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Research Article

Determination of Optimal Irrigation Scheduling for Tomato (*Solanum Lycopersicum*) Crop Under Rain Shelter for Effective Irrigation Water Management

Etefa Tilahun Ashine[1, *], Minda Tadesse Bedane[1], Robel Admassu Lakewu[2]

[1]Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center, Jimma, Ethiopia
[2]Ethiopian Institute of Agricultural Research, Debrezeit Agricultural Research Center, Bishoftu, Ethiopia

Abstract

Tomato (*Solanum Lycopersicum*) is a staple vegetable and important cash crop in Ethiopia. However, extreme weather events and recurrent droughts affected the yield and quality of tomatoes and their marketability. Irrigation can mitigate the negative impacts of drought in a water-scarce area. Since water is scarce, it needs effective management for water productivity improvement and sustainable production. Effective management of water could be attained by irrigation scheduling, i.e, giving the required amount of water at the right time (when and how much) for the crop. Therefore, the objective of the current study was to determine the optimal depletion level of tomato for irrigation scheduling to effectively manage irrigation in a control environment under a rain shelter. The experiment was conducted at the Jimma Agricultural Research Center on the tomato Galilama variety under a rain shelter. Randomized Complete Block Design **(**RCBD) with three replications was used. Five treatments of different depletion levels were randomized in the plots. All agronomic and crop management practices were applied to all treatments in accordance with the recommendations made for the crop. Tomato yield and growth parameters data were recorded, and the treatments were compared based on yield and growth parameters using the SAS 9.2 software. The result reveals that, the plant height, biomass, and tomato yield were not affected statistically ($p > 0.05$) due to the depletion level of water under the rain shelter. However, the maximum plant height and maximum yield were recorded at 60% of the available soil moisture depletion level, and the maximum biomass was recorded at 120% of the available soil moisture depletion. The different levels of depletion significantly influenced the root length, biomass, and water productivity of tomatoes. The statistical analysis result showed that the maximum root length of 31.05 cm was recorded at a 120% available soil moisture depletion level (ASMDL4). The maximum agricultural water productivity was obtained at 60% available soil moisture depletion level (ASMDL1). It could be recommended that 60% of the available soil moisture depletion level was the best for yield improvement, water productivity and water management under the rain shelter for tomato production.

Keywords

Depletion, Irrigation Techniques, Sustainable Agriculture, Tomato Growth, Water Management, Water Productivity

*Corresponding author: etefatilahun@gmail.com (Etefa Tilahun Ashine)

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1. Introduction

Agriculture is the primary livelihood in Ethiopia and remains a critical sector in many developing countries [1, 2]. The Ethiopian economy has suffered from erratic rainfall, frequent droughts, and limited use of the water resources that are available, as well as a strong reliance on rain-fed subsistence farming. This reliance on rainfall limits productivity, and recurrent droughts further hinder sustainable agricultural output [3-5]. Over the years, subsistence farming transformed into intensive agriculture, which requires a higher application of inputs to produce food, fiber, and fuel [6]. Irrigation development, an essential component of intensive agriculture, has played a vital role in economic growth because it generated employment, way of livelihood and drove industries to feed the growing population [6, 7]. It is one of the intervention areas that boosts agricultural production, helps overcome rainfall, and provides a sustainable supply of water for cultivation that increases food security [8]. According to Ababa [9] development of irrigation is considered as a key instrument for supporting rural development and sustainable economic growth, and it is regarded as the foundation for reducing poverty and ensuring food security in Ethiopia. However, it needs an effective water management for the sustainable use of the water resources under the water scarce areas mainly in the arid and semi-arid areas of the country and could be secured through increasing the agricultural water use efficiency [10].

Water scarcity will pose serious threats to food production, especially in arid and semi-arid areas where it is the main factor limiting the expansion of arable land. Hence, managing water in a way that optimizes plant productivity per unit of water utilized and scheduling irrigation is ideal [11]. It is evident that efficient water scheduling is crucial for optimizing irrigation use, as excessive irrigation reduces yield while inadequate irrigation causes water stress and reduces production [12, 13]. On the other hand, the water supplied for the crop should be maintained at the optimum level to maximize returns to the farmer. High-frequency water management minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant, and maintains a high soil matric potential in the root to reduce plant water stress [14, 15]. For planning and determining the optimal irrigation, that is, the timing and amount of water application that could result in the minimum irrigation cost to the farmers, adapting irrigation scheduling is essential [16, 17]. Additionally, to meet the ever-growing population food demand and sustain subsistence farming through irrigation, it needs 70–90% irrigation because of the climate change impact [18, 19].

