9. Determination of Irrigation Water Requirements and Frequency for Tomato in Efratanagidm District, North Shewa

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Abstract

Information on crop water requirements and the frequency of crops is vital for irrigation water planning. Irrigation scheduling is planning when and how much water to apply to maintain healthy plant growth during the growing season. It is an essential daily management practice for farmers growing irrigated crops. However, irrigation practice in terms of the amount of water to be used and frequency of application has lacked proper knowledge. The purpose of this study is therefore to deliver preliminary information on the seasonal water requirement of tomatoes based on the widely used FAO cropwat model. The experiment was conducted at the north Shewa Amhara region Efratanagidim District yimilo irrigation site. The experiment was conducted in a randomly completed block design with three replication and 15 treatments. The type of soil in the experimental site is clay textural class soil. The highest yield was 54.49 tha^{-1}while the lowest was 37.89 tha^{-1}. Statically 48.5 tha^{-1} yield in the amount of irrigation water 376.71 mm depth with the water use efficiency 10.79 Kgm^{-3} and safe 3127.33m^{-3} water from one hectare and get 0.59 ha additional irrigation land. The application of water in each stage was initial 33.64 mm with 5 days interval, development-one 60.54 mm with 9 days interval, development-two 94.18 mm with 14 days interval, mid 94.18 mm with 14 days interval and late 94.18 mm with 14 days interval water application used. Therefore, the total depth of the water during the growth period of tomato at Ataye and the same agroecology was to get 48.95 tha^{-1} tomato yield gave an additional irrigation land without high yield penalty.

Keywords: Efratanagidiem district, tomato, water amount, water use efficiency

Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably leads to an increase in food demand. Food security is a major concern in many parts of the world including East Africa, Rift valley of Ethiopia where rainfall is unpredictable and unreliable (Tesfaye, 2008). To maintain self-sufficiency in the food supply, one viable option is to raise the unit yield. A favorable method for raising yield per unit area is through irrigation.

Reported showed that the crop water requirement of crops correlated with the temperature and irrigation water demand (Kijne, 2010; Surendran *et al*., 2014). Developments in irrigation are often instrumental in achieving high rates of agricultural goals but proper water management must be given due weightage to effectively manage water resources. The proper management of existing irrigated areas is important for fulfilling food security to the increasing population (Hari *et al*., 1996).

Irrigation water management is a crucial component of any irrigation project. Wise use of water resources is becoming an important element in agriculture as the demand for the resource is dramatically increasing because of population pressure and hence feeding the world is a priority issue. Knowledge of crop water requirements is therefore quite helpful for planning a sound irrigation scheduling where water can be used efficiently and effectively.

Operational applications of ET estimate yet heavily rely on the FAO-56 model because of the minimum requirement of phonological and standard meteorological inputs (Evett *et al*., 1995; Eitzinger *et al*., 2002). In the FAO-56 approach, actual ET is calculated by combining reference evapotranspiration (ETo) and Kc. The Food and Agriculture of the United Nations has been extensively working on models that are capable of estimating crop water requirements and exercising irrigation scheduling of crops for any irrigation project for the last thirty years. The models have been widely used in the research, academia, and developments sectors.

Understanding crop water needs is essential for irrigation scheduling and water-efficient use in an arid region (Parry *et al*., 2005). Further, with increasing scarcity and growing competition for water, judicious use of water in the agricultural sector will be necessary (Ali*Figure* , 2010). Predicting water needs for irrigation is necessary for the development of an adequate water supply and the proper size of equipment. In our study area, consistent information on irrigation water use is still lacking. CROPWA is an FAO model for irrigation management designed by Smith (1991) which integrates data on climate, crop, and soil to assess reference evapotranspiration (ETo), crop evapotranspiration (ETc), and irrigation water requirements

The CROPWAT model a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well-established methodologies for the determination of crop evapotranspiration (FAO, 1998) and yield responses to water (Doorenbos and Kassam, 1979).

In Ethiopia, the major portion of irrigation water management is traditional where farmers are irrigating as long as the water is available, without considering whether it is above or below the optimum of the crop water requirement. For large dams, the information of crop water requirement of the proposed crops is usually used for design purposes and it is not exercised on the real duty of irrigation operation, however. Moreover, in areas where farmers are cultivating on small scale, the same information is critically limiting and more water is believed to be wasted (Roth G., 2014).

