resulted in the largest volume of irrigation water required, whereas the F_2W_1 treatment resulted in the lowest amount of irrigation water needed.

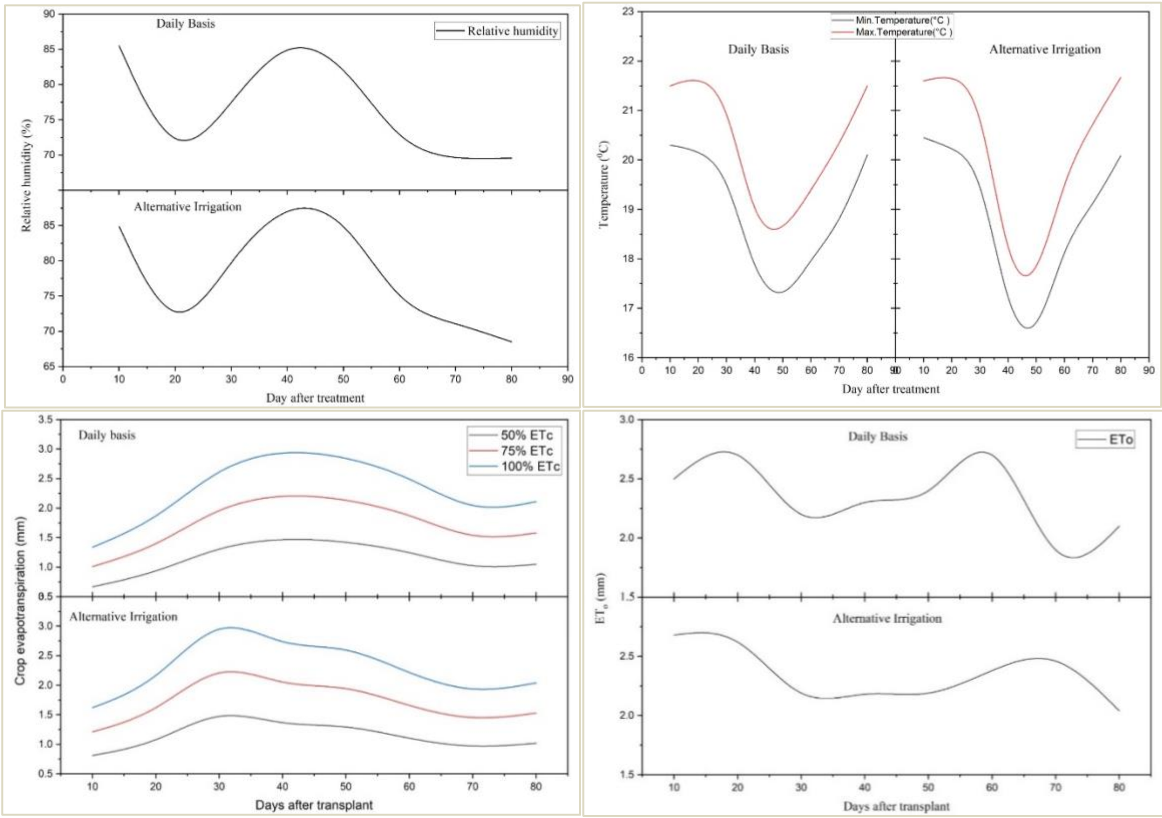

Figure 1. Trend of change of weather data and evapotranspiration during the experiment.

Table 2: Crop Water Requirement for tomato under the different treatments.

Treatment	Total NIR (mm)	Total Irrigation water (L)
F_1(Daily basis)		
W_1	83.62	24.41
W_2	125.43	36.61
W_3	167.24	48.81
F_2(Alternate day)		
W_1	40.83	11.92
W_2	61.23	17.87
W_3	81.65	23.83

W and F represent water dose and irrigation frequency, respectively. W_1: 50% ETc; W_2: 75% ETc; W_3: 100% ETc; F_1: daily basis; F_2: every alternate day.

Tomato Production and Quality

Plant Height

As shown in Table 3, the effect of water dose and irrigation frequency on plant height during the initial 15 days following transplanting was insignificant. At 30 to 80 days after transplanting, the effect of irrigation frequency and water dose on plant height was statistically significant ($p < 0.05$). As shown in Table 3, the highest water dose and the highest irrigation frequency resulted in the greatest plant height for treatment F_1W_3. Conversely, the lowest water dose and the lowest irrigation frequency produced the shortest plant height for treatment F_2W_1.

