**Evaluation of alternate, fixed and conventional furrow irrigation systems on tomato** (*Solanum lycopersicum L.*)**yield and water use efficiency in Wolita area, Southern Ethiopia**

# ABSTRACT

This research addresses the growing challenge of water scarcity in arid and semi-arid regions, where efficient water use is essential for sustainable agricultural production. With limited water resources available for irrigation, optimizing water use efficiency (WUE) is critical to ensuring adequate crop yields, especially for high-value crops like tomato. To cope with scarce water supplies, applying irrigation water below full crop-water requirements is an important tool to achieve the goal of reducing irrigation water use and increase water use efficiency (WUE). By evaluating three different furrow irrigation systems Alternate Furrow Irrigation (AFI), Fixed Furrow Irrigation (FFI), and Conventional Furrow Irrigation (CFI) the study aims to identify the most effective irrigation method for maximizing tomato yield and water use efficiency. The findings of this research are significant for improving irrigation practices and supporting water conservation in regions facing water scarcity. The objective of this research was to evaluate the three furrow irrigation systems on fresh tomato yield and water use efficiency and identify the furrow irrigation method which allows achieving optimum tomato yield. The experiment was arranged in randomized complete block design with three treatments and six replications. The irrigation treatments were Alternate Furrow Irrigation (AFI), Fixed Furrow Irrigation (FFI) and Conventional Furrow Irrigation (CFI) method. The analysis of variance indicated highly significant differences in yield and water use efficiency (P < 0.05). The result showed that conventional furrow irrigation method gave maximum fruit yield (32 ton/ha) and alternative furrow irrigation method showed highest water use efficiency (8.82 kg/m3), and has high marginal return rate. Therefore, to maximize tomato yield in areas with adequate water supply, it is recommended to apply water through a conventional furrow irrigation system during the growing season. In areas with limited water resources, alternative furrow irrigation systems are found to be the most cost-effective and efficient way to use water.

KEY WORDS: Agricultural water management, crop water requirement, evapotranspiration, furrow irrigation method.

1. **Introduction**

In Ethiopia, tomato is one of the most widely cultivated vegetables with an annual production volume of about 41,948 tons (FAOSTAT, 2020).The importance of tomato is increasing since it is a high value commodity, and has been given top priority in vegetable research in Ethiopia. Small-scale farmers and commercial growers could grow the crop for its fruits in different regions of the country. It is produced both during the rainy and dry seasons under supplemental irrigation (Lemma, 2002). While, on a global scale, water resources are still ample, serious water shortages are developing in the arid and semiarid regions as existing water resources reach full exploitation. The great challenge for the coming decades will, therefore, be the task of increasing food production with less water, particularly in countries with limited water, land resources and inefficient water use (FAO, 2002).As water scarcity intensifies in many regions of the world, better management of water is becoming an issue of paramount importance (Lorite*et al*, 2007) because; it is the most severe constraint for agriculture production particularly in arid and semiarid areas of the world.

Agriculture is the main pillar of the Ethiopian economy, contributing to 42% of the national gross domestic product (GDP), 70% of export earnings and 80% of employment. The bulk of production in the agriculture sector (90%) comes from smallholder farmers. The country has huge potential for agricultural development, but the sector has issues of poor production and productivity. Rainfall variability, land and soil degradation, and poor agricultural water management along with traditional farming systems contribute to these issues (Langan *et al*., 2015).

Alternate furrow irrigation (AFI) is the technique of partial root-zone drying. This system saves irrigation water and is very useful and crucial in areas of water scarcity. Alternate furrow irrigation of cotton plantings was studied and water savings was 25% with yield losses of 20% compared to conventional furrow irrigation (Einsenhaver and Youth, 1992).Soil evaporation of AFI is lower than that of CFI for the same treatment. The difference in soil evaporation between AFI and CFI would become smaller and smaller with the increase of the lower limit value of soil moisture (Majumdar, 2002).

It is possible to make efficient use of water and bring more area under irrigation using the available water resources. This can be achieved by introducing advanced methods of irrigation and improved water management practice (Zaman *et al*., 2001). Many studies have been carried out worldwide regarding the effects of deficit irrigation on yield of mainly horticultural crops (Fabeiro *et al*., 2003; Olalla *et al*., 2004; Sezen *et al*., 2008). The yield reduction resulted by deficit irrigation will be insignificant compared with the benefits gained through diverting the saved water to irrigate additional cropped area (Kirda, 2002; Gijón*et al*., 2007).