Irrigation scheduling is planning when and how much water to apply to maintain healthy plant growth during the growing season. It is an essential daily management practice for a farm manager growing irrigated crops. Proper timing of irrigation water applications is a crucial decision for a farm manager to 1) meet the water needs of the crop to prevent yield loss due to water stress; 2) maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources, and 3) minimize the leaching potential of nitrates and certain pesticides that may impact the quality of the groundwater.

Irrigation criteria, in terms of frequency of irrigation and amount of application per irrigation, seasonal net irrigation requirement, and gross irrigation requirement for most of the lowland crops that are grown in the Middle Awash region of Ethiopia have been quantified by Melka Werer Research Centre. However, there was little effort undertaken in the many parts of Ethiopia especially in the Amhara region. Crop water use studies that were conducted in some other areas are not adopted because it was highly location-specific.

In North Shewa as such, there is no attempt to determine crop water requirements of irrigated crops except a study conducted at Shewarobit for onion and pepper and at Bakelo for wheat and potato to estimate crop water requirements. The aim of this research was therefore to estimate the net irrigation requirement of tomatoes (Lycopersicon*esculentum) and* estimate the irrigation frequency for tomatoes using the CROPWAT computer model in Ataye.

Materials and Methods

Description of the Study Area: The experiment was conducted at the Amhara region north Shewa Efratanagidim District yimilo irrigation site (Fig. 1). The site is located 154 km from Debreberehan town and 9 km from Ataye town. The geographic location of the experimental site is 39^0 54' 27'' E and 10°17' 28''N with an altitude of 1514 m.a.s.l. The area has two major seasons; the rainy and dry seasons. The rainy season lasts from the beginning of June to the end of September with a mean annual rainfall of 822 mm, while the dry season lasts mainly from October to the end of May. The hottest months, February, April, and May with a mean monthly maximum temperature of 27.7°C, while the coldest months are November and December with a mean minimum temperature of 11.5°C.

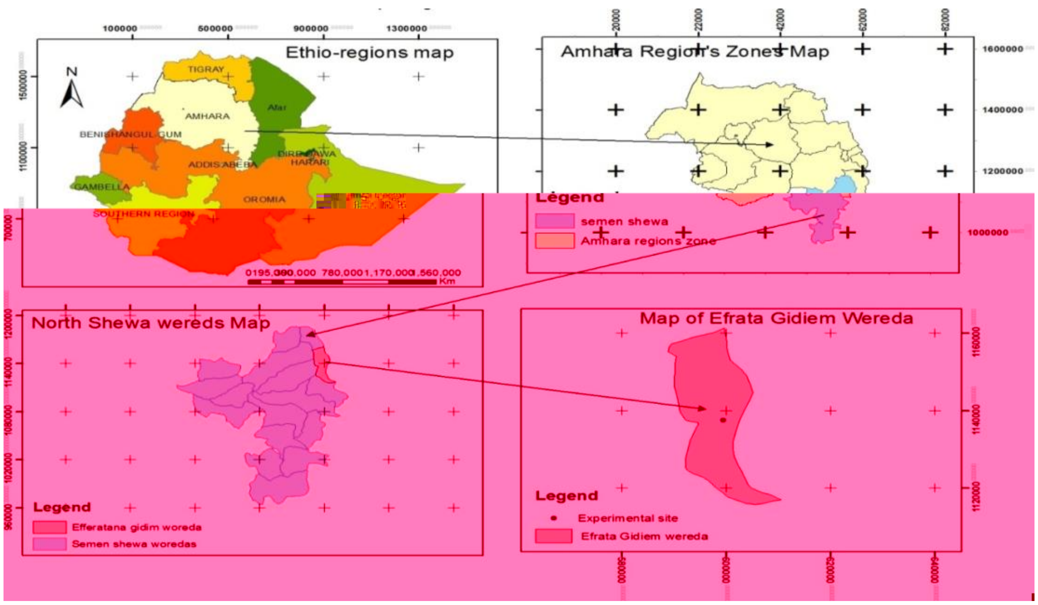

Figure 1. Location map of the experimental area

Field Layout and Experimental Design: The experiment was conducted in a randomized complete block design with three replication and 15 treatments set up. The unit plot size was $8.4m^2$. Treatments were assigned to each experimental plot by using SAS Software to randomize within a replication. The space between plant, row, plot, and replication was 30cm, 75cm, 1m, and 2m respectively. The treatment set up shows in (Table 1).