Stem diameter

The variation in stem diameter was not significantly affected by water dose and irrigation frequency ($p < 0.05$), as shown in Table 3. The greatest diameter of the stem was achieved with a moderate water dose in treatment W_2 and the highest frequency irrigation under treatment F_1. Conversely, the smallest diameter of the stem was obtained with the least water dose under treatment W_1 and the lowest frequency irrigation under treatment F_2.

Number of Flowers

The statistical analysis demonstrated that there was a significant relationship ($p < 0.05$) between water dose, irrigation frequency, and the number of flowers, as shown in Table 3. The number of flowers in the F_2 treatment significantly decreased by 13% than F_1. The quantity of flowers in the W_1 treatment was reduced by 13.7% compared to the W_3 treatment. In contrast, the W_2 treatment suffered a 9% reduction in flowers compared to the W_3 treatment. In treatment F_1W_3, the maximum water dose and highest irrigation frequency resulted in the greatest quantity of flowers. Conversely, treatment F_2W_1, which utilized the lowest water dose and lowest irrigation frequency, produced the fewest flowers (Table 3).

Table 3. Analysis of Variance and Duncan's multiple range test of the average plant height, stem diameter and flowers per plant.

Factor	Plant Height (cm)						Stem Diameter (mm)	Flowers per Plant
	7 DAT	15 DAT	30 DAT	45 DAT	60 DAT	80 DAT		
Irrigation Frequency								
F_1	13.50	17.99	41.27 a	62.43 a	75.05 a	82.67 a	19.44	43.33 a
F_2	13.48	17.20	36.56 b	56.95 b	69.40 b	79.33 b	19.25	37.67 b
Water Dose								
W_1	13.31	17.15	35.15 b	55.79 b	68.19 b	76.50 c	18.43	37.50 b
W_2	13.50	17.61	39.04 a	60.20 a	72.41 a	80.50 b	20.38	40.50 ab
W_3	13.65	18.03	42.55 a	63.08 a	76.08 a	86.00 a	19.24	43.50 a
ANOVA								
F	ns	ns	**	***	**	*	ns	**
W	ns	ns	**	***	**	***	ns	**
F× W	ns	ns	ns	ns	ns	ns	ns	ns

W and F represent water dose and irrigation frequency, respectively. W_1: 50% ETc; W_2: 75% ETc; W3: 100% ETc; F_1: daily basis; F_2: every alternate day; DAT: days after transplant; *: significant at $p < 0.05$; **: significant at $p < 0.01$; ***: significant at $p < 0.001$; ns: no significant at $p < 0.05$. Values within the same columns that are accompanied by different letters vary significantly at $p < 0.05$.

Table 4. Analysis of Variance and Duncan's multiple range test of the total yield, total water, fruits per plant, total water per plant and water use efficiency.

Factor	Total Yield (kg)	Total Water (m^3)	Fruits per Plant	Total yield (kg $plant^{-1}$)	Total water (m^3 $plant^{-1}$)	WUE (kg m^{-3})
Irrigation Frequency						
F_1	34.99 a	0.5857 a	30.33 a	2.19 a	0.04 a	59.18 b
F_2	18.83 b	0.2857 b	25.00 b	1.18 b	0.02 b	64.62 a
Water Dose						
W_1	16.64 c	0.2906 c	24.00 b	1.04 c	0.02 c	57.64 c
W_2	26.80 b	0.4358 b	27.50 b	1.68 b	0.03 b	62.51 b
W_3	37.28 a	0.5808 a	31.50 a	2.33 a	0.04 a	65.56 a
ANOVA						
F	***	***	**	***	***	***
W	***	***	**	***	***	***
F× W	***	***	ns	***	***	***

W and F represent water dose and irrigation frequency and T_0 represents the farmers practice, respectively. W_1: 50% ETc; W_2: 75% ETc; W3: 100% ETc; F_1: daily basis; F_2: every alternate day; WUE: water use efficiency; *: significant At $p < 0.05$; **: significant at $p < 0.01$; ***: significant at $p < 0.001$; ns: no significant at $p < 0.05$. Values within the same columns that are accompanied by different letters vary significantly at $p < 0.05$.