Similar studies on onion by Samson and Tilahun (2007) that deficit irrigation throughout the growing season as 50% and 75 % of ETc reduced yields from full irrigation and resulted in the highest water saving and crop water use efficiency.

Most of the research results indicate that AFI has the potential to save water and labor and ensure high water use efficiency, although they recommended conducting similar experiments for other vegetable crops(Deribew, 2006; Woldesenbet, 2005; Mitslal, 2008). A serious of water shortage, poor water management, application of the right amount of water at the right time, and unwise use of irrigation water causes low crop water productivity and high production cost. This research is crucial in addressing the increasing challenges of water scarcity and the need for more sustainable agricultural practices in arid and semi-arid regions. By evaluating and comparing different furrow irrigation systems for tomato production, the study aims to identify optimal methods that improve water use efficiency and yield, ultimately contributing to more water-efficient and cost-effective farming. With the growing pressure on water resources globally, this research holds significant potential to help farmers maximize crop production while conserving valuable water resources, thus promoting long-term agricultural sustainability. The study aimed to identify furrow irrigation systems will result in higher water use efficiency and improved tomato yield compared to conventional furrow irrigation systems, due to better water distribution and reduced water loss.

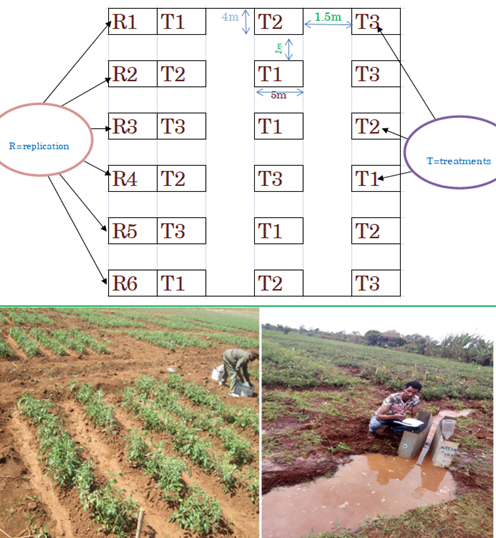
## Materials and Methods

## Description of the Study Area

The study was conducted from 2018 to 2020 for two years at Humbo woreda, woliyta zone of southern nation nationality and peoples of Ethiopia, which is located 327 km south of Addis Abeba. The experimental station is located at approximately 37°48′ E longitude and 06°44′ N latitude with an altitude of 1611 m.a.s.l. The experimental field was irrigated using the furrow irrigation system with water sourced from Ella River. The study area experiences two main cropping seasons due to its bimodal rainfall system. The first cropping season, called Belg, extends from March to June, whereas the second season, called Meher, extends from the last week of August to November. According to national meteorological data, the mean annual rainfall in the area is 1001 mm; mean maximum temperature varies from 23.1˚c to 29.81˚c while the mean minimum temperature varies from 14˚c to 15.3˚c. The main grown crop in the woreda were tomato (*Solanum lycopersicum L.*), onion (*Allium cepa L.*), pepper (*piper nigrum*), pigeon pea (*cajanuscajan*), ginger (*Zingiberofficinale*), maize (*Zea mays*), haricot-bean, sorghum, teff, sesame and cabbage, are also among the widely cultivated crops in the area (Alemayehu *et al*., 2016).

* 1. **Experimental treatment and design**

The experiment hadthree treatments with six replications and arranged in randomized complete block design. The treatments were alternate furrow irrigation (AFI), fixed furrow (FFI) and conventional furrow irrigation (CFI). Where, the CFI with 100 % ETc = all furrow get full water requirement, FFI with 100 % ETc = fixed open furrow get full water requirement and AFI with 100% ETc = alternate open furrow get full water requirement. Each treatment had six replications making a total of 18 experimental plots. Each plot had 20 m2 (5.0 m x 4.0 m), space between plots and replications were 1 m and 1.5 m respectively; within each plot there are six furrows with five ridges, and single row tomato with spacing of 30cm between plants and 90cm between rows was used.



b

a

Figure 1: Experimental layout plan (a) and water application and measurement (b).

