SAARC J. Agric., 22(1): 125-138 (2024) *DOI: https://doi.org/10.3329/sja.v22i1.72849*

ENHANCING WATER USE EFFICIENCY AND CROP PRODUCTIVITY IN TOMATO CULTIVATION THROUGH VARYING IRRIGATION SCHEDULES: A STUDY IN OPEN FIELD AND POLYHOUSE OF ASSAM, INDIA.

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ABSTRACT

Tomatoes are a prevalent crop commonly cultivated in the Indian state of Assam. An experiment was carried out to assess the impact of varying irrigation schedules on water use efficiency for tomato cultivation within and outside polyhouses in hilly terrain. Four drip irrigation levels were tested: Treatment-1 (T-1) (50% of crop evapotranspiration, ETc), T-2 (75% of ETc), T-3 (100% of ETc), and T-4 (125% of ETc), analysing their effects on crop growth, yield, economic benefit and water use efficiency. Tomato plants (Lycopersicon esculentum) were grown in both polyhouses and open fields, with three replications per irrigation treatment. Measurements of fruit number, individual fruit length, and yield were taken at 5-day intervals. T-1 in polyhouses exhibited superior growth and the highest yield compared to other treatments, demonstrating elevated water use efficiency. This research underscores the potential of polyhouses to enhance year-round vegetable productivity and water use efficiency in North East India's hilly regions, offering solutions for agricultural water scarcity challenges.

Keywords: Crop evapotranspiration, Drip irrigation, Irrigation scheduling, Tomato, Water use efficiency

INTRODUCTION

Increase in global water shortages are severely constraining regional, social and economic progress due to a significant difference between water availability and demand. Agriculture's substantial water usage primarily contributes to this issue, and inadequate water supply to meet crop requirements poses a threat to food security (Zhang et al., 2022). In hilly regions, the significant elevation and presence of

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Received:25.04.2024 *Accepted: 10.06.2024*

mountain ranges contribute to a wide range of rainfall variations (Sharma et al., 2019). Despite the abundant rainfall (exceeding 2000 mm) in the hilly terrains of Assam, these areas face pronounced challenges stemming from both water scarcity and water excess during rainy and post-rainy periods. These issues persist due to inadequate storage facilities and the absence of efficient water delivery and drainage systems.

Because it is difficult to cultivate tomatoes, capsicums, cucurbits, french beans, and other high-value crops in Northeast India's open fields, various types of covered structures have been devised to shield high-value crops from extreme cold and frost (Chakraborty et al., 2015). Many growers have switched from open-field to protected tomato cultivation due to the rising demand for quality tomatoes in both domestic and foreign markets, especially during the off-season. (Gowda et al., 2022). The tomato is one of the most popular and widely grown vegetables in the world. It is also high in vitamins and antioxidants. The environment and amount of irrigation in greenhouses have a significant impact on tomato growth, yield, and quality (Gong et al., 2022).

One of the key elements influencing the quantity and quality of agricultural products is the irrigation system (Darré et al., 2019). Water management is therefore essential for preventing crop moisture stress during the crop growth stages. Given the current global expansion of irrigated land and the limited availability of water for irrigation, there is a critical imperative to optimize water use efficiency (WUE) to increase crop yields, particularly under conditions of frequent deficit irrigation. Maximizing WUE involves deploying deficit irrigation technology, precise irrigation scheduling, and implementing enhanced agricultural practices to effectively enhance crop yields. (Alam et al., 2003, Shi et al., 2021, Zain et al., 2021, Patel et al., 2023). One of the main challenges to vegetable production in the Northeast's steep terrain is water management and scarcity throughout the winter, with micro irrigation acting as the only other option. Drip irrigation increases profitability, reduces energy, labour, runoff, avoid wetting of leaves which minimises the risk of diseases, minimises conventional water losses by deep percolation (Narayanamoorthy, 2005). Drip irrigation increases crop yield and water use efficiency (Cetin and Bilgel, 2002; Ibragimov et al., 2007; El–Metwally et al., 2022; Wang et al., 2022).