Table 1. 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 3-day interval
T7	75% ETC before 3-day interval
T8	100% ETC before 3-day interval
T9	125% ETC before 3-day interval
T10	150% ETC before 3-day interval
T11	50% ETC after 3-day interval
T12	75% ETC after 3-day interval
T13	100% ETC after 3-day interval
T14	125% ETC after 3-day interval
T15	150% ETC after 3-day interval

The Reference evapor-transpiration value (ETo) for the site was calculated from the long-term meteorological variables (Monthly Minimum and Maximum temperature, wind speed, sunshine hours, and relative humidity) using the crop was version 8.0, based on the Penman-Moeinth formula. The Kc values have been adopted from the FAO cropwat computer model. FAO's (2009) cropwat computer model has finally been employed to obtain the crop water requirements of the crop and exercising irrigation scheduling for the site.

Experimental Field Management: Before planting the experimental field was first prepared by oxen power tiller according to farmers' conventional plowing practice (plowing was done twice before sowing the test tomato crop traditional plow called *Maresha*, drawn by a pair of oxen). Stubbles, weeds, etc. were removed from the field. The experimental field was divided into three main blocks (Replicates) and each block was divided into fifteen plots that received different treatment combinations. All agronomic practices were applied equally for each treatment according to the recommendation of the area (starting from sowing to harvesting recommended package of practices were followed). Disease, insect pests, weeding management, and fertilizer application were carried out as required.

Soil Sampling and Analysis: The composite soil samples were taken from the experimental field at 0-20cm depth using an auger before sowing. The soil samples were prepared with air-drying at room temperature, ground using a pestle and a mortar, and allow passing through a 2mm sieve. Working samples were obtained from bulk sample and was analyzed to determine the soil Physico-chemical properties like soil texture, organic carbon, organic matter, and soil pH, and electrical conductivity (EC) and bulk density (Table).

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

Table 2. Method to determine chemical and physical properties of soil	Properties of the soil		method
	Chemical	Physical	
pH	✓		P^H –meter or electrometer
EC	✓		EC-meter or electrometer
OC	✓		Walkley and black,1934
OM	✓		1.724*OC, Broadbent, 1953
Soil texture		✓	Hydrometer, Bouyoucous, 1962
Bulk density		✓	Volumetric meter

Field Operations and Yield Harvesting: The tomato (Woino variety) was raised on a plot of land adjacent to the experiment plot for thirty days under the recommendation of Anonymous, (1976) before being transplanted. The recommendation rate of Phosphorus and Nitrogen as a source of NPS and Urea fertilizer was applied at the rate of 240 $Kgha^{-1}$ and $100Kgha^{-1}$ respectively to the field.

Tomatoes harvested were estimated into marketable and non-marketable yields. Marketable yields were those crops harvested and transported to the market with the market prevailing price. Non-marketable yields were those crops obtained from the experimental site as damaged tomatoes and/or those that could not be sold.

Water-use Efficiency: According to Rasul, & Thapa, (2004) water use efficiency can be determined as the ratio of the amount of marketing yield crop yield to the amount of water required for growing the crops. It can be calculated as; $Eu = \frac{Y}{WR}$

Where; Eu = field water use efficiency (t/ha-mm)

Y = crop yield (t/ha)

WR = Water requirement of the crop (ha-mm)

Data Collected: The meteorological data were collected from the kombolcha branch meteorology agency. The crop data taken from the experimental site for analysis were growth parameters (plant height, fruit diameter, and the number of fruit), yield parameters (fruit yield) both marketable and unmarketable yield, and amount of water and frequency (interval) during the application period.

Data analysis: The collected data were subjected to analysis of variance (ANOVA) using SAS 9.0. Where ever the treatment effect was significant, mean separation was made using the least significance difference (LSD) test at a 5% level of probability. Correlation analyses of selected parameters were also performed using Pearson correlation.

Results and Discussion

Physico-chemical Properties of Soil before Planting: Some of the physio-chemical properties of soils of the study sites before planting are summarized in (*Table*). Accordingly, the location of soils belongs to the clay textural class based on the soil textural class determination triangle of the International Soil Science Society (ISSS) system (Rowell, 1994).

Table 3 Soil physical and chemical properties at Ataye

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/mm)	0.23	PWP (%)	6.95

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

Reference Evapotranspiration of the Experimental Site: The simulated result of the metrological data for reference evaporation of the study site is summarized concerning each month and the average ETO shows in (Table 4).