2.4 Crop establishment and management practices

Tomato (Lycopersiconlycopersci) seeds Roma VF variety was selected based on farmer interest and market acceptability. Roma VF is a versatile and resilient tomato variety, especially favored in commercial farming for its processing capabilities, resistance to common tomato diseases, and high yield potential. It’s a popular choice for both fresh markets and processing industries like canned tomatoes, sauces, and pastes. The selected variety was sawn on 1m width and 10 m length seed bed. At the morning and night at two days interval irrigation water was applied to the nursery seed using bucket. Transplanting is usually done to the field 5 to 6 weeks after sowing. A week before transplanting reduced the applied water to resist the new environment and the applied treatment. However, 12-14 hours before they are taken out of the seedbed they should be thoroughly watered again to avoid excessive damage to the roots. Seedlings of 15-25 cm tall with 3-5 true leaves are most suitable for transplanting. Transplanting was done in the afternoon or on a cloudy day to reduce the transplanting shock (Shankara*et al*., 2005).The seedlings were then transplanted on well prepared experimental plots on one sides of furrow ridge at row and plant spacing of 90cm and 30cm, respectively. According to agronomy and soil feasibility report (ASFR, 2007), single fertilization with NPS at transplanting and split application of Urea at transplanting and 45 days after transplanting was done by hand placement at a rate of 100 kg/ha and 100kg/ha, respectively and mancozeb was sprayed 3 kg/ha in seven-day interval to prevent late blight disease and 0.4 l/ha karate was sprayed to control bollworm, Whitefly and aphids pest diseases condition.

* 1. **Soil sampling and analysis**

Composite soil samples were collected from four depths 0-20 cm, 20-40 cm, 40-60cm, 60-100 cm at five points of the experimental field. The soil was analyzed in laboratory, gravimetric method, pH meter method, soil and water ratio method and titration method were used to determine soil moisture content, PH value, electrical conductivity and organic matter content respectively. Hydrometer method was used for analysing particle size distribution and the textural class of the soil was determined using USDA textural triangle following the procedures indicated by Derek *et al*., (2015).

The soil bulk density was determined from undisturbed soil samples which were collected by core samplers. Undisturbed soil samples were collected by using a cylindrical soil sampler with known volume. The samples were dried in an oven at 105˚c for 24 hours and the bulk density was calculated using the equation given by Hillel (2004).



Where Ws is the mass of dry soil (g), Vc is volume of soil in the core (cm 3) and ****is soil bulk density (g/ cm3)

Using a pH meter in a 1:2.5 supernatant suspension of the soil:liquid mixture, the pH of the soil was determined (Batjes, 1995). Electrical conductivity (EC) of 1:5 soils to water ratio extracts was carried out with a conductivity meter (Yangbo*et al*.,2012). Organic matter content titration method was used, which is oxidation under standardized condition with potassium dichromate in sulpheric acid, was followed for organic carbon determination. Finally, conversion of organic carbon to organic matter was obtained by multiplying percentage organic carbon by 1.724 as described by Bianchi *et al* (2008).

Field capacity and permanent wilting point of soil sample analysis were analized at Ethiopian Construction Design and Supervision Work Corporation Research Laboratory and Training Center of Addis Abeba.Soil samples were saturated for two days and using a pressure plate apparatus of a pressure of 1/3 bar for field capacity and 15 bar for permanent wilting pointwas provided until no further change in soil moisture content be observed (Werner, 2002). After getting soil moisture values corresponding to these constants, available water holding capacity of the soil was calculated. The total available water (TAW) for the use by the plant in the root zone was estimated as the difference in moisture content between field capacity and permanent wilting point using the following equation (Allen *et al*., 1998).



Where, FC = field capacity, PWP= permanent wilting point, BD = bulk density of the soil in gm cm-3, and Dz= maximum effective root zone depth in mm.

Soil samples were regularly collected from experimental plots before and after irrigation for gravimetric method.The weight of collected sample soil was measured before and after oven dried, and gravimetric water contentwas determined using the following equation (Cuenca, 1989). The gravimetric water content was calculated by the equation:



Where,  water content expressed on weight basis in (%),  weight of wet soil (g) and weight of dry soil (g).

Volumetric water content



Where, volumetric moisture content in (%), soil bulk density (gcm-3) and water density (gcm-3).