The tomato (*Solanum lycopersicum*) crop is a staple vegetable and important cash crop in Ethiopia. It is a popular and widely grown vegetable crop, ranking 8th in terms of annual national production and being consumed in every household in different modes [20-22]. In addition to income generation, it was used in the form of fresh or processed products such as tomato paste, tomato juice, tomato ketchup, and cherry type in Ethiopia. Its production is on an increasing trend, even though it doesn't meet the current market demand. Tomato consumption in Ethiopia is set to reach 30,000 metric tons by 2026. However, extreme weather events like hail, frost, and recurrent drought can negatively affect the yield, quality and marketability of the tomatoes [23]. The adaptation of irrigation, managing scarce water resources through irrigation scheduling, and other crop-specific characteristics are essential for the production and productivity improvement of tomatoes, in addition to controlling the problem of recurrent drought and water scarcity. However, its response to irrigation level was different in different soil conditions, management and agro ecology [24]. Therefore, it is essential to determine the impact of irrigation level on tomato crop in the agroecology and soil condition of Jimma and similar agroecology.

Irrigation scheduling is a key to water management and is one of the beneficial techniques used for quantifying water required at a particular interval in plants and thereby improving irrigation efficiency. It is essential to optimize crop production per unit area. It has improved the yield and water productivity of onion and tuber yield of potato [25, 26]. According to Parameshwarareddy *et al.* [27], different water regimes obtained by combining the amount of water and irrigation interval give useful indications on the possibility of improving the nutritional quality of tomatoes by reducing irrigation water applied during tomato cultivation. Given that approximately 32-40% of smallholder farmers in Ethiopia rely on irrigation for tomato cultivation [20], there is a pressing need to develop effective water management strategies to enhance crop productivity in irrigated agriculture. Tomato demands a relatively high amount of water, and application of too much water causes excessive accumulation of biomass and reduces the yield [28]. Characteristics of the crop, such as growth stage, nature of the crop, and root depth; properties of the soil, such as texture and its water holding capacity; climatic conditions where the plant is cultivated; and method of irrigation were the major factors that govern the irrigation scheduling.

Irrigation scheduling, according to Lopez-Urrea [29], is the process of accurately and timely supplying water to the crop. It is essential for preserving water, enhancing irrigation efficiency, and ensuring the long-term viability of irrigated agriculture. Daily irrigation is challenging because of limited labor and technical support that demand the operation of the system, and it is also challenging because of the investment it demands. The number of fields that must be concurrently managed in a medium to large size vegetable operation, the diversity of vegetables and number of crop rotations per season, and the number of field operations that must be coordinated during a crop cycle were challenges of irrigation scheduling [30]. Hence, predetermined crop and agro-ecology-specific irrigation scheduling is essential for irrigation management, production, and productivity improvement. Parameshnaik et al [31] disused that higher growth and yield attributes, yield and economics in the cultivation of hybrid safflower can be achieved under scheduling of irrigation at critical stages of the crop. However, there was a research gap on the irrigation scheduling of tomato for effective irrigation water management in the agroecology of Jimma. Therefore, the overall objective of the study was to determine the optimal depletion level of tomato for irrigation scheduling to effectively manage irrigation in a control environment under a rain shelter.

2. Material and Methods

2.1. Description of the Study Site

The experiment was conducted at Jimma Agricultural Research Center in south-west Ethiopia in the 2014/15 cropping season in a controlled environment under a rain shelter. The site is located at 7°46′ N latitude, 36°0.08′ E longitude, and at an altitude of 1753 m above mean sea level (Figure 1). The average annual rainfall of the study area was 1,500 mm distributed non-uniformly, with an average monthly mean maximum and minimum temperature of 27°C and 10°C, respectively. During the experimentation period, the external weather conditions of the site's average relative humidity, wind speed, and sunshine hours were 70.13%, 1.11 km/hr, and 6.6 hr/day, respectively (Figure 2).

