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Effect of irrigation regime on yield component and water use efficiency of tomato at Ataye irrigation scheme, Ataye Ethiopia

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Abstract. The importance of an irrigation regime is that it enables the irrigator to apply the exact amount of water to achieve optimum production and minimize adverse environmental impact. In the study area, the amount of irrigation and the frequency of application are not well determined, and the farmers are unaware of how much water and when to apply for tomato crops. Therefore, the objective of this study is to quantify the effects of irrigation regimes on yield and yield components of tomatoes in lowland areas of Ethiopia. The treatments were factorial combinations of five irrigation depths (50, 75, 100, 125, and 150 % of ETc) and three irrigation intervals and laid out in a randomized complete block design with three replications. The collected data were analyzed using R-software and significant treatment means separated using the least significant difference at 5 %. According to the findings, irrigation level and frequency had a significant (P< 0.05) effect on marketable fruit yield, water use efficiency, and plant height of tomatoes. The highest and lowest yields were 54.49 t/ha and 37.89 t/ha respectively. The optimum yield (48.5 t/ha) and water use efficiency (10.79kgm^{-3}) were obtained from 75% ETc before the 3-day interval. Therefore, for the study area and similar agro-ecologies, tomatoes can be irrigated with 376.72 mm net irrigation depth with 33.64 mm and 5-day interval, 60.54 mm and 9-das interval, 94.18 mm and 14-day interval, 94.18 mm and 14-days interval, and 94.18 mm and 14-days irrigation interval at initial, development one, development two, mid and late stages of tomatoes crop respectively and saving 3127.33 m^3 water to irrigate an additional 0.59 ha to achieve a yield of 29.00 t/ha for the user without a high yield penalty.

Keywords: irrigation regime, Tomato yield, water use efficiency, irrigation land, Ethiopia.

1. INTRODUCTION

Many regions of the world, particularly East Africa, are extremely concerned about food security. Ethiopia is a country with a total population of more than 110 million, of which about 80% of the total population is engaged in subsistence farming in rural areas (CSA, 2017). The distribution of Ethiopia's rainfall is erratic and unpredictable due to climate change is one of the most important challenges for crop production (Bezu, A., 2020). Currently, climate change is negatively influencing the availability of water resources, crop production, and food security in the world. Raising the unit yield is one practical way to keep the food supply self-sufficient. Several studies showed that irrigation is a good way to increase yield per unit of space (Hume et al., 2021).

Tomato is an important commercial vegetable crop in the world (Costa and Heuvelink, 2018). In Ethiopia tomato is one of the most economical and widely grown vegetable crop by smallholder farmers, commercial state and private farms (Emana et al., 2017). Water availability is a major limiting factor for tomato crop growth and productivity, thus a successful production of tomatoes requires irrigation (Chand et al., 2021). Irrigation water plays a great role in vegetable production as it affects the growth, yield, and quality of the tomato crop (Kuscu et al., 2014; Abdelhady et al., 2017).

Irrigation management practices such as amount and time of application are considered as components of major limiting factors of tomato crops production. However, water resources in many parts of the world are limited and thus there is an urgent need to apply effective irrigation strategy to operate under the prevailing conditions of water scarcity (DeNicola et al., 2015; Xinchun et al., 2017).

USING the CROPWAT model to determine the amount and time of application of irrigation water suitable for practicing irrigation water management to effectively use irrigation water to optimize crop production and productivity (Hossain et al., 2017). The CROPWAT 8 program was developed by FAO from the Penman-Monteith method, based on FAO Irrigation and Drainage Paper 56 named FAO56. FAO56 adopted the P - M (Penman - Montieth) method as a global standard to estimate ETo from meteorological data (Allen et al., (1998)). The FAO CROPWAT program incorporates procedures for reference crop evapotranspiration and crop water requirements and allow the simulation of crop water use under various climates, crop, and soil conditions. ETo was calculated for every ten days (defined as a "decade" by FAO) and then cumulated to monthly data. Soil characteristics considered for the estimation of crop water requirements are available water content (mm/m) and depth of soil (cm) (Surendran et al., 2015). Temperature and irrigation water demand were found to be related to crop water needs (Surendran et al., 2014).