### 2.6 Soil infiltration rate

Infiltration rate of the soil in the experimental field was determined using double ring infiltrometer before experimental work is started. The test was conducted at three representative locations of the experimental field. It was installed the inner and outer ring with the cutting edge facing down on the groundand put the driving plate on top of the inner ring and the outer ring. Use the impact-absorbing hammer to insert the inner and outer ring about 5cm vertically into the soil and measuring ruler inside the inner ring. It was fill the outer ring and the inner ring with water simultaneously using bucket. The outer ring's water prevented the inner ring's water from moving laterally. Recording was done immediately to determine the initial water level inside the inner cylinder and start the stop watch. Record the change in water level inside the inner cylinder at time intervals and the procedure was repeated until consecutive uniform infiltration depth was observed (Walker 2003).

## 2.7 Climate data

Long term climate data such as maximum and minimum air temperature, relative humidity, wind speed, sunshine hours, and rainfall were collected from National Meteorological Agency for determination of reference evapotranspiration(ETo), planning irrigation schedule and crop water requirement. A plastic rain gauge was set up to measure rainfall in the experimental field, and daily weather data from the meteorological station was gathered during the growing season.

Figure 2: Average climate data of the study site

*Where, Max.temp = maximum temperature (0C), Min.temp = minimum temperature (0C), Rainfall (mm), Wind speed (m/s) and Relative humidity (%).*

## 2.7 Crop data

As indicated in Table 1, length of growing season, crop coefficient (Kc), rooting depth (m) average soil depletion fraction (p) and yield response (Ky) were the necessary crop data for determination of crop water requirement.

Table 1: Crop data required for CWR determination

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Growth stage | | | |
| Crop data | Initial | Development | Mid | Late |
| Length of growing season(days) | 30(19) | 40(25) | 40(28) | 25(18) |
| Crop coefficient(Kc) | 0.6(0.6) | 0.89(0.89) | 1.15(1.15) | 0.8(0.8) |
| Rooting depth(m) | 0.7(0.7) | 0.98(0.85) | 1.5(1) | 1.5(1) |
| Average soil water depletion fraction(p) | 0.4(0.4) | 0.4(0.4) | 0.4(0.4) | 0.4(0.4) |
| Yield response (Ky) | 0.5(0.5) | 0.6(0.6) | 1.1(1.1) | 0.8(0.8) |

\*Source: FAO 56(Allen *et al.*, 1998) and Areka Agricultural Research Center

## 2.8 Crop water requirement

The amount of water needed (CWR) to compensate the amount of water lost throughevapotranspiration (ETc), requires reference evapotranspiration (ETo) and tomato cropcoefficient (Kc) is given by Allen et al. (1998) as 0.6 for the initial stage, 0.6 <Kc< 1.15 for the development stage, 1.15 for the mid-season stage and 1.15 >Kc> 0.8 for the late seasonstage. As indicated in section 2.4 crop water requirements were calculated from ETo and Kc.

The **net irrigation requirement** was calculated using the CROPWAT computer program based on Allen *et al*. (1998) as follows:

IR = CWR – Pe

Where, IR =Irrigation requirement (mm), CWR= crop water requirement in mm and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production.

Theeffective rainfall (Pe) is estimated using the method given by (Allen *et al*., 1998) as.

For Pmonth≤ 70 mm

For Pmonth>70 mm

Where: Pe (mm) = effective rainfall and P (mm) = total rain fall.

## Gross irrigation requirement

Taking application efficiency of a short, end diked furrow as 60% (Brouwer and Prins, 1989), the gross irrigation requirement was obtained as:



where,Ig = the gross irrigation depth in mm, In = net irrigation depth in mm, and Ea=the furrow application efficiency (%).

The time required to deliver the desired depth of water into each furrow was calculated using the equation given by Michael (2008):



where,Ig = gross depth of water applied (cm), t = application time (min), l= furrow length (m), w= furrow spacing (m), and Q= flow rate (l/s).

The total amount of water estimated using the CROPWAT model was diverted to the furrow with calibrated Parshall Flume. As indicated appendix Table 5,free flow discharge values for different size of Parshall Flumes outlined by (Kandiah, 1981).The time of application was monitored using stopwatch during each irrigation water application in order to assess the treatment effects.The irrigation water to be applied to the plots was measured using a 3 inch Parshall Flume installed at the upper stream near the experimental field.