Numerous studies have been undertaken on tomato cultivation in the hilly terrain of Assam. Hazarika and Phookan, (2005) assessed the development, production, and quality of 27 tomato cultivars grown in polyhouses. Brahma et al., (2010) examined the effects of drip irrigation's N and K fertigation level on fruit quality, marketable output, growth, and economics. Sarma et al., (2020) investigated the usage of agricultural chemicals in three Assamese agroclimatic zones for the production of tomatoes. Kalita et al., (2023) carried out a field experiment in Jorhat, Assam, to investigate how tomato growth and yield are affected by changed microclimates and radiation usage efficiency. To the best of our knowledge, based on the literature review referred, no studies have been conducted on the effects of varying irrigation schedules on water use efficiency in tomato cultivation in Assam's soil and agro-climate, particularly with regard to drip irrigation treatments using different levels of crop evapotranspiration. Therefore, this study was conducted to assess the impacts of various irrigation schedules on water use efficiency and economic returns in tomato production, both within and outside a polyhouse, in a hilly terrain.

Materials and method

Description of the experimental site

The experimental site is situated in the Department of Agricultural Engineering, Assam University, Silchar. The hilly terrain of Assam University has a total area of 968.28 m^2 with latitude of 24.68˚N and longitude of 92.75˚E with altitude of 40.80 m from Mean Sea Level.

Soil physio chemical properties

The study assessed soil physical-chemical traits like moisture content, bulk density, soil texture, pH, and electrical conductivity. Soil samples collected from 9 locations (2 in each treatment) and 2 depths (0-15, and 15-30 cm) were collected for analysis of soil. Soil moisture content was determined using the oven-drying method (Reynolds, 1970). The depth wise variation of bulk densities (dry and wet) for both the treatments were determined by the soil core method (Brady and Weil, 1999) with known height (h) and diameter (d) of soil cores. Soil particle size and texture were determined through the hydrometer method, applying the USDA textural classification triangle (Bouyoucos, 1962). A pH meter and an electrical conductivity (EC) meter were used to measure the EC and pH of the soil, respectively.

Wilting point and field capacity of a soil sample was determined by the pressure plate apparatus (Karkansis, 1983). The field samples of soil were collected and stored at pressures of 0.3 bar, 1 bar, 5 bar, and 15 bar. The sample's field capacity was determined by its moisture content at 0.3 bar of pressure, and the sample's wilting point was determined by its moisture content at 15 bar of pressure.

Experiment layout

Four different irrigation treatments were included in the fully randomized block design of the experiment. For Tomato, plant to plant distance was taken as 60 cm and row to row distance was taken as 50 cm. So, in each treatment number of replication was 3 with 4 number of tomato plants.

The irrigation practice for both inside and outside the polyhouse consists of four treatments with different levels of water amount based on crop evapotranspiration (ETc).

- Treatment 1 (T1)—50% of ETc
- Treatment 2 (T2)—75% of ETc
- Treatment 3 (T3)—100% of ETc

- Treatment 4 (T4)—125% of ETc

Each treatment had three replications, and they were all arranged randomly. Using the crop evapotranspiration (ETc) for tomatoes, which was determined using the FAO Penman–Monteith technique (Allen et al., 1998) based on the meteorological data observed inside and outside the polyhouse, the amount of irrigation water to be applied for the experiment was assessed. The FAO Penman–Monteith equation is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\Delta u_2)} \quad \ldots (1)$$

Where ET_o = reference evapotranspiration (mm day^{-1})

R_n = net radiation at the crop surface (MJ m^{-2} day^{-1})

G = soil heat flux density (MJ m^{-2} day^{-1})

T = mean daily air temperature at 2m height (℃)

u_2 = wind speed at 2m height (m s^{-1})

e_s = saturation vapour pressure (kPa)

e_a = actual vapour pressure (kPa)

$e_s - e_a$ = saturation vapour deficit (kPa)

Δ= slope vapour pressure deficit (kPa)

γ = psychrometric constant (kPa℃$^{-1}$)

The actual crop ET_c for tomato was calculated with the following equation using the crop coefficient K_c developed from the FAO-56 Irrigation and Drainage paper (Allen et al. 1998).

$$ET_{c,adj} = K_s \times K_c \times ET_o \quad \ldots \quad (2)$$

Where $ET_{c,adj}$ (mm day^{-1}) is the adjusted ET_c calculated by multiplying ET_o(mm day^{-1}) by a crop coefficient $K_c$and by a soil water stress coefficient K_s. The coefficient K_s=1 because there is no soil water stress in this situation, where the soil evaporation accounts for a small portion of ET_c. For tomato crop K_c is equivalent to 0.6 at the initial stage, 1.15 at the mid-stage and 0.80 in the end of growing season which was determined according to FAO 56 (Allen et al. 1998).