Table 4. Reference evapotranspiration (ETO) values at Ataye

Month	Min Temp	Max Temp	Humidity	Wind	Radiation	ETo
	°C	°C	%	km/day	MJ/m²/day	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

However, using 10 years' metrological data the reference evaporation generates by the CROPWAT model. As mentioned in Table 4, the highest monthly ETO for the site was observed in May (4.74 mm/day), while the lowest was observed in August 2.65 mm/day. This result indicated that ETO was higher during the dry season and lower in the rainy season. The study in line with FAO (1998) reported that the only factor affecting ETO is climate parameters which are the ETO increase with increasing of temperature in the dry season. The probable irrigation season for Ataye may start as early as November where the evapotranspiration rates are relatively low until the crops will have full maturity and hence planting during those periods will have two advantages; using the soil moisture reserve that could have been stored from that recedes in late September or early October. Secondly, planting crops at times of low evapotranspiration is implicated that the demand for the crops for water is also low. Therefore, irrigation water saving is more practical for early planning. To determine the amount of water needed and when to apply it, calculate the ETc (crop water use) between irrigations with the following equation, where Kc is the crop coefficient and ETo is the reference crop vapotranspiration: ETc = Kc * ETo**.** Doorenbos and Pruitt (1977) divided the kc curve into four stages: initial, crop development, mid and late-season stages. The Initial growth stage occurs from sowing to about 10% ground cover, the crop development stage from about 10% to70% ground cover. The Mid-season stage includes flowering and yield formation, while the Late-season includes ripening and harvesting.

Crops have different water requirements depending upon the place, climate, soil type, cultivation method, etc., and the total water required for crop growth is not equally distributed over its whole life span (Some, *et al*., 2006). The trend of average crop evapotranspiration (ETc) and reference evapotranspiration (ETo) for tomatoes was illustrated for the whole growing season in Figure . The ETc values were less than ETo in the early developmental stages, but the ETc increased with time due to canopy growth until it exceeded ETo near the end of the crop season. Low ETc rate occurred during the first Days or the month of Jan when only a few leaves contributed to the evapotranspiration and most ETc was evaporation from the soil. Water consumption increased from Feb to Mar, mainly due to water use by the plants during the vegetative stage. Maximum water requirements occurred during the flowering stage or the month of April (mid-stage) and water use decreased from the last day of April (fruit set stage). Daily ET crop varied from <2.41 mm/day at crop establishment to 2.92 mm/day at early vegetative growth and 4.33 mm/day at late vegetative growth and achieved a peak of 5.05 mm/day at flowering. ET crop then declined to a value of 4.35 mm/day during the ripening stage (late-stage). The performance of the various depth of water applied was based on tomato yield. These result agreements with FAO (1986) reported that the maximum water demand for tomato crop growth is the flowering stage.

Table 5. Crop water requirement for tomato

Month	Decade	Stage	Kc coeff	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
Totals					463	463	