## 2.9 Observation of crop yield and components

During harvesting Stand count, weight of marketable yield, weight of unmarketable yield were measured from the net harvested area of each plot. Fruit that was rotting, undersized, pest-affected, or attacked by birds produced unmarketable fruit output. To measure yield per hectare, the weight of all fruit yields (both marketable and unmarketable) per plot at harvesting from the net area was noted and added up.

**2.10 Water use efficiency**

The water use efficiency (kg/m3) was estimated by dividing marketable yield in kilogram to unit volume of water in cubic-meter. Crop water use efficiency wasobtained by the marketable yield harvested in kilogram per total water used (Micheal,2008).



where, WUE = crop water use efficiency (kg/m3), Y = yield (kg/ha), and ETc = is the amount of water used by the crop (mm).

## 2.11 Crop response factor

The upper limits for yield are set by soil fertility, climatic conditions and management practices (Bauder*et al*., 1988). Where all of these are optimal throughout the growing season, yield reaches the maximum value as does evapotranspiration (ETm) Soil Water Storage (SWS) has an impact on water availability (WA) for a crop and, subsequently, on actual yield and actual evapotranspiration (ETa) (English, 1990). Fereres and Soriano (2007) stated that when water deficit occurs during a specific crop development period, the yield response can vary depending on crop sensitivity at that growth stage. The degree of sensitivity also varies with amount of water deficit and with crop type. Therefore, knowledge of crop response factor for water deficit and time of irrigation is a tool for scheduling irrigation where a scarce supply of water is available. Although it is difficult to measure the actual evapotranspiration values during the experimental season, water applied in the total growing season for full irrigated treatment , was taken as the maximum evapotranspiration (ETm), and the deficit water applications values were taken as actual evapotranspiration(ETa). A standard formulation equation relates these four parameters (*Ya*, *Ym*, *ETa*, *ETm*) to yield response factor(Ky), which links relative yield decrease to relative evapotranspiration deficit (Vaus and Pruitt, 1983):



Where, ya = actual yield (kg/ha), ym = maximum yield (kg/ha),ETa = actual evapotranspiration (mm), ETM = maximum evapotranspiration (mm).

Ky relates relative yield decrease to relative evapotranspiration deficit. Two series of Ky values obtained from FAO data sets and from (IAEA) and (CRP) showed a wide range of variation for this parameter. 0.20 <Ky< 1.15 (FAO, 2002), and 0.08 <Ky< 1.75 (IAEA) (Moutonnet, 2002; Kipkorir et al., 2002). According to (Steduto*et al*., 2012), the Ky values are crop specific and vary over the growing season. For Ky>1, crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced. For Ky<1, crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use. For Ky =1, yield reduction is directly proportional to reduced water use.

**2.12Economic analysis**

Economic evaluation is analyzing the cost that invested during growing season and benefit gained from yield produced by application of water. Marginal Rate of Return (MRR) was used for analysis following the CYMMYT method (CIMMYT, 1988). Economic water productivity was calculated based on the information obtained at the study site: the size of irrigable area, the price of water applied and the income gained from the sale of tomato yield by considering the local market price.

Yield and economic data were collected to evaluate the benefits of application of water in different irrigation systems and treatments. Input costs such as those for labor, seeds, fertilizer, fuel, and water (water price) are included in economic data. The costs that differ between treatments, however, are labor and water prices. The net income (NI) treatments were calculated by subtracting total cost (TC) from gross income (GI) and were computed as:



Change in net income (ΔNI) is the difference between a therapy's net income and its next higher variable cost treatment. If bigger net benefits come at a significantly higher cost, they might not be appealing (CIMMYT, 1988). Hence, it is required to calculate marginal costs with the extra marginal net income. The marginal rate of return (MRR) indicates the increase of the net income, which is produced by each additional unit of expenditures and it is computed as follows:



Where, ΔNI= change in net income, ΔVC= change in variable cost

## 2.13 Statistical Analysis

The collected data were analyzed analysis of variance method using Statistical Agricultural Software (SAS 9.0) and least significance difference (LSD) at 5% was employed to see a mean difference between treatments.