Number of fruits

In the experiment, water dose and frequency of irrigation had a significant impact on the quantity of fruits produced by each plant. F_2 produced fewer fruits per plant by 17.5% compared to F_1. With decreased irrigation frequency, the number of fruits per plant decreased, whereas it increased with increasing water dose. According to the data presented in Table 4, the F_1W_3 treatment produced the greatest number of fruits per plant, whereas the F_2W_1 treatment yielded the fewest fruits per plant.

Yield

The yield response to water dose and frequency was significantly reduced in comparison to F_1W_3 treatment and farmer practice. In comparison to F_1, the total yield and yield per plant from the F_2 treatment were reduced by 46%. Likewise, the overall production and per-plant yield of W_1 and W_2 were reduced by 55% and 28%, respectively, in comparison to W_3. As the frequency of irrigation decreases, both the total yield and yield per plant diminish (Table 4). The experiment required the highest water volume at the maximum dose.

Water Use Efficiency

Table 4 presents the impact of watering frequency and water dose on water use efficiency was statistically significant ($p<0.05$). The water use efficiency in F_2 treatment was significantly increased by 8.4% than F_1. The W_1 treatment significantly decreased 12% water use efficiency than W_3, whereas the W_2 treatment significantly decreased 4.6% water use efficiency than W_3. In the experiment, the maximum water use efficiency was achieved under F_2W_3 treatment, whereas the lowest water use efficiency was obtained from F_1W_1, as shown in Table 4.

Water Use-Yield Relationship

The water–yield relationship was affected by irrigation frequency and water dose (Table 4). At treatment F_1, the amount of water consumption and yield per plant dramatically increased by 50% and 54%, respectively, in comparison to treatment F_2. Instead, the least amount of yield was gained at the lowest water dose, which needed the least amount of water. The maximum yield was obtained at the highest water dose, which demanded the most water.

Table 5. Analysis of Variance and Duncan's multiple range test of the average weight per fruit, average diameter per fruit, and average length per fruit.

Factor	Average Weight Fruit^{-1}(gm)	Average Diameter Fruit^{-1}(mm))	Average Length Fruit^{-1}(mm)
Irrigation Frequency			
F_1	70.45 a	48.48 a	48.02 a
F_2	46.05 b	43.96 b	41.06 b
Water Dose			
W_1	42.41c	42.38b	41.30 b
W_2	59.74 b	45.62b	44.65 ab
W_3	72.60 a	50.67a	47.68 a
ANOVA			
F	***	**	***
W	***	**	*
F× W	ns	ns	ns

W and F represent water dose and irrigation frequency, respectively, and T represents the farmer's practice, respectively. W_1: 50% ETc; W_2: 75% ETc; W_3: 100% ETc; F_1: daily basis; F_2: every alternate day; *: significant at $p < 0.05$; **: significant at $p <0.01$; ***: significant at $p < 0.001$; ns: no significant at $p < 0.05$. Values within the same columns that are accompanied by different letters vary significantly at $p < 0.05$.

Fruit Weight

Both the water dose and the frequency of irrigation had an impact on the average weight of each fruit (Table 5). Each fruit's average weight increased as the water dosage increased, but a decrease in irrigation frequency led to a decrease in the weight of each fruit. According to the results of the experiment, the treatment F_1W_3 produced the highest average weight per fruit, while the treatment F_2W_1 produced the lowest average weight per fruit.

Fruit Length

The average length per fruit was significantly affected by water dose and irrigation frequency presented in Table 5. In comparison to F_1, the mean length per fruit in F_2 was considerably reduced by 14.5%. As water quantities increased, fruit length increased, as shown in Table 5. W_3 resulted in fruit length that was 13.4% and 6.4% greater than W_1 and W_2, respectively.

Fruit Diameter

The impact of water dose and irrigation frequency on fruit diameter was found to be statistically significant ($p < 0.05$), as shown in Table 5. The average diameter per fruit in treatment F_2 was reduced by 9.2% less than treatment F_1. The mean diameter per fruit exhibited a positive correlation with escalating water dosages and irrigation frequency. The experimental results indicated that treatment F_1W_3 yielded the greatest average diameter per fruit, while treatment F_2W_1 produced the smallest average diameter per fruit.