Irrigation scheduling

Determining the precise amount, duration, and interval of irrigation is a key component of irrigation scheduling. Using the FAO Penmen-Monteith equation, the amount of irrigation was determined (Allen et al., 1998).

CWR ($m^3 day^{-1}$) = ET_o($mm\ day^{-1}$) × crop coefficient (K_c) × crop area (m^2) ...(3)

Where CWR= crop water requirement ($m^3 day^{-1}$)

Water Use Efficiency

The ratio of water used by plants for metabolism to water lost via transpiration is known as irrigation water use efficiency (IWUE.) This formula was used to determine IWUE (Howell *et al*., 1990):

$$IWUE = \frac{\text{crop yield } (\text{tha}^{-1})}{\text{Total irrigation water applied (mm)}} \quad \ldots (4)$$

Cropping

To assess the tomato plants' vegetative development, growth parameters such as plant height, stem diameter, number of leaves in 5-day interval, number of flowers and fruits per plant, fruit length and width in cm, individual fruit weight in gram, yield per plant in kg; yield per plot in kg and yield in tonnes/hectare in each replication and treatments i.e. inside high tech poly house and open field condition was monitored once at the time of harvesting.

Statistical Analysis

To investigate potential variations in yield, WUE, and ET_c between irrigation regimens, analysis of variance (ANOVA) was used. The associations between grain yield and irrigation level, evapotranspiration; water use efficiency and irrigation level, evapotranspiration; and irrigation level and total cost, economic return were all investigated using correlation analysis using SPSS 18.0 software.

RESULTS AND DISCUSSION

Soil physical and chemical properties

Using the USDA textural classification triangle, it was found that the soil was clay loam and loam in polyhouse and open field respectively. The average initial soil moisture content inside the polyhouse were found to be 16.13% and average initial soil moisture content in open field for were found to be 13.69%.

The average bulk density on dry basis inside the polyhouse for found to be 1.46 g/cc respectively and average bulk density on wet basis inside the polyhouse were found to be 1.98 g/cc respectively. The average bulk density on dry basis in open field were found to be 1.48 g/cc and average bulk density on wet basis in open field were found to be 1.72g/cc.

The pH of all the soil samples from each treatment were found in the range of 4.79 to 5.37 and 4.56 to 5.32 in polyhouse and open field which indicates that the soil is acidic in nature and about 50% of applied fertilizer may be available to plants. The EC of the soil samples were found in the range of 0.052-0.222 and 0.016-0.072 mS/cm in polyhouse and open field, respectively.

Reference evapotranspiration

The average reference evapotranspiration for the months of February, March, April and May were 2.73, 3.52, 4.14, 4.66 mm/day (Fig 1).

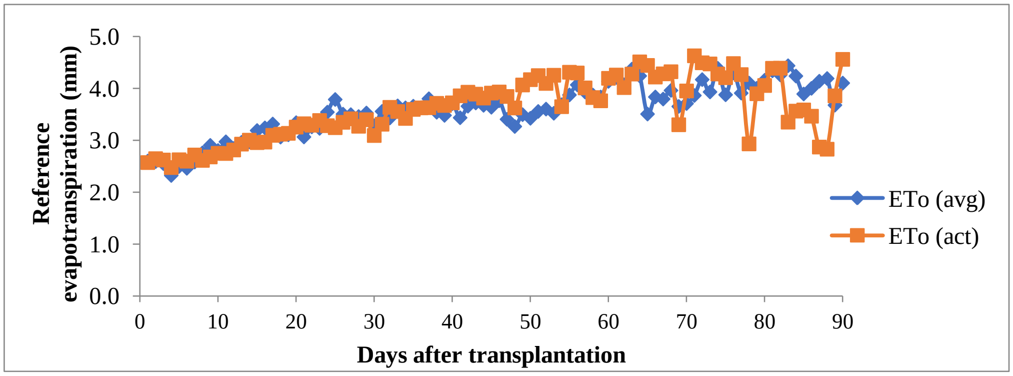

Fig. 1. Variation of reference evapotranspiration for the growing period

Effect of Irrigation System on Tomato growth and yield

Observations were recorded at 5 days interval after plantation. The average plant height which was tallest was observed in replication R-1(141.92 cm) of T-1 in polyhouse and average plant height was lowest in R-1 (39 cm) of T-3 in open field. The average stem diameter which was highest was observed in R-2 (10.20 mm) of T-1 in polyhouse and average stem diameter was lowest in R-2 (5.84 mm) of T-4 in open field.