The majority of irrigation water management in Ethiopia is traditional, meaning that farmers irrigate their land not properly which there is water available without taking into account whether it is above or below the crop's ideal water demand. The information on the crop water requirements of the anticipated crops is typically used for major dam design purposes rather than for the actual responsibility of irrigation operation. However, the availability of the same information is severely constrained in regions where farmers practice small-scale agriculture, and more water is thought to be wasted there (Roth G., 2014). For irrigation planning and water-efficient use in an arid area, understanding crop water requirements is crucial (Levidow et al., 2014). In addition, water usage in the agriculture sector would be required due to the growing shortage of water and the increased competition for it (Flörke et al., 2018). For the creation of a sufficient water supply, it is required to forecast the water requirements for crops in irrigation.

Using known techniques for calculating crop evapotranspiration and yield responses to water stress, the CROPWAT 8.1 model simulates agricultural water stress situations and estimates yield decreases (Swelam et al., 2019).

In the study area, farmers can irrigate their crops based on traditional know-how causing nutrient leaching, waterlogging, and severe water shortage problems. The amount and scheduling of tomato irrigation are still unknown and not properly manage the agricultural water to the field. Therefore, the objective of this study was to determine the effect of the irrigation regime on the yield and water use efficiency of tomatoes in lowland areas of Ethiopia for better resource allocation and crop productivity.

2. MATERIALS AND METHODS

2.1. Description of the study area

The experiment was conducted in the Efferatana Gidim district, Amhara Region, Ethiopia. The experimental site is located at 39°54'27" Easting and 10°17'28" Northing and an altitude of 1514 m above sea level. The two main seasons in the study area are the wet and dry ones. The dry season primarily lasts from October to the end of May, while the rainy season lasts from the beginning of June to the end of September, with a mean annual rainfall of 1010 mm. The mean maximum and minimum temperatures are 27.7°C and 11.3°C respectively in Table 6. Use the CROPWAT model to determine the amount of crop water needed in the study area. The trial was conducted in the Ataye irrigation scheme (Fig. 1). The precipitation versus reference evapotranspiration (ETo) of the study area shown in Fig. 2.

2.2. Reference evapotranspiration (ETo)

The reference evapotranspiration ETo was calculated by the FAO Penman-Monteith method, using decision

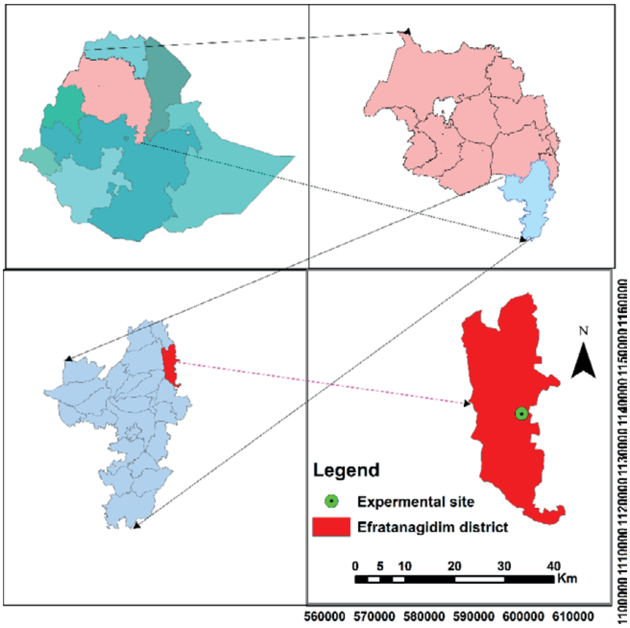

Figure 1. Location map of the experimental area.

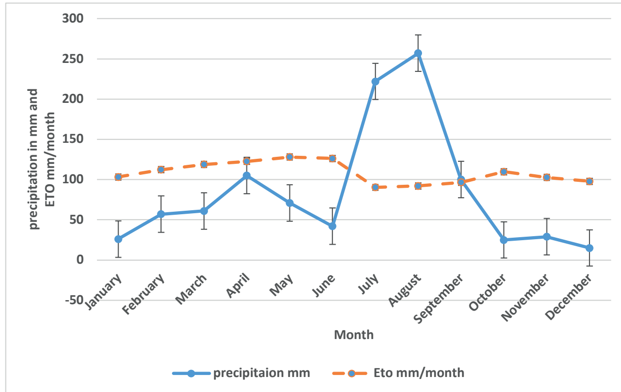

Figure 2. The precipitation and ETo of the study area.

support software CROPWAT8 developed by FAO, based on Allen et al.,(1998). The Penman-Monteith equation integrated in the CROPWAT program is expressed by the following equation 1 (FAO, 1998a).

$$ETo = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+00.34\,u2)} \quad (1)$$

where: ETo is reference evapotranspiration (mm day^{-1}), Rn, G, and T are net radiation values at crop surface (MJ m-2 day^{-1}) at 2 m height, soil heat flux density (MJ m^{-2} day-1) and daily mean temperature °C respectively. Also, u_2, es, ea, (es–ea), Δ and γ represent wind speed at 2 m height (m s^{-1}), the saturated vapor pressure at the given temperature (kPa), actual vapor pressure (kPa), saturation vapor pressure deficit (kPa), the slope of the saturation vapor pressure curve (Pa/°C) and psychometric constant (kPa/°C), respectively.