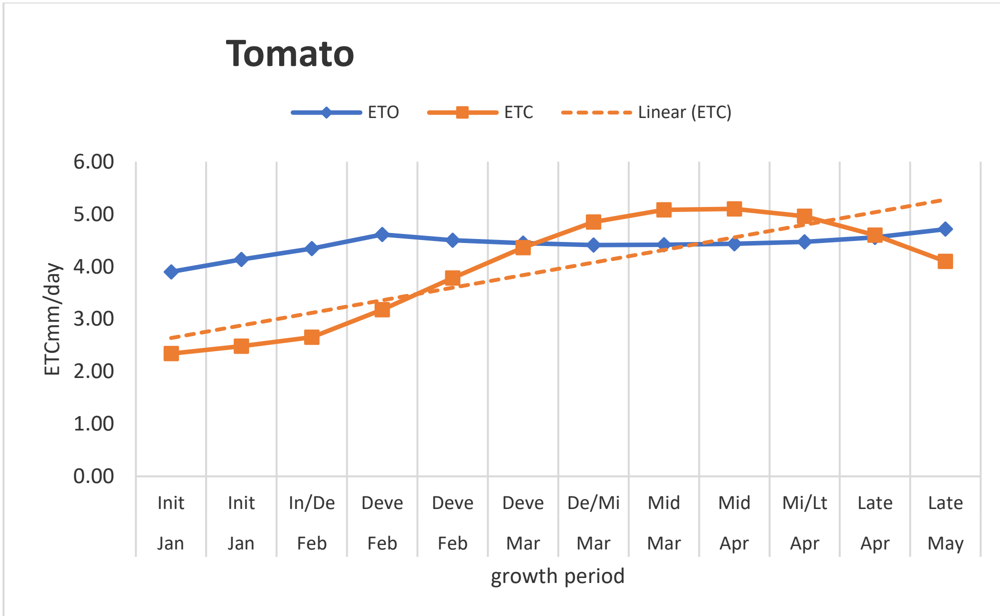

Figure 2. Temporal Crop evapotranspiration (ETc) and Reference crop Evapotranspiration (ETo) of Tomato

The total tomato crop water requirement was 463 mm/dec (Table). The resulting agreement with (Ahmed *et al*., (2020): Brouwer & Heibloem (1986)) reported that the total water requirement after transplanting of tomato crop grown in the field for 90 to 120 days is 400 to 600 depending on the climate.

Tomato Yield and Yield Parameter: The trend of PH, NMF, and NUMF growth yield parameters in the first year and second year for tomatoes was illustrated for the application of different amount levels of water depth (Table 6). In the first year, the maximum values of PH, NMF, and NUMF in the treatment of 125% ETc before the 3-day interval, 125% ETc, and 100% ETc before the 3-day interval, and the minimum values parameters 50% ETc before the 3-day interval, 50% ETc after the 3-day interval and 150% ETc before 3-day interval respectively.

Table 6. The response of plant height, number of marketable fruits, non-marketable fruit, on the application of the different amounts of water in two years

	First-year			second year
Treatment	Ph cm	NMf /ha	NU6(ha)] TJ	

10%fETU16(c be)88(f)-3ortd3m

The maximum values of MYF, UNMYF, and TYF were in the 125% ETc, 125% ETc before the 3-day interval, and 125% Etc. And the minimum values of the yield parameters were in the 50% ETc, 50% ETc before 3 days interval, and 50% ETc respectively. The maximum and minimum water application amount in the treatment of 150% ETc after the 3-day interval and 50% ETc respectively due to the application difference level and the time interval. Table 8, statically show that the analysis of variance tomato crop yields distribution for treatments, which indicated that there was a significant difference among the marketable yield, total yield, and water productivity of crop at 5 % level of significance and there was no significant difference among the total number of fruits, unmarketable fruit yield at 1 % level of significance. The highest yield was 54.49 tha^{-1} while the lowest was 37.89 tha^{-1}. Statically 48.5 t/ha yield in the amount of irrigation water 376.71 mm depth with the water use efficiency 10.79 Kgm^{-3} and safe 3127.33m^{-3} water from one hectare and get 0.59 ha additional irrigation land. The study coincides with FAO (1986) reported that a good commercial yield of tomato under irrigation is 45-65 tha^{-1} fresh fruits and the water utilization efficiency for harvested yield for fresh tomato is 10-12 Kgm^{-3}. The study coincided with the previous findings reported that the fresh yield of tomato in the range of 45-65 t/ha (Nuruddin, (2001): El-Naggar, A. (2020)).

Table 7. The response of marketable fruit yield, unmarketable fruit yield and total fruit yield on the Application of different amount of water

Treatment	MYF tha^{-1}	UNMYF tha^{-1}	TYF tha^{-1}	WUE Kgm^{-3}	TW m^3ha^{-1}
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 3-day interval	33.56^{f}	4.97	38.52^{e}	11.28^{a}	3389.96
75% ETc before 3-day interval	41.66^{abcde}	7.29	48.95^{abcd}	10.79^{ab}	4431.94
100% ETc before 3-day interval	38.65^{bcdef}	7.01	45.66^{bcde}	8.10^{cd}	5465.34
125% ETc before 3-day interval	39.00^{bcdef}	7.04	46.05^{abcde}	6.97^{de}	6505.11
150% ETc before 3-day interval	37.38^{bcdfe}	6.18	43.56^{de}	5.99^{e}	7460.39
50% ETc after 3-day interval	35.98^{cdf}	6.26	42.25^{de}	9.27^{bc}	4473.65
75%ETc after 3-day interval	42.78^{abcd}	6.50	49.29^{abcd}	8.52^{cd}	5641.17
100 ETc% after 3-day interval	39.36^{bcde}	7.06	46.42^{abcde}	6.31^{e}	7624.39
125% ETc after 3-day interval	43.57^{abc}	6.56	50.13^{abc}	5.73^{e}	9254.32
150% ETc after 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	
LSD (0.05)	2564.1	NS	2743	0.58	