DISCUSSION

Effect of Irrigation Schedule on Crop Water Requirement

The experiment was carried out in winter seasons (December to February), and it was low in average air temperature and high in relative humidity. The ET_0 was estimated using the Penman-Monteith method and shown in Figure 1. The variation in ET_0 values is indicative of the fluctuating meteorological parameters within the designated study area. During the winter months, evapotranspiration was diminished due to the reduced wind speed, high relative humidity, and low temperatures (Alemayehu et al., 2009). The ETc values throughout the experimental period are depicted in Figure 1, and the fluctuations seen can be attributed to the crop coefficient, as indicated in Table 1. Although the Kc fluctuated minimally, it was not consistent in any growth stage (De Azevedo et al., 2007). The ETc values for all the treatments illustrated in Figure 1 were found to be minimal at the onset and conclusion, when the crops were at their most productive stage, and increased during the mid-phases. The profundity or quantity of water required to replace the water lost by ETc is referred to as the crop water demand. There is an uneven distribution of the total amount of water needed for crop development throughout the crop's life cycle; rather, it varies according to location, climate, soil type, cultivation method, effective precipitation, and other factors. (De Azevedo et al., 2007). In our case, two irrigation frequencies with three water doses were observed for the irrigation schedule. This was because the irrigation requirement varied at different treatments (Table 2).

Effect of Irrigation Schedule on Plant Growth

The frequency of irrigation and water dosage had a substantial impact on plant height, flower count presented in Table 3. From the results, we found that the plant height decreased as the water dose decreased and increased as irrigation frequency increased. The highest altitude was attained under F_1W_3, and the lowest height was obtained under the F_2W_1 treatment. The findings are consistent with these results and agree with Agbna et al. (2017), who observed that vegetative growth decreased in deficit irrigations. This was because significantly reduced photosynthesis by plants diminished the quantity and energy of metabolites required for healthy plant development under water-stress conditions. Wu et al. (2021) explained that water dose had an adverse influence on plant height and stem diameter. Tomato yields decreased in response to reduced irrigation amounts, these declines were accompanied by reductions in plant height and leaf count. These changes may be caused by increased water stress. In our experiment, the plant height decreased with the decrease in irrigation frequency. This result is supported by Oke et al. (2020). In this study, stem diameter was unaffected by the frequency of irrigation or water dosage, supported by Alves Souza et al. (2020), who confirmed that the values of stem diameter could not significantly be affected by one- or four-day irrigation intervals. This study indicated that the number of flowers varied with irrigation frequency and water dose. At the maximum water dosage and frequency of watering, the greatest number of blooms as each plant was produced, whereas the lowest quantity of flowers per plant was obtained at the lowest irrigation dose and highest irrigation interval indicated in Table 3. Tolerant genotypes may exhibit a reduced rate of floral abscission as a result of photosynthate translocation to the reproductive organs and maintenance of photosynthesis under drought conditions. In susceptible cultivars, the lack of available assimilates to the developing floral organs may result from a reduction in photosynthesis during times of water stress, which subsequently causes the abscission of flowers and flower buds explained by Sivakumar & Srividhya (2016). A scarcity of water during this phase would have resulted in a diminished flower production, and as hypothesized (Mahendran & Bandara, 2000), water scarcity during the flowering stage not only hinders the development of flowers but also elevates the rate of blossom shedding. Table 4 shows how the frequency of irrigation and water dosage impacted the amount of fruit produced in each plant. The quantity of fruit that each plant produced was not influenced by either water doses or irrigation frequencies explained by Colimba-Limaico et al., (2022). On the contrary, the results of Biel et al., (2021) & Wu et al., (2021) indicate that the quantity of fruits produced is influenced by the dosage of water. Tomato plants are particularly susceptible to severe water stress while blossoming and fruiting (Zegbe et al., 2006). Flower abortion can lead to a reduced fruit yield per plant. As a result, both the quantity and weight of fruits may be diminished due to water stress observed by Hao et al., (2013).