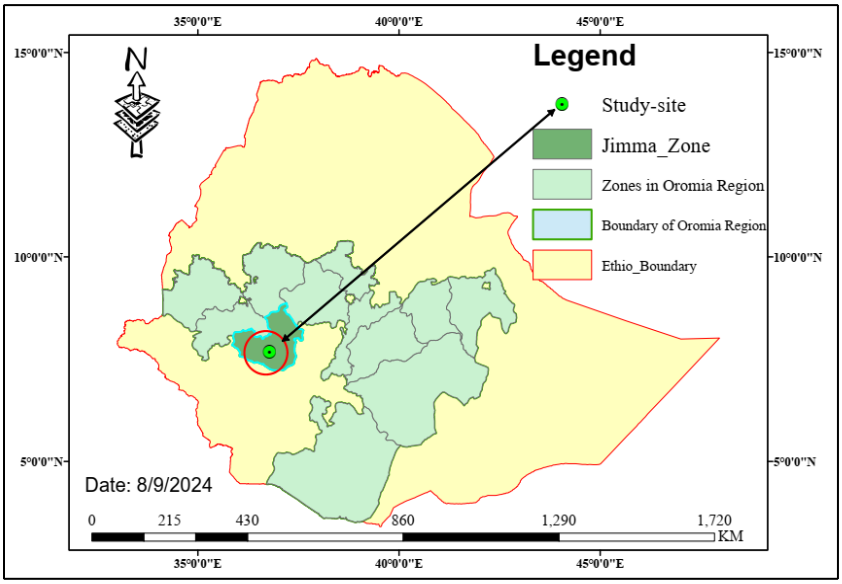

Figure 1*. Location of the study site.*

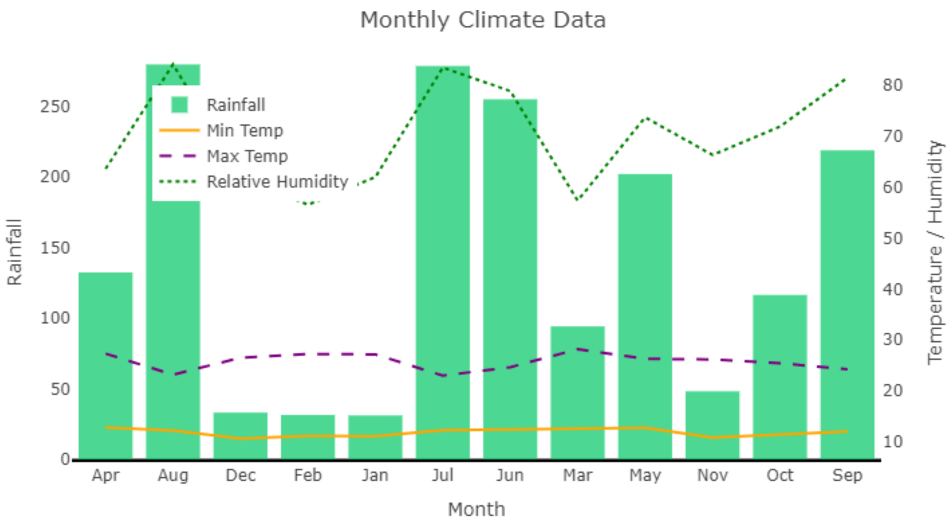

Figure 2*. Climatic condition of the study site.*

2.2. Planting Materials

At Jimma Agricultural Research Center, tomato seeds were used as the test crop. The seed multiplication farm was plowed and harrowed, and a bed was made ready for sowing the tomato seed. The seed bed was raised to manage irrigation water flow, to increase light exposure and soil temperature, stimulating germination. The raised bed was prepared, the tomato seeds was added, and then dry vetiver grass was spread over the surface. Tomato yield is primarily determined by germination, and this covering was necessary to improve it. To maintain a more uniform moisture on the entire surface of the bed for good seed germination, irrigation water was applied through a watering cane before transplanting to the pot.