The average number of leaves which was highest was observed in R-2 (43.56) of T-1 in polyhouse and average number of leaves was lowest in R-3 (20.11) of T-4 in open field. The average number of fruits which was highest was observed in R-3 (47.20) of T-1 in polyhouse and average number of fruits was lowest in R-3 (22.85) of T-4 in open field. It was observed that average length of fruit in R-2 (54.97 mm) of T-1 in polyhouse recorded biggest among all, while the length of Tomato observed in R-3 (38.28 mm) of T-4 in open field was smallest. Similarly, it was observed that, the width of fruit in R-1 (53.13 mm) of T-1 in polyhouse recorded biggest among all, while the width of Tomato plant observed in R-3 (32.21 mm) of T-4 in open field was smallest. The highest yield was observed in R-1 (0.84 kg) of T-1 in polyhouse and lowest yield was observed in R-2 (0.17 kg) of T-4 in open field.

Our study demonstrated that under polyhouse conditions, T-1 (50% of ETc) resulted in a greater total yield of 16.73 kg compared to other irrigation levels. Conversely, under open field conditions, T-3 (100% of ETc) showed a greater total yield of 13.81 kg (Fig. 2). Burato et al., (2024) carried out open field trial in Foggia, Italy and found that IRR (full irrigation, restoring 100% ETc) showed slightly higher results in total and marketable yield compared to RDI (Regulated deficit irrigation, restoring 50%

ETc). S. Locatelli et al., (2024) calculated the fresh yield under full irrigation (FI) was 45.94 Mg ha^{-1} and under deficit irrigation (DI) at 75% of FI was 41.94 Mg ha^{-1} for the mineral and unfertilized treatments, indicating a yield reduction of 8.7% with DI in a polyethylene green house at University of Paldova, Italy. The variation in results can be attributed to the unique topographical and climatic conditions of Assam's hilly terrain which could influence water availability and plant water needs differently compared to other regions. The variation in results may also stem from differences in experimental design, irrigation scheduling, replication techniques, and statistical analysis.

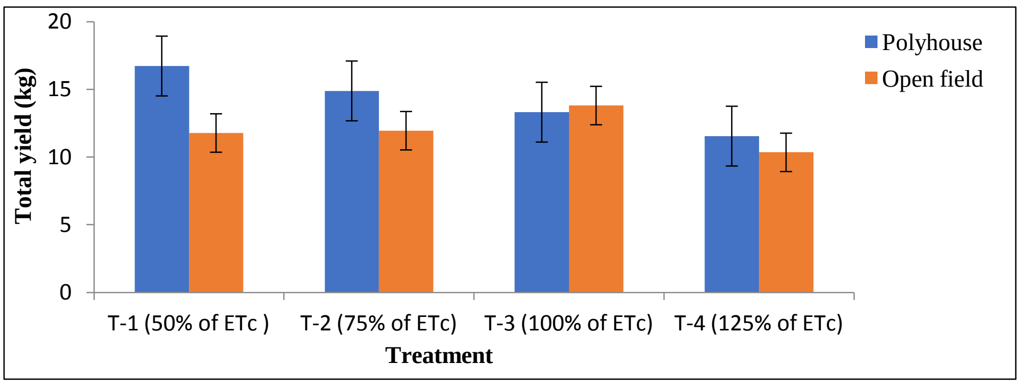

Fig. 2. Treatment wise variation of total fruit yield observed in each treatment in polyhouse and open field

Water use efficiency

It was found that the water use efficiency was highest for T-1 (0.09 ton/ha mm) in polyhouse and lowest for T-4 (0.04 ton/ha mm) in open field (Table 1, Fig. 3 and Fig 4). Burato et al., (2024) found that in comparison to the IRR (full irrigation, restoring 100% ETc) regime, remarkable water savings (21.46%, average of two years) were made under RDI (Regulated deficit irrigation, restoring 50% ETc) without significantly affecting total and marketable yield.