The yield and land opportunity which got from saving water in the application of water through time interval illustrated in Figure . The highest land and yield got from treatment six which saving 4169.31 $m^3$of water and 0.81 ha of additional irrigation land to get the 31.4 tha^{-1} yield of tomato. The lowest land and water were in the treatment fifteen. But statistically the relationship between yield and land opportunity (land which develops by saving water) shows that treatment seven (75% ETc before the 3-day interval) was a better land opportunity which safe 3127.33m^3 of water amount and 0.59 ha additional irrigation land to get 29.00 tha^{-1} yield for the user without high yield penalty.

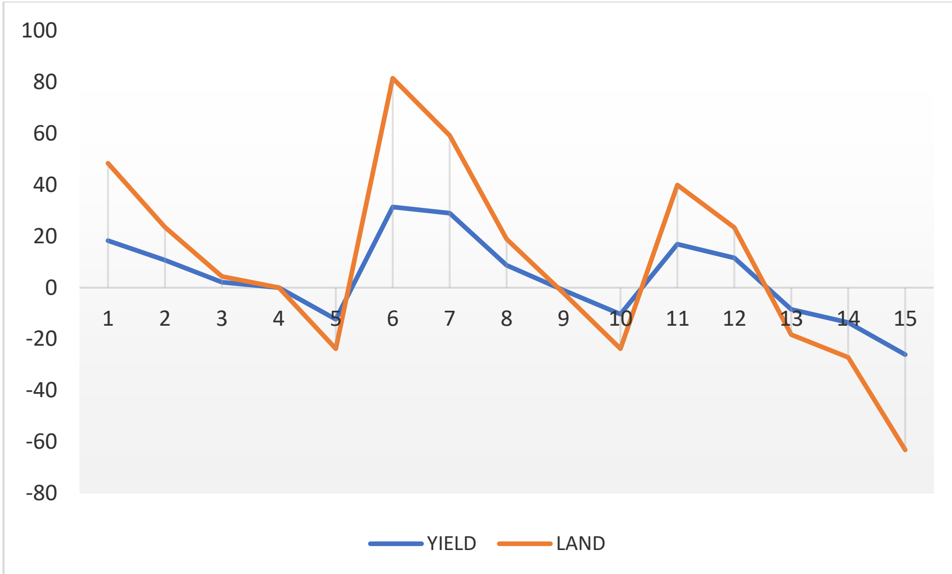

Figure 3 the yield and land opportunity

Tomato Yield- Water Use Function: Table 8 reveals that tomato yields increased with the depth of water applied up to an optimum value of 54.49 t/ha and thereafter decreased with more water. The result of this study corroborates that of Muchovej *et al.* (2008) who reported that the high quality and yield of vegetable crops are directly associated with proper water management. It is observed that the water use efficiency decreases with an increase in water depth.

Correlation Functions of the Growth and Yield Parameters: The relation function of the growth and yield parameters illustrated in Table 9. The highly positively correlated between all growth and yield parameters which indicated that the relation is above 0.70 correlation value. The water amount and the correlation of the parameters were less than 0.7 and less positively correlated.

Table 8. Correlation

	NMY*	NUMY	MY Kgha^{-1}	UNMY Kgha^{-1}	TY Kgha^{-1}	water amount m3ha^{-1}
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 amountm3/h	0.489	0.509	0.562	0.511	0.578	1

**Number of marketable yields, number of unmarketable yields, marketable yield, unmarketable yield, total yield, water amount*

Conclusions and Recommendation

The crop yield increase with an increase in depth of water applied up to an optimum value beyond which it tends to reduce crop yield in the experimental area which is predominantly clay loam in texture. Statistically, the total depth of the water during the growth period of tomato at Ataye and the same agroecology was 4431.94m^3ha^{-1} to get 48.95tha^{-1} tomato yield gave an additional irrigation land without high yield penalty. The application of water in each stage was initial 33.64 mm with 5 days interval, development-one 60.54 mm with 9 days interval, development-two 94.18 mm with 14 days interval, mid 94.18 mm with 14 days interval and late 94.18 mm with 14 days interval water application used. This research result could be verified for confirmation and it works should be carried out using different tomato variety and irrigation method.

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