2.3. Experimental Design

The experiment was carried out at the Jimma Agricultural Research Center experimental site under rain shelter during the 2014/15 cropping seasons using the Galilama tomato variety. Due to the equal number of replications and the design's simplicity and flexibility, the randomized complete block design (RCBD) with three replications was implemented, following [32]. For the identification of the soil moisture depletion level, as indicated in Table 1, five treatments with varying degrees of irrigation depletion were randomized in plots. The FAO-recommended available soil moisture depletion (ASMDL) served as the control, and the five treatments including the control treatments were 60%, 80%, 120%, 140%, and ASMDL (100% FAO-recommended ASMDL) and accordingly, the experiment had five treatments and 15 plots. All agronomic and crop management practices were applied to all treatments in accordance with the recommendations made for the crop.

Table 1. *Treatment Arrangement.*

S. No	Treatments
1	60% Available soil moisture depletion level (ASMDL1)
2	80% Available soil moisture depletion level (ASMDL2)
3	100% Available soil moisture depletion level (ASMDL3)
4	120% Available soil moisture depletion level (ASMDL4)
5	140% Available soil moisture depletion level (ASMDL5)

2.4. Crop Water Requirement and Irrigation Scheduling

Crop water requirements were calculated using the FAO Penman-Monteith method in CROPWAT8.0 software [33, 34]. The CropWat8.0 model has the capability of calculating reference evapotranspiration of crops, water supply for an irrigation scheme of more than one crop, and determining effective rainfall. In this study, average long-year climate data for a period of 18 years of monthly climate data (1997–2014), including maximum and minimum temperatures, relative humidity, wind speed, and sunshine hours, were collected from the Jimma Agricultural Research Center meteorological station and used as input data for the CROPWAT 8.0 software to estimate the reference crop evapotranspiration (ETo) (equation 1).

For tomatoes, the crop water need was calculated using equation 2 by multiplying the ETo by the crop coefficient (Kc), and the irrigation requirement was found using equation 3 as shown below. However, the crop coefficients at different growth stages were provided and adjusted according to Allen et al. [35]. The CROPWAT8.0 program was used to determine the irrigation schedule based on the FAO-recommended depletion level. From there, the requirement for the remaining treatments was applied by subtracting and adding 20% of the requirement according to the treatment using equation 4. Rainfall was not considered since the experiment took place under a rain shelter, and crop water requirements and irrigation needs were the same. Equation 1 calculates the reference crop evapotranspiration (ETo).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_{s} - e_{a})}{\Delta + \gamma(1 + 0.34U_2} \quad (1)$$

Where: ETo= is the reference crop evapotranspiration (mm/day); Δ = is the slope of the saturation vapor pressure curve (kpa/℃); R_n = is net radiation at the crop surface (MJ/m^2day); G = is the soil heat flux density (MJ/m^2day); T = is the mean daily air temperature at 2 m height (℃); U_2 = is the wind speed at 2 m height (m/s); e_s - e_a = is saturation vapor pressure deficit (kPa); e_s = is the saturation vapor pressure at a given period (kPa); e_a = is actual vapor pressure (kPa); and γ = is the psychrometric constant (kPa/℃).

$$ETc = ETo \times Kc \quad (2)$$

Where, ET_c= actual evapotranspiration by the crop (mm/day), ETo= reference evapotranspiration (mm/day), and Kc = crop coefficient at a specific growth stage.

The net irrigation requirement (IR_n) was computed from the following expression:

$$IR_n = ET_c - P_{eff} \quad (3)$$

Where P_{eff} = effective rainfall (mm), however, there was no rainfall contribution and it was nill.

The irrigation interval was calculated by using the following formula:

$$\text{Irrigation interval (days)} = \frac{IR_n}{ET_C} \quad (4)$$

Finally, the water was applied by using a water cane on the pot, and the amount of water applied at each treatment was calculated from the full irrigation using the tomato crop water requirement (CWR) at the crop rooting depth.