2.3. Determination of irrigation requirements and scheduling

Crop water use (ETc) was determined by multiplying ETo by the crop coefficient (FAO, 1998a) for initial, development, mid-season, and late stages. Irrigation water to be applied to tomatoes was determined at an allowable constant soil moisture depletion fraction (p = 0.3) (Table 1) of the total available soil water (TAW) and readily available water (RAW).

The crop water use (ETc) was calculated as equation 2:

Table 1. Crop parameters as an input for the CROPWAT model (Allen et al., 1998).

Growth stage	Initial	Development	Mid	Late	Total
Stage lengths (days)	30	40	45	30	145
Crop coefficient (Kc)	0.6	<<	1.15	0.7	
Rooting depth (m)					0.7-1.15
Depletion levels (P)	0.4	0.4	0.4	0.4	

$$ETc = ETo*kc \quad (2)$$

where ETc = crop water use (actual evapotranspiration); ETo = Reference evapotranspiration; Kc = Crop factor.

The irrigation Requirement of the crop based on long-term rainfall data estimated from study sites was as follows equation 3 (FAO, 1998a);

$$IR = ETc - Reff \quad (3)$$

where IR= Net irrigation requirement (mm); ETc = Crop water requirement (mm) and Reff = Effective rainfall (mm).

Effective rainfall is a part of rainfall that enters into the soil and is made available for crops. It can be calculated as follows equation 4 and 5 (FAO, 1998a);

Effective rainfall (mm) = 0.6 * RF (mm) – 10 for RF < 70 mm (4)

Effective rainfall (mm) = 0.8 * RF (mm) – 24 for RF > 70 mm (5)

where, RF = Rainfall (mm/month); Peff= Monthly decades of effective rainfall (mm).

The optimal irrigation schedule was worked out using the CROPWAT 8.0 computer model and assumed

Table 2. Method to determine chemical and physical properties of soil.

Parameters	Methods of analysis	References
pH	PH –meter	
EC	EC-meter or electrometer	
Organic carbon (OC)	Rapid titration method	(Walkley and black,1934)
Organic matter (OM)	1.724*OC	(Pribyl, 2010)
Soil texture	Hydrometer	Bouyoucous, 1962
Bulk density	Core sampler	(Hillel, 2000)
Field capacity (FC) and wilting point (PWP)	Pressure plate apparatus	

the irrigation regime applied at 100% readily available soil moisture. The RAW is the amount of water that crops can extract from the root zone without experiencing any water stress.

The TAW and RAW are calculated as follows equation 6 and 7 respectively (FAO, 1998).

$$\text{TAW} = \frac{(FC-PWP)}{100} * BD * Dz \qquad (6)$$

$$\text{RAW} = \text{TAW} * \text{P} \qquad (7)$$

where FC and PWP are in % on a weight basis, BD is the bulk density of the soil in gm cm^{-3}, and Dz is the maximum effective root zone depth in mm. RAW in mm, p is soil water depletion fraction for no stress in fraction and TAW is the total available soil water of the root zone in mm per root depth.

2.4. Soil sampling and analysis

Before planting, the experimental field's composite soil samples were collected using an auger at a depth of 0-20 cm. After the composite samples had been well mixed 500 grams of subsamples were taken in a plastic bag, and brought to the Debre Birhan Agricultural Research Center soil and water laboratory for analysis.

At the Debre Birhan Agricultural Research Center Soil Laboratory, physical-chemical soil characteristics were evaluated by using the manual for soil and plant analysis laboratories (Ryan et al., 2001). The soil samples were processed by permitting passage through a 2 mm sieve, grinding with a pestle and mortar, and allowing air drying at room temperature (Changwen et al., 2007). Working samples from bulk samples were taken, and they were then examined to evaluate the physicochemical characteristics of the soil, such as its texture, organic carbon content, organic matter, pH, and so on (Table 2).