Effect of Irrigation Schedule on Yield and Yield Components

The present study showed a significant difference in fruit yield and yield components by water dose and irrigation frequency. Total yield and yield components increased with increasing water doses and irrigation frequency. The frequency of irrigation has significant in terms of statistics impact on tomato yield, which is consistent with the findings of Alves Souza et al., (2020), who examined the effects of six different irrigation frequencies (2, 3, 4, 5, 6, and 7 days interval) on tomatoes cultivated in an open field and found that the highest yields were obtained with the highest watering frequency (2 days). Tomato yield was found to be substantially impacted by water doses; these results are consistent with previous research that has demonstrated the detrimental effect of the lowest water doses on fruit yield (Agbna et al., 2017; Wu et al., 2021). Furthermore, following our findings, Sezen et al., (2010) observed that the tomato yield was greatest at the maximum water dose (150% ETc). The reason for the lower yield observed in the treatments subjected to deficit water stress can be attributed to the inadequate development of flower buds in these conditions. It is well-established that water stress can have an impact on flower bud development (Naor et al., 2008). Table 5 displays the impact of irrigation frequency and water dosage on yield components. The fruit weight, fruit length, and fruit diameter increased with increasing water doses and irrigation frequency. The decrease in the irrigation frequency might reduce the length, diameter, and weight of the tomato fruits explained by (Rebouças Neto et al., 2017).

Effect of Irrigation Schedule on Water Use Efficiency

The lowest irrigation dose produced the best WUE, according to Wu et al., 2021; Abdulhady et al., 2017 and Wang & Xing, 2017. These findings, however, differ from those of Kuscu et al., (2014) and Liu et al., (2019). These inconsistent findings could be explained by the fact that irrigation, whether excessive or insufficient, tends to reduce WUE and yield explained by Hao et al., (2013). The observation that the maximum watering frequency resulted in the highest WUE is consistent with the findings of Oke et al., (2020), which suggest that an increase in irrigation frequency leads to a greater quantity of fruits, which subsequently increases yield and enhances WUE. On the contrary, Fara et al., (2019) noted that higher irrigation intervals (7 and 9 days) resulted in the highest water use efficiency. The authors further proposed that increasing the irrigation intervals could potentially lead to more effective water usage. According to López Ordaz et al., (2011), plants that were subjected to more frequent irrigation intervals exhibited reduced water usage efficiency as a result of developing their roots more superficially.

However, in our case, the lowest irrigation frequency and maximum water dose resulted in the highest water use efficiency under the 100% ETc treatment every other day.

The Optimal Irrigation Scheduling

The optimal scheduling of irrigation must consider fruit quality, yield, and water use efficiency. However, because of the complicated interactions they involve, establishing the correct balance between them is difficult. It is, therefore, necessary to examine their quantitative relationship (Liu et al., 2019). By balancing yield, fruit quality, and water use efficiency in an open-field tomato producer, our results may be capable of approximating the optimal frequency and dose of irrigation. To attain equilibrium between tomato production, fruit quality, and water use efficiency, this study demonstrates that the local producer dose is not advisable. In the study, the local dose increases yield but decreases fruit size and WUE in comparison to the other dosages. The 100% ETc water dose achieves a greater yield and WUE than the 50% ETc and 75% ETc water doses. According to the experimental findings, the optimal combination of watering frequency, in addition to amount, at $F_1 + W_3$ produced the most comprehensive outcomes. Considering the prevailing weather conditions, this irrigation schedule may be the most logical for tomato production.

CONCLUSION

Tomato evapotranspiration varied slightly on every alternate day thus, that would be wise to make daily schedules for irrigation to better regulate water dosages. Under the experimental conditions, plant growth, fruit production, and water usage efficiency were significantly impacted by irrigation frequency and water doses, except for stem diameter. The highest yield was obtained from the highest irrigation frequency at F_1 and the highest water dose at W_3, but the highest WUE was obtained at a lower irrigation frequency under the treatment F_2 and the highest water dose at W_3. The irrigation water requirement was highest at the highest irrigation frequency with the highest water dose at F_1W_3, whereas the irrigation requirement was lowest at lower irrigation frequency with the lower water dose at F_2W_1.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Conflict of interest

The authors state there is no competing interest.

Author contribution

Tahmina Akter: Wrote the main manuscript text, analyzed the results and discussion, and reviewed the manuscript.
Nargis Akter: Collected the data from the field, analyzed the results and discussion, and reviewed the manuscript.
Ashutus Singha: Analyzed the results and discussion, reviewed the manuscript.
M.N.N. Mazumder: Interpreting the results, reviewed the manuscript.

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