2.5. Data Collection

Tomato yield and growth parameters were recorded and compared across treatments. Tomato yield was harvested from each plot. Plant height was measured using a rod meter, and stem girth with a caliper. The water productivity was calculated by the ratio of harvested yield in kg per total water used in m^3 (using equation 5). Additionally, Soil physicochemical properties were collected and used as inputs for irrigation scheduling (Table 2).

$$\text{Water Productivity (Wp)} = \frac{\text{Harvested grain yield (Kg)}}{\text{Total Water Used (m}^3\text{)}} \quad (5)$$

Table 2. *Average Soil Physicochemical Properties of the Site.*

No	Tested Parameter	Average
1	Sand (%)	50.42
2	Clay (%)	37.92
3	Silt (%)	11.66
4	Soil textural Class	SCL
5	Soil bulk density (g/cm^3)	1.26
6	Field capacity (FC) (%)	35.74
7	Permanent wilting point (PWP) (%)	24.76
8	Total available water (TAW) (mm/m)	138.4
9	pH (1:2.5)	5.70
10	Organic carbon (OC) (%)	2.28
11	Organic matter (OM) (%)	3.82
12	Electric conductivity (EC) (dS/cm)	32.68
13	Cation exchange capacity CEC (meq/100 gm)	20.08
14	Magnesium (meq/100 gm)	0.54

2.6. Partial Budget Analysis

The partial budget was analyzed by using both production cost (variable cost for water, fertilizer and labor) and benefit that will be gained from the product. The yield was adjusted to 10% considering potential yield loss because of the perishable nature of the crop, then multiplied by the previous cost available during conducting the experiment. For determining the variable cost, the irrigation cost was estimated 1 Ethiopian Birr (ETB) for 1m^3 of irrigation water and the benefit gained was considered to be 5 Ethiopian Birr (ETB) per kg of tomato yield during the cropping year locally, which is the market cost of tomato. The marginal rate of return plays a pivotal role in determining the feasibility of production of the commodity. It measures the returns on increasing the investment in an input assuming no change in other inputs. Finally, the marginal rate of return was determined by using equation 6.

$$\text{Marginal rate of return (\%)} = \frac{\text{Change in net benifit}}{\text{Change in total variable cost}} \times 100 \quad (6)$$

2.7. Data Analysis

The data were analyzed by Statically Analysis Software (SAS). In this study, SAS software version 9.2 for windows was used for analysis [36]. Whenever the treatment effects were found to be significant, a general linear model test at 5% was performed to assess the significant difference among the treatment means.

3. Result and Discussion

3.1. Soil Physicochemical Properties of the Site

Determining the soil physical and chemical properties is essential at the beginning of the crop season for improved and efficient control of the soil's salinity and acidity, if any. The soil data collected from the site reveals that the texture was sandy clay loam (SCL) (Table 2). The contents of sand, clay and silt were 50.42, 37.92 and 11.66, percent respectively. The p^H of the soil was 5.74 and the total available water (TAW) was 138.4 mm per meter of soil depth. According to Denis *et al* [37], well drained soils with a PH range from 5.5-7.0 are ideal for tomato production, which is consistent with the current finding. The current finding reveals that the selected soil does not affect the treatment arrangement of the experiment and it could be affected by the depletion and water and other management aspects under the rain shelter.

3.2. Water Requirement of the Crop

Water is one of the essential environmental factors that affects both the yield and quality of tomatoes. To achieve maximum production and quality while mitigating climate change risks, effective irrigation management techniques are essential. As shown in Table 3 below, the total crop water requirement of tomatoes in the cropping season of 2014/15 was 439 mm depth of water. The irrigation requirements were 38mm, 91mm, 183mm, and 127mm depth at the initial, development, mid, and late season, respectively. The crop water requirement at the mid stage was higher than the remaining growth stage. Conversely, at the initial stage, it was low and the irrigation frequency was for a short duration. Similarly, according to FAO [38], depending on the climate, a tomato crop grown in the field for 90 to 120 days may require 400 to 600 mm of total water (ETc) after transplanting. It is evident that the findings were obtained under a rain shelter, where effective experimental and disease management was applied; however, additional investigations are needed under field conditions. Since the net irrigation requirement was fully supplied to the crop, the climatic conditions at the cropping site are a major factor influencing water requirements. The current finding could be a basic for the effective management of the water in a water scarce area.