Table 3. Soil physical and chemical properties in the study area.

Parameter	Value	Parameter	Value
Sand (%)	28	OC (%)	1.8
Clay (%)	38	OM (%)	3.04
Silt (%)	34	BD (g/cm^3)	1.37
pH	7.8	FC (%)	23.4
EC (ds/m)	0.23	PWP (%)	6.95
Textural class	Clay		

OC = organic carbon, OM = organic matter, BD = bulk density, PWP = permanent wilting point, FC = field capacity and EC = electric conductivity

2.5. Physical-chemical properties of soil

The physical-chemical properties of the soils of the study area are presented in Table 3. Based on the triangle of the International Soil Science Society (ISSS) methodology, the study area soil textural class was established (Rowell, 1994). Clay is the dominant soil type in the study area. The pH and EC results, which were 7.8 and 0.23 dS/m, respectively in Table 3, showed that the soil is moderately suitable for surface irrigation to the increment of commercial crop production (Hussien et al. (2019).

2.6. Experimental design and data collection

A factorial randomized complete block design (RCBD) with three replications and 15 treatments was used to experiment (Table 4). The unit plot was 2.1m by 4 m (8.4 m^2). The SAS software was used to randomly assign treatments to each experimental plot within a replication. 30 cm, 75 cm, 1 meter, and 2 meters, respectively, separated the plant, row, plot, and repetition. The layout of the treatment is shown in Table 4. As a source of NPS and urea fertilizer, phosphorus, and nitrogen were applied to the field at the suggested rates of 240

Table 4. Treatments and applied water levels.

Treatments	Applied water level
T1	50% ETC
T2	75% ETC
T3	100% ETC
T4	125% ETC
T5	150% ETC
T6	50% ETC before a 3-day interval
T7	75% ETC before the 3-day interval
T8	100% ETC before a 3-day interval
T9	125% ETC before a 3-day interval
T10	150% ETC before a 3-day interval
T11	50% ETC after a 3-day interval
T12	75% ETC after a 3-day interval
T13	100% ETC after a 3-day interval
T14	125% ETC after a 3-day interval
T15	150% ETC after a 3-day interval

T= Treatment, ETC= evapotranspiration of the crop.
The amount of water and frequency in each growth stage during the tomato growth period is represented in table 5.

kg per hectare and 100 kg per hectare, respectively. The water application method was a surface irrigation technique that was applied through furrow and a siphon hose was used for measuring the amount of water we applied using a constant head. The flow rate was estimated using the volumetric method. This has been done by collecting water in a tank of known volume. Q = V/t where, V = volume of the container (m^3), t = time taken (hr), and Q = discharge of irrigation water (m^3 hr–1) for both experimental sites (Gore and Banning, 2017).

The crop data that were collected from the experimental location for analysis included yield characteristics (fruit yield), marketable and non-marketable yield, amount of water, and frequency (interval) during the application period.

2.7. Water productivity

Rasul and Thapa (2004) claim that the ratio between the amount of agricultural yield used for selling and the amount of water used to grow the crops can be used to calculate water productivity. It can be calculated as shown in equation 8.

$$Eu = \frac{Y}{WR} \quad (8)$$

where; Eu = water use efficiency (t/ha-mm); Y = crop yield (t/ha); WR = Water requirement of the crop (ha-mm).

2.8. Statistical analysis

Using R 4.2.2 software, an analysis of variance (ANOVA) was performed on the gathered data. The least significant difference (LSD) test was used to make a mean separation in cases when the treatment effect was significant at a 5% level of probability. Using Pearson correlation, correlation analyses of particular factors were also carried out.

3. RESULTS AND DISCUSSION

3.1. Reference evapotranspiration and crop water requirement of the experimental area

The simulated result of the metrological data for reference evaporation of the study area is summarized concerning each month and the average ETO is shown in Table 6.

The highest monthly ETO for the study area is observed in May (4.74 mm/day), while the lowest is observed in August 2.65 mm/day in Table 6. According to this finding, ETO was higher in the dry season and lower in the wet season. This finding is supported by FAO (1998a), the ETo that rises with rising temperature during the dry season. In the study area, the average ETO is 3.93 mm/day (Table 6) determine the amount of water needed and when to apply it presented in *Table 7*. Depending on the location, climate, type of soil, cultivation technique, etc., crops have various water needs, and the total amount of water needed for crop growth is not distributed evenly throughout the crop's life (Some et al., 2006).