Francaviglia and Bene (2019) proved that WUE in was generally higher for treatments involving reduced irrigation (50% of ETc) compared to full irrigation (100% of ETC) for tomato production in Italy.

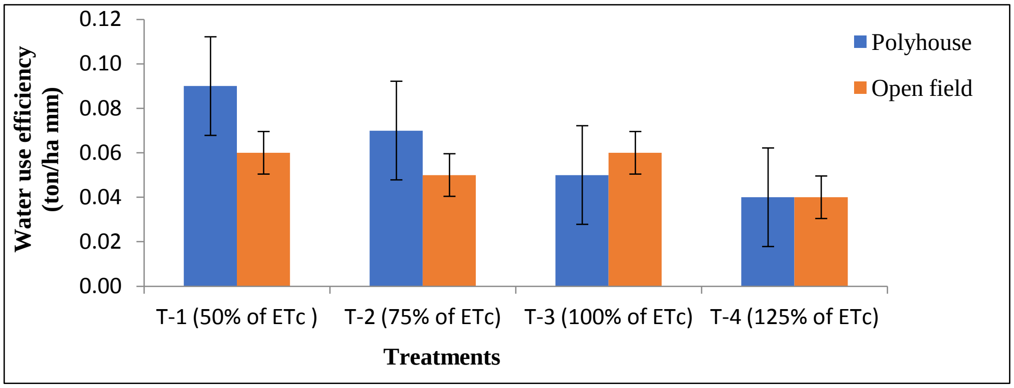

Fig. 3. Treatment wise variation of water use efficiency observed in each treatment in polyhouse and open field

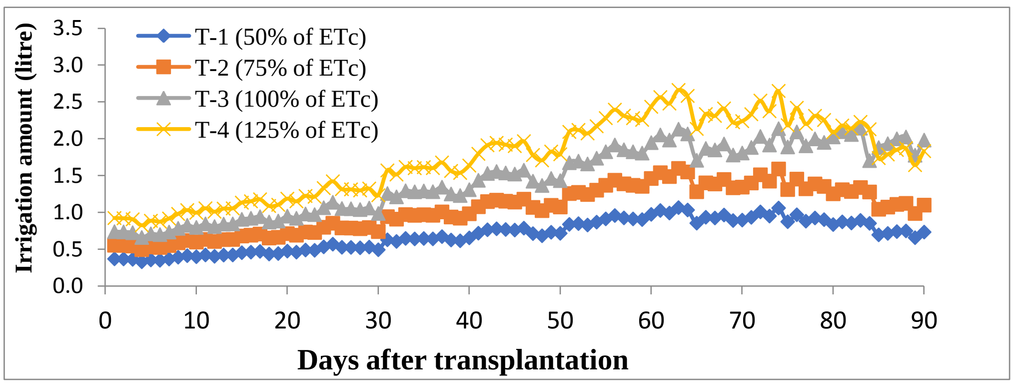

Fig. 4. Irrigation water applied in each treatment in polyhouse and open field

Table 1. Treatment wise water use efficiency observed in each treatment plot

Treatment	Yield (t ha^{-1})		Irrigation water applied (mm)	Water Use Efficiency (t ha^{-1} mm^{-1})	
	Polyhouse	Open field		Polyhouse	Open field
T-1 (50% of ETc)	34.28	24.14	397.2	0.09	0.06
T-2 (75% of ETc)	30.51	24.49	454.68	0.07	0.05
T-3 (100% of ETc)	27.3	28.3	507.33	0.05	0.06
T-4 (125% of ETc)	23.67	21.21	539.08	0.04	0.04

Statistical Analysis

ANOVA test of Tomato fruit yield and water use efficiency has been done. The results shows that the significance value is 0.012 which is less than 0.05% significance implying significant Tomato fruit yield (Table 2). The result shown in Table 3 shows that the significance value is 0.021 which is less than 0.05% significance implying significant water use efficiency.

Table 2. ANOVA parameter analyses comparing yield per plot in polyhouse and open field

ANOVA					
Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.082	1	3.082	7.525	0.012
Within Groups	9.009	22	0.410		
Total	12.091	23			

Table 3. ANOVA parameter analyses comparing water use efficiency in each treatment in polyhouse and open field

ANOVA					
Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.001	3	0.000	2.381	0.0210
Within Groups	0.001	4	0.000		
Total	0.002	7			

Economics and cost of production for Tomato

The experiment was conducted considering the existing constructed protected structures and drip irrigation system only their installation costs is not included in the cost of production.