Table 3. *Crop Water Requirement of Tomato.*

Crop	Growth period (Stage)	Kc	ETc (mm/day)	CWR (mm)	NIR (mm)
Tomato	Initial	0.6	2.19	38	38
	Development	0.76	2.92	91	91
	Mid	1.14	4.83	183	183
	Late	0.98	4.33	127	127
Total/ cropping season				439	439

3.3. Effects of Depletion Level on the Growth Parameter and Yield of Tomato

3.3.1. Plant Height

Soil moisture depletion level has no effect on the plant height of tomato statically insignificant (p>0.05) under the rain shelter (Table 4). However, the maximum and minimum plant height of 70.88 and 61.96 cm were recorded at ASMDL1 and ASMDL5, respectively. At ASMDL5, water stress may have contributed to the variation in plant height (Table 4). This suggests that as the depletion is low, it needs frequent irrigation, i.e., at 60% ASMDL (ASMDL1), it needs frequent irrigation when compared with 140% ASMDL (ASMDL5). Similarly, Ughade and Mahadkar [39] found similar results in their study on the effects of different planting densities, irrigation, and fertigation levels on the growth and yield of brinjal.

Other studies have shown that short-term water stress can affect plant height. According to Labdelli et al. [40], soil depletion-related water stress decreases plant height by directly slowing cell division or indirectly reducing developmental rates. Similarly, Nawata and Sakuratani [41], found that most growth parameters of plants could be reduced because of water stress. According to Abdelhady et al [42], the elongation of plant cells is typically restricted in dry conditions due to the obstruction of water flow from the xylem to the adjacent elongating cells, which is influenced by irrigation scheduling. This could account for the relatively low plant height that occurred when water stress increased.

3.3.2. Root Length

The root length of the tomato crop was statistically significant (p<0.05) and affected by the rate of soil moisture depletion. As shown in Table 4 below, the maximum root length of 31.05 cm was recorded at a 120% depletion level (ASMDL4). This is mainly due to the amount of water applied according to the treatment. The water applied to the crop indicates that once depletion falls below 20%, it does not significantly affect root distribution because frequent water application prevents deep penetration into the soil resulting in limited root elongation. According to Oliveira et al. [43], the total root length intensity decreases as the amount of water applied decrease.

Root length plays a crucial role in water and nutrient uptake, as it is the first organ to sense and respond to soil conditions (Chen *et al*. [44], cited by Bui *et al*. [45]), the 60% soil moisture depletion could not be recommended for tomato cultivation in the current study. If the root of the crop cannot uptake enough water from the soil and nutrients, it could cause water stress, which may lead to a low yield. However, since the crop needs frequent irrigation, the 60% depletion could be recommended considering the development stage of the crop. Additionally, during the sampling of root zone data, which involved destructive sampling it was observed that there was a difference in horizontal root distribution, indicating that irrigation water depletion levels had an impact. It was observed that, at a low soil moisture depletion level that needs frequent irrigation, there was a better distribution of root. However, prolonged irrigation results in fragile root distributions that show signs of water stress. Similarly, Carefoot and Major [46] found that application of early and frequent irrigation is better for growth of the root system. According to Fawzy [47], soil moisture depletion level affects the growth of the root, transpiration and uptake of nutrients by plant roots. From this finding it could be recommended that, deep rooting system is beneficial for water and nutrient uptake from the soil and this can be achieved through higher soil moisture depletion levels and appropriate irrigation scheduling.

3.3.3. Above Ground Biomass of the Crop

The total above-ground biomass was not statistically significant (p > 0.05) across the different levels of soil moisture depletion (ASMDL) under the rain shelter (Table 4). However, the maximum above-ground biomass of 13,833 kg/ha was recorded at a 140% soil moisture depletion level (ASMDL5), while the lowest biomass of 10,000 kg/ha was noted at a 60% depletion level (ASMDL1). This result indicates that as the soil moisture depletion level decreases, above-ground biomass also decreases; conversely, higher depletion levels lead to increased biomass. There was a 6% increase in biomass yield when comparing the FAO-recommended soil moisture depletion level to the 140% depletion level (ASMDL5). With the exception of the 120% soil moisture depletion level, there was a linear increase in biomass production corresponding to the volume of water applied. Similarly, Chand et al. [48] recorded an 8% loss in plant biomass under deficit irrigation treatments that maintained soil moisture at 60% field capacity compared to the control. Cantore et al. [49] stated that as the volume of water applied decreases, biomass also decreases due to water shortages in the root zone. This decrease in biomass production could lead to reduced yield and increased susceptibility to disease, negatively impacting quality. Similarly, Fawzy et al. [47] found that applying irrigation water at 100% ETc significantly increased the number of leaves per tomato plant, directly contributing to above-ground biomass. Abdelhady et al. [42] also reported similar findings for tomatoes. However, this result contradicts Robel et al.'s [50] study on soybean, which found different outcomes regarding moisture levels and biomass production.