Early in the development process, the ETc values were lower than ETo in Table 7, but as the canopy grew over time, they eventually surpassed ETo close to the end of the crop season. Early in January, when there were few leaves to contribute to evapotranspiration and most evapotranspiration was caused by soil evaporation, low ETc rates were observed. Water use by plants during the vegetative stage was the main reason for the rise in water use from February to March. Water use increased after the last day of April, with the peak demands occurring during the flowering stage or in April (mid-stage) (fruit set stage) in Table 7. Daily ET crop varied from 2.34 millimeters per day at crop establishment to 2.65 millimeters per day during early

Table 5. The amount of water and frequency in each growth stage during the tomato growth period.

Treatment	Initial		dev. 1		dev.2		Mide		Late	
	depth(mm)	interval	depth(mm)	interval	depth(mm)	interval	depth(mm)	interval	depth(mm)	interval
50% ETc	36	8	53.69	12	76.75	17	76.75	17	76.75	17
75% ETc	54	8	80.53	12	115.12	17	115.12	17	115.12	17
100% ETc	72	8	107.37	12	153.49	17	153.49	17	153.49	17
125% ETc	90	8	134.22	12	191.86	17	191.86	17	191.86	17
150% ETc	108	8	161.06	12	230.24	17	230.24	17	230.24	17
50% ETc before 3-day interval	22	5	40.27	9	63.20	14	63.20	14	63.20	14
75% ETc before 3-day interval	33.64	5	60.40	9	94.80	14	94.80	14	94.80	14
100% ETc before 3-day interval	45	5	80.53	9	126.40	14	126.40	14	126.40	14
125% ETc before 3-day interval	56	5	100.66	9	158.00	14	158.00	14	158.00	14
150% ETc before 3-day interval	67	5	120.80	9	189.60	14	189.60	14	189.60	14
50% ETc after 3-day interval	49.5	11	67.11	15	90.29	20	90.29	20	90.29	20
75% Etc after a 3-days interval	74.25	11	100.67	15	135.44	20	135.44	20	135.44	20
100% ETc after 3-day interval	99	11	134.22	15	180.58	20	180.58	20	180.58	20
125% ETc after 3-day interval	123.75	11	167.78	15	225.73	20	225.73	20	225.73	20
150% ETc after 3-day interval	148.5	11	201.33	15	270.87	20	270.87	20	270.87	20

Note: 100% ETC means Application of 100% CROPWAT model generated depth with respective interval in each stage, 100% ETc before 3-day interval means Application of 100% CROPWAT generated depth with 3 day before generated the CROPWAT model interval, and 100% ETc after 3-days interval means Application of 100% of CROPWAT generated depth with 3 days after generated CROPWAT model interval and the other treatments are the same meaning.
Dev.1=development stage one, dev.2= development stage two.

Table 6. The reference evapotranspiration (ETO) values in the study area.

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Radiation MJ/m²/day	ETo mm/day
January	12.1	25.7	60	156	18.2	3.9
February	12.8	27	60	173	21.1	4.59
March	13.6	26.7	59	173	18.5	4.4
April	13.6	27.7	69	156	19.9	4.45
May	14	27.2	62	173	21.2	4.75
June	13.8	26.1	76	104	18.1	3.73
July	11.8	21.1	88	104	15	2.82
August	12	20.8	90	104	14.9	2.77
September	12.8	22.5	83	112	16.9	3.24
October	12.6	24.6	64	190	19.8	4.23
November	11.3	25	62	190	21.1	4.3
December	11.5	25.2	60	173	18.9	3.97
Average	12.7	25	69	150	18.6	3.93

vegetative growth to 4.85 millimeters per day during late vegetative growth, with a peak of 5.1 millimeters per day during flowering. The ET crop was reduced to 4.96 mm/day in the ripening stage (late stage) (Table 7). According to FAO (1986), the flowering stage is when tomato crop growth requires more water than the other growth stage.

The total crop water requirement for tomatoes was 463 mm/dec (Table 7). The findings are supported by Ahmed et al. (2020) and Casals et al. (2021)), a tomato crop cultivated in the field for 90 to 120 days after transplanting, depending on the climate.

Table 7. Crop water and irrigation requirement for tomatoes.