Data on crop productivity was collected for 120 days starting on the transplantation date (Table 4 and Table 5).

The gross return ($/ha), net return per unit area ($/ha) net profit per unit production ($/ton) and BC ratio values were found significantly higher in T-1 in polyhouse and lowest in T-4 in open field (Table 4 and Table 5).

Table 4. Cost of production and economic analysis for Tomato in each treatment in polyhouse

Cost of Production of Tomato in each treatment in Polyhouse (USD, $)				
Components	Polyhouse			
	T-1	T-2	T-3	T-4
Nursery/Seedlings	0.24	0.24	0.24	0.24
Land preparation	0.36	0.36	0.36	0.36
Manures and Fertilizers	0.18	0.18	0.18	0.18
Plant protection	0.24	0.24	0.24	0.24
Land revenue	0.30	0.30	0.30	0.30
Hired Human Labour	1.20	1.20	1.20	1.20
Total Cost for 4.88 m^2 Area	2.58	2.58	2.58	2.58
Total cost in $/ Ha	5.1	5.1	5.1	5.1
Economics of Production of tomato in each treatment				
Yield (kg/plot)	0.20	0.18	0.16	0.14
Selling Price ($/kg)	0.60	0.60	0.60	0.60
Cost of Cultivation ($/Ha)	5276.88	5276.88	5276.88	5276.88
Total Yield (kg/ha)	410.62	365.45	326.92	283.48
Gross Returns ($/Ha)	20530.72	18272.72	16346.04	14173.91
Net returns per unit area ($/Ha)	15253.84	12995.84	11069.16	8897.03
B:C Ratio	2.89	2.46	2.10	1.69

Table 5. Cost of production and economic analysis for Tomato in each treatment in open field

Cost of Production of Tomato in each treatment in Open field (USD, $)				
Components	Open field			
	T-1	T-2	T-3	T-4
Nursery/Seedlings	0.24	0.24	0.24	0.24
Land preparation	0.36	0.36	0.36	0.36
Manures and Fertilizers	0.18	0.18	0.18	0.18
Plant protection	0.24	0.24	0.24	0.24
Land revenue	0.30	0.30	0.30	0.30
Hired Human Labour	1.20	1.20	1.20	1.20

Total Cost for 4.88 m^2 Area	2.58	2.58	2.58	2.58
Total cost in $/ Ha	5.1	5.1	5.1	5.1
Economics of Production of tomato in each treatment				
Yield (kg/plot)	0.14	0.14	0.17	0.12
Selling Price ($/kg)	0.60	0.60	0.60	0.60
Cost of Cultivation ($/Ha)	5276.88	5276.88	5276.88	5276.88
Total Yield ($/ha)	289.12	293.30	338.95	254.03
Gross Returns ($/Ha)	14456.18	14664.80	16947.36	12701.32
Net returns per unit area ($/Ha)	9179.30	9387.92	11670.48	7424.44
B:C Ratio	1.74	1.78	2.21	1.41

CONCLUSION

The crop growth parameters, yield and water use efficiency for tomato crop revealed the crop with drip irrigation at T-1 inside the polyhouse was found best in plant height, stem diameter, leaves at all stages of development than other irrigation treatments The water use efficiency was highest for the T-1 (0.09 ton/ha mm) in polyhouse.

The agricultural production economic study revealed that the initial cost for cultivation in poly house is quite higher but the net return was found highest from T-1 in poly house than open field. The T-1 in polyhouse resulted significantly more benefit cost ratio for growing of Tomato as compared to open field. Therefore, the polyhouse cultivation with drip irrigation at 50% of crop evapotranspiration (ETc) can be the most appropriate irrigation treatment for tomato crop with better crop growth, higher yield and high-water use efficiency in hilly terrain of North Eastern Region.

ACKNOWLEDGEMENT

The authors are thankful to the Department of Agricultural Engineering, Assam University Silchar for providing the opportunity and infrastructure to complete this research work.

DISCLOSURE STATEMENT

The authors report there are no competing interests to declare.

DECLARATION OF FUNDING

No funding was received

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