3.3.4. Yield of the Crop

Tomato yield is determined by fruit weight and number. The rate of soil moisture depletion affects tomato yield, as shown in Table 4. The maximum and minimum marketable tomato yields of 24,811 kg/ha and 22,376 kg/ha were recorded at 60% (ASMDL1) and the FAO recommended soil moisture depletion level (ASMDL3), respectively. Despite no statistically significant difference between the treatments (p >0.05), the maximum and minimum unmarketable tomato yields of 8,111 kg/ha and 3,698 kg/ha were recorded at 140% (ASMDL5) and 80% (ASMDL2) soil moisture depletion levels, respectively. This suggests that frequent irrigation may improve tomato yield, fruit number, and quality. Tomato quality is determined by size, colour, and the absence of cracks. Unmarketable yield refers to tomatoes that are produced but are not suitable for commercial sale. Since tomatoes are cash crops and perishable, they can deteriorate if stored for long periods after harvesting. Therefore, a soil moisture depletion level of 60% is optimal for water management and yield improvement in tomatoes.

Similarly, Tefera et al. [51] found the highest bulb yield with frequent irrigation in garlic. Their study indicates that maintaining soil moisture content above the allowable depletion levels of 60% and 80% is beneficial compared to recommended and lower levels. Moges [52] also found the maximum onion bulb yield and water use efficiency at a 60% soil moisture depletion level. Under Wondo Genet conditions, irrigating lemongrass at 60% of total available water increases herb and oil yields as well as the plant's water use efficiency (Tesfaye et al. [53]). Based on the current and related findings, irrigating tomatoes at a soil moisture depletion level of 60% is advisable for yield improvement in Jimma and similar agroecological regions.

3.3.5. Water Productivity

One of the basic advantages of irrigation scheduling was to improve the water productivity in agricultural field. Water productivity refers to the yield obtained per unit of water utilized. In addition to reducing the likelihood of conflict, reallocating water currently designated for low productivity uses will ensure its availability to meet the rising demand for food, fiber, and other needs. Increasing the efficiency of water use in agriculture can reduce the additional freshwater withdrawals needed for each sector [54]. Additionally, the current findings indicate that water productivity improved under the rain shelter.

The water productivity was influenced by varying soil moisture depletion levels of tomatoes under the rain shelter. Statistical analysis revealed significant differences between the treatments ($p < 0.05$). Maximum water productivity was achieved at a 60% available soil moisture depletion level (ASMDL1), with values of 3.02 kg/m^3 and 1.96 kg/m^3 recorded at ASMDL1 and ASMDL3, respectively (Table 4). Irrigation scheduling also influenced water productivity in this study. For efficient water management and to enhance water productivity in shallow- to medium-rooted crops, frequent irrigation is recommended. Based on the current findings, a soil moisture depletion level of 60% is advised for tomato cultivation. The following table summarizes the effects of different soil moisture depletion levels on growth parameters, yield, and water productivity of tomatoes:

Table 4. *Effects of The Different Depletion Level on Growth Parameter, Yield and Water Productivity of Tomato.*

No	Treatments	Plant Height (cm)	Root Length (cm)	Biomass Yield (Kg/ha)	Crop Yield		Water Productivity (Kg/m^3)
					Marketable (Kg/ha)	Unmarketable (Kg/ha)	
1	ASMDL1	70.88	24.01^{b}	10,000	24811	4857	3.02^{a}
2	ASMDL2	66.44	26.89^{ab}	10,167	22961	3698	2.01^{ab}

No	Treatments	Plant Height (cm)	Root Length (cm)	Biomass Yield (Kg/ha)	Crop Yield		Water Productivity (Kg/m^3)
					Marketable (Kg/ha)	Unmarketable (Kg/ha)	
3	ASMDL3	65.25	27.72^{ab}	13,000	22376	5862	1.96^{ab}
4	ASMDL4	62.17	31.05^{a}	11,167	23861	3701	2.35^{ab}
5	ASMDL5	61.96	26.56^{ab}	13,833	23716	8111	2.07^{ab}
Cv		7.78	12.17	29.98	26.06	25.15	24.5
Lsd@5%		Ns	6.26	Ns	Ns	Ns	1.05