Month	Decade	Stages	KcCoefff	ETcrop mm/day	ETcrop mm/dec	Ir. Req. mm/day	Ir. Req. mm/dec
Jan	2	Init	0.6	2.34	11.7	2.34	11.7
Jan	3	Init	0.6	2.48	27.3	2.48	27.3
Feb	1	In/De	0.61	2.65	26.5	2.65	26.5
Feb	2	Dev.t	0.69	3.18	31.8	3.18	31.8
Feb	3	Dev.t	0.84	3.78	30.2	3.78	30.2
Mar	1	Dev.t	0.98	4.36	43.6	4.36	43.6
Mar	2	De/Mi	1.1	4.85	48.5	4.85	48.5
Mar	3	Mid	1.15	5.08	55.8	5.08	55.8
Apr	1	Mid	1.15	5.1	51	5.1	51
Apr	2	Mi/Lt	1.11	4.96	49.6	4.96	49.6
Apr	3	Late	1.01	4.6	46	4.6	46
May	1	Late	0.87	4.1	41	4.1	41
Total					463		463

3.2. Effect of irrigation regime on Tomatoes yield components

The effect of irrigation level and frequency on the tomato growth parameters is presented in Table 8. The trend of PH, NMF, and NUMF growth yield components in the first year and second year of tomatoes was illustrated for the application of different amount levels of water depth and frequency (Table 8). The mean height of the tested tomato was in the range of 63 -95.2 cm which is in line with the observations of Zou *et al.*,(2017) and Xiao et al.,(2022) who reported that the height of tomato plants varied between the ranged from 36.80-126.7cm. In general, the higher the number of fruits the more fruit yield is happened; fruit size also determines the yield estimation (Koirala *et al.,* 2019). The mean number of fruits per plant lay between 4 and 98 (Nangare *et al.,* 2016) reported values between 10 and 1589, while in Ethiopia, Lendabo (2021) reported that the fruit number per plant was between 26 and 62. The number of fruits per plant is a character affected by genetic and environmental differences.

Based on our findings in the first year, the maximum treatment values of PH, NMF, and NUMF were, 125% ETc before the 3-day interval, 125% ETc after the 3-day interval, and 150% ETc before the 3-day interval, respectively and the minimum values were 50% ETc before the 3-day interval, 50% ETc after the 3-day interval, and 150% ETc before the 3-day interval. The yield component maximum values in the second year were 125% ETc after three days, 50% ETc, and 50% ETc, while their minimum values were 75% ETc before three days, 150% ETc before three days, and 50% ETc before three days interval. The difference is brought on by the amount of water applied and the frequency of days. The PH and NUMF are significant ($P<0.05$) influenced by water level and frequency in the first year. However, in the second year the PH, NMF, and NUMF were non-significant ($P<0.05$) influenced by water level and frequency (Table 8). The same findings were observed plant height and number of marketable fruit were affected by irrigation regime (Fawzy, 2019).

3.3. Effect of irrigation regime on tomatoes yield and water productivity

The effect of the irrigation regime on the combined two years of MYF, UNMYF, and TYF yields and water productivity for tomatoes were presented in (Table 9). The maximum values of MYF, UNMYF, and TYF were in the 125% ETc, 125% ETc before the 3-day interval, and 150% ETc, and the minimum values of the yields were in the 50% ETc, 50% ETc before 3 days interval, and 150% ETc after 3 days interval respectively. The maximum and minimum water application amount is in the 150% ETc after a 3-day interval and 50% ETc respectively due to the application difference level and the time interval (Table 9). In the research area, water level and frequency had a significant ($P <0.05$) effect on tomato marketable yield, total yield, and water use efficiency. Marketable fruit yield is the major determinant variable for selection of tomato productivity, as it directly affects commercialization and thus income generation of the farms (Koirala *et al.,* 2019). The findings reported that the irrigation regime were significant ($P<0.05$) affected on marketable fruit yield.

According to Lendabo (2021), the sunburnt, small-sized, cracked, disease-affected, and insect pest-damaged

Table 8. Effect of irrigation regime on tomatoes yield components in two years.