# 3. RESULTS AND DISCUSSIONS

## 3.1Experimental field Soil

According to the lab results, the average percentages of sand, silt, and clay were 24.5%, 9%, and 66.5%, respectively. Therefore, the % particle size determination for the experimental site indicated that the soil texture could be categorized as clay soil in accordance with the USDA soil textural categorization. Compared to the subsurface (1.34g/cm3), the top soil surface had a somewhat lower bulk density (1.15g/cm3). This could be because of slight decrease of organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The critical value of bulk density for restricting root growth varies with soil type (Hunt and Gilkes,1992) but the general bulk density greater than 1.6 g/cm3 tend to restrict root growth(McKenzie et al., 2004). Moisture content at field capacity of the experimental site soils were 34.49%, 32.67%, 32% and 31% at 0-20cm, 20-40cm, 40-60cm and 60-100cm soil depth respectively. Moisture content at permanent wilting point also shows variation with depth and has values 18%, 17.2%, 16% and 14.05% at 0-20cm, 20-40cm, 40-60cm and 60-100cm soil depths respectively. The totalaverageavailable water (TAW) is directly related to variation in FC and PWP. The representative value of TAW was 206.1 mm/m and the TAW range of 190 – 260 mm/m is the characteristic for clay soil (Brouwer*et al*., 1985)

Table 2: Physical characteristics of the soil at the study area

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Soil property | | Soil depth in (cm) | | | | |
| 0-20 | 20-40 | 40-60 | 60-100 | Mean |
| Particle size  Distribution | Sand (%) | 26 | 30 | 20 | 22 | 24.5 |
| Silt (%) | 12 | 6 | 10 | 8 | 9 |
| Clay (%) | 62 | 64 | 70 | 70 | 66.5 |
| Textural class | | Clay | Clay | Clay | Clay | Clay |
| Bulk density (g/cm3) | | 1.15 | 1.26 | 1.32 | 1.34 | 1.27 |
| FC (Vol %) | | 34.49 | 32.67 | 32 | 31 | 32.54 |
| PWP (Vol %) | | 18 | 17.2 | 16 | 14.05 | 16.31 |
| TAW (mm/m) | | 189.6 | 194.9 | 211.2 | 227.1 | 206.1 |

**Infiltration rate of the soil**

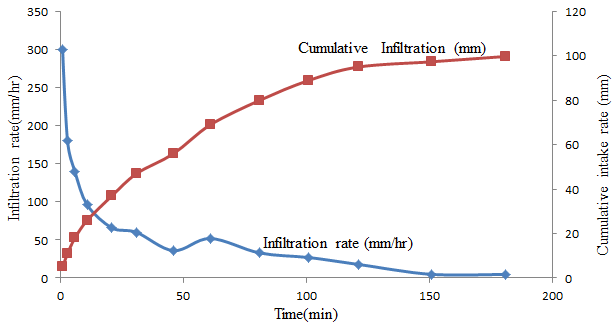
The basic infiltration rate of the experiment site was found to be 4.8 mm/hr which is in the lower range of clay soil (1-5mm/hr) (Hillel, 2004). This indicates that it took an hour for a 4.8 mm water layer to penetrate the soil's surface.

Figure 3: Cumulative Intake Depth and Cumulative Infiltration Rate of Experimental Soil

The average pH value of the experimental site through the analyzed depth was found to be slightly acidic, with average value of 5.71. Tomato can be grown on a wide range of soil but a well-drained, with pH of 5 to 7 is preferred (Doorenbos*et al.*, 1979).The experimental soil had an average electrical conductivity of 1.1dS/m through 100 cm profile which is below the threshold value for yield reduction that is 1.2 dS/m (Smith *et al*., 2011).The organic matter content and organic carbon content of the soil had average values of 5.6 % and 3.2 %, respectively.

Table 3: Soil chemical properties

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Soil property | Soil depth | | | | |
| 0-20 cm | 20-40 cm | 40-60 cm | 60-100 cm | Average |
| pH | 5.68 | 5.73 | 5.79 | 5.64 | 5.71 |
| EC(ds/m) | 1.18 | 1.06 | 1.18 | 1.05 | 1.1 |
| OM (%) | 6.6 | 6.3 | 5.6 | 4 | 5.6 |
| OC | 3.7 | 3.7 | 3.3 | 2.3 | 3.2 