3.3.6. Partial Budget Analysis

In crop production, the economic benefits gained from the product are essential, alongside providing food supplements for farmers and supporting their livelihoods. From the current study, the partial budget analysis reveals that the total net benefit ranged from 89,185 to 101,799 Ethiopian Birr (ETB) per hectare. The maximum and minimum Marginal Rate of Return (MRR) were 707% for ASMDL4 and 264% for ASMDL5, respectively (Table 5). Therefore, to maximize net benefits, irrigating at the 60% available soil moisture depletion level (ASMDL1) could be advantageous for tomato production.

Additionally, since tomatoes are perishable, prolonged storage can lead to spoilage and economic losses. Frequent irrigation can enhance the maturity of the crop by regulating irrigation schedules, thus increasing yields. However, if irrigation is delayed and the crop receives water after a stress period, it may blossom immediately and mature simultaneously, leading to management challenges and potential economic losses. Table 5 presents the partial budget analysis of tomato production at different soil moisture depletion levels:

Table 5. *Partial Budget Analysis of Tomato at Different Depletion Level.*

No	Treatments	Marketable Yield (Kg/ha)	Adjusted Yield (Kg/ha)	TVC (ETB)	TRC (ETB)	NET BENEFIT (ETB)	Absolute MRR	MRR (%)
1	ASMDL1	24811	22329.9	9851	111649.5	101799	D	D
2	ASMDL2	22961	20664.9	10679	103324.5	92645	D	D
3	ASMDL3	22376	20138.4	11507	100692	89185	-	-
4	ASMDL4	23861	21474.9	12336	107374.5	95039	7.07	707
5	ASMDL5	23716	21344.4	13164	106722	93558	2.64	264

Generally, this research was conducted with the following limitation and needs an additional investigation.

The research was conducted in a controlled environment, which may not fully represent field conditions. Variations in climate, soil type, and pest pressure in different locations could affect the applicability of the findings to broader agricultural practices.

The duration of the study may have been insufficient to capture the long-term impacts of irrigation scheduling and soil moisture management on tomato yield and water productivity. Longer-term studies are necessary to assess the sustainability of these practices.

The focus on only one crop (tomatoes) limits the generalizability of the results. Future studies should consider a broader range of crops to understand better how different species respond to various irrigation and moisture management techniques.

The partial budget analysis may not encompass all economic factors, such as market fluctuations or additional costs associated with irrigation infrastructure, which could influence the net economic benefits. Therefore, it is better to investigate an additional research to address the above issue.

4. Conclusion

Implementing effective agricultural water management techniques that conserve water while maintaining yield and economic benefits is essential today. The adaptation of these techniques should consider crop specificity and agroecological factors, as water management is fundamentally influenced by these elements.

This study demonstrated that managing soil moisture content at different depletion levels significantly impacts the production and water use efficiency of tomatoes in a controlled environment. Given the medium root structure of tomatoes, implementing crop-specific irrigation water management is crucial to prevent plant diseases caused by excess water accumulation around the roots.

The findings revealed significant differences in yield and net economic benefits among the treatments. Maximum yield and net economic benefits were achieved at 60% ASMDL, while the minimum occurred at ASMDL3 (the FAO-recommended depletion level). The differences in yield and net economic benefits between ASMDL1 and ASMDL3 were 10% and 11%, respectively. Consequently, frequent irrigation is recommended for tomato crops to optimize yield and economic benefits. Based on the findings regarding soil moisture depletion for improved yield and water productivity, managing soil moisture at 60% available soil moisture depletion (ASMDL1) is recommended for irrigation scheduling of tomatoes under rain shelter conditions.

Abbreviations

RCBD	Randomized Complete Block Design
ASMDL	Available Soil Moisture Depletion
ETc	Crop Evapotranspiration
FAO	Food and Agricultural Organization
MRR	Marginal Rate of Return

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Availability of Data and Materials

The necessary data are available upon request from the corresponding author.

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Conflicts of Interest

The authors declare no conflicts of interest.

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