Treatments	First-year			Second year		
	PH cm	NMf /ha	NUMf /ha	PH cm	NMf/ha	NUMf /ha
50% ETc	63[fgh]	479369	96428.57	84.33	338892.9	47226.19
75% ETc	65[efgh]	478179	99607.14	75.87	267059.5	35714.29
100% ETc	77[ab]	537702	106345.2	80.27	194440.5	25000
125% ETc	70[cdef]	525000	142857.1	89.2	244440.5	34916.67
150% ETc	62[gh]	490083	95238.1	85.6	319047.6	36511.9
50% ETc before the 3-day interval	60[h]	448809	67464.29	85.47	233726.2	22226.19
75% ETc before the 3-day interval	64[efgh]	489678	99202.38	74.93	304369	41666.67
100% ETc before a 3-day interval	76[ab]	475797	130559.5	78.07	216666.7	26988.1
125% ETc before the 3-day interval	82[a]	494845	130321.4	84	196273.8	36904.76
150% ETc before the 3-day interval	72[bcd]	416512	74607.14	83.47	188571.4	28571.43
50% ETc after a 3-day interval	74[bcd]	399202	85714.29	85.2	278964.3	36107.14
75% Etc after a 3-day interval	70[cdef]	525000	85321.43	83.93	297619	36511.9
100% ETc after a 3-day interval	67[defg]	402143	109916.7	67.67	244845.2	39678.57
125% ETc after a 3-day interval	65[efgh]	473417	84607.14	95.2	311904.8	33726.19
150% ETc after a 3-day interval	68[defg]	473012	86904.76	76.07	263488.1	32535.71
CV (%)	5.41	10.55	17.51	16.1	30.34	28.6
Mean	69	473917	99673.01	81.95	260021.2	34285.71
LSD (0.05)	2.79	NS	10.96	NS	NS	NS

Note: PH= plant height in cm, NMf= number of marketable fruit NUMF= number of unmarketable fruit.

Figure 3. The experiment performance of the irrigated tomatoes at development stage.

fruits are considered as unmarketable. Unmarketable fruit yield did not differ substantially at the 5% level of significance and was not affected by the irrigation regime. The result agreed with the study the difference in irrigation regime had significant ($P<0.05$) effect on the total fruit yield of tomatoes (Djurović et al., 2016). The highest and lowest yields were yield 54.49 t/ha and 37.89 t/ha respectively. The results are generally in agreement with Fawzy (2019) and Zou *et al.,* (2017) who reported that total fruit yield of tomato ranging from 6.46-82.50 t ha-1 in their study. The optimum yield with high water use efficiency was 48.5 t/ha of irrigation water at a depth of 376.71 mm and saving 3127.33 m^3 of water to irrigate an additional 0.59 ha to achieve a yield of 29.00 t/ha for

Figure 4. The irrigated tomato yield performance of the field experiment during harvesting.

the user without a high yield penalty (Table 9). The present finding clearly indicated that the irrigation regime were to determine the quantity of the Tomato production (Lovelli et al., 2017). This study lined with a decent commercial production of tomatoes under irrigation is 45–65 t/ha of fresh fruits, and the water efficiency for fresh tomato harvest is 10–12 kg/m3, according to FAO (1986). The research supported earlier findings that the fresh tomato output ranged from 45 to 65 t/ha (El-Naggar, 2020).

3.4. Water saved, additional area irrigated and possible yield to be obtained

The yield and land opportunity obtained from saving water in the application of water through time intervals is illustrated in Figure 5. The land and water levels in Treatment 15 (150% ETc after a 3-day interval) were the lowest. However, treatment seven (75% ETc before the 3-day interval) was a better land opportunity, saving 3127.33 m^3 of water and 0.59 ha of additional irrigation land to achieve a yield of 29.00 t/ha for the user without a high yield penalty. This is because of the statistical relationship between yield and land opportunity (land developed by saving water).

3.5. Tomato yield- water use function

The tomato yields rose with applied water depth up to a maximum value of 54.49 t/ha before falling with more water (Table 9). The findings of this study sup-

Table 9. Effect of irrigation regime on tomato yield and water productivity.

Treatment	MYF t/ha	UNMYF t/ha	TYF t/ha	WP kg/m^3	TW m^3/ha
50% ETc	31.11^{f}	6.78	37.89^{e}	9.42^{bc}	3931.81
75% ETc	39.39^{bcde}	5.79	45.19^{bcde}	8.46^{cd}	5244.2
100% ETc	43.00^{abcd}	6.04	49.04^{abcd}	7.39^{de}	6546.25
125% ETc	47.62^{a}	6.88	54.49^{a}	7.24^{de}	7559.27
150% ETc	44.84^{ab}	6.69	51.53^{ab}	5.87^{e}	9227.11
50% ETc before the 3-day interval	33.56^{f}	4.97	38.52^{e}	11.28^{a}	3389.96
75% ETc before the 3-day interval	41.66^{abcde}	7.29	48.95^{abcd}	10.79^{ab}	4431.94
100% ETc before a 3-day interval	38.65^{bcdef}	7.01	45.66^{bcde}	8.10^{cd}	5465.34
125% ETc before the 3-day interval	39.00^{bcdef}	7.04	46.05^{abcde}	6.97^{de}	6505.11
150% ETc before the 3-day interval	37.38^{bcdfe}	6.18	43.56^{de}	5.99^{e}	7460.39
50% ETc after a 3-day interval	35.98^{cdf}	6.26	42.25^{de}	9.27^{bc}	4473.65
75%ETc after a 3-day interval	42.78^{abcd}	6.50	49.29^{abcd}	8.52^{cd}	5641.17
100 ETc% after a 3-day interval	39.36^{bcde}	7.06	46.42^{abcde}	6.31^{e}	7624.39
125% ETc after a 3-day interval	43.57^{abc}	6.56	50.13^{abc}	5.73^{e}	9254.32
150% ETc after a 3-day interval	35.20^{def}	6.06	41.26^{cde}	3.72^{f}	10970.1
CV (%)	15.37	26.58	14.14	17.79	
mean	39.44	6.43	45.87	7.68	
LSD (0.05)	2564.1	NS	2743	0.58	

MYF=marketable fruit yield, UNMYF= unmarketable fruit yield, TYF= total fruit yield, WP=water productivity, TW= total water amount.

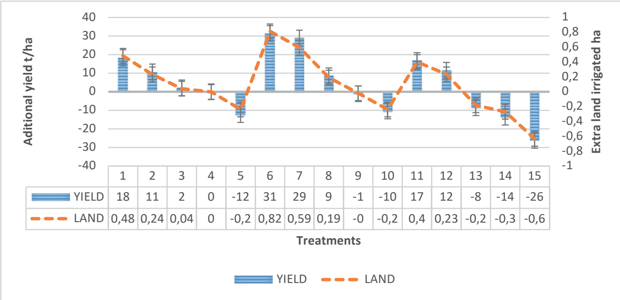

Figure 5. Additional area to be irrigated with the saved water and possible yield.

port those of Samui et al. (2020), who claimed that good water management directly contributes to the high quality and productivity of vegetable crops. It has been found that as water depth increases, water use efficiency also decreases.

3.6. Correlation functions of the growth and yield parameters

The correlation functions of the growth and yield components of tomatoes are presented in *Table 10*. The yield of all fruits and the number of marketable fruits are strongly positively correlated, whereas the yield of all fruits and the volume of water are medium correlated (Table 10).

4. CONCLUSIONS AND RECOMMENDATIONS

In the lowlands of Ethiopia, where water is not available for surface irrigation and farmers are not aware of irrigation management the adoption of the right amount of water and frequency is an important issue. The net irrigation requirement and gross irrigation requirement of garlic were found as 463 mm and 658 mm respectively. Up to a certain point in the experimental region increasing the depth of water applied enhanced tomato crop yield. The soil in the research area has a clay texture. The findings indicate that a 48.95 t/ha tomato yield output required a total water depth of 4431.94 m^3/ha over the tomato crop growth period in the research location, which allowed for the addition of more irrigation land without suffering a severe yield penalty. At each stage, water was used as follows: Initial measurement was 33.64 mm with a 5-day interval, Development One was 60.54 mm with a 9-day interval, Development Two was 94.18 mm with a 14-day interval, mid-stage was 94.18 mm with a 14-day interval, and late stage was 94.18 mm with a 5-day interval with net irrigation depth 376.72mm and saving 3127.33 m^3 water to irrigate an additional 0.59 ha to achieve a yield of 29.00 t/ha for the user without a high yield penalty. It is recommended that various tomato varieties and irrigation techniques be used in this study.

AUTHOR CONTRIBUTION STATEMENT

Belihu Nigatu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; wrote the paper.

Demisew Getu, Tsegaye Getachew, and Biruk Getaneh: Conceived and designed the experiments; performed the experiment.

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Table 10. Correlation function of the parameters.

	NMY	NUMY	M Y (Kg)/ha	UNMY (Kg)/ha	TY (Kg)/ha	Water amount m^3/ha
NMY	1					
NUMY	0.809	1				
M Y (Kg)/ha	0.835	0.798	1			
UNMY (Kg)/ha	0.772	0.894	0.729	1		
TY (Kg)/ha	0.862	0.859	0.988	0.826	1	
water amount m^3/ha	0.489	0.509	0.562	0.511	0.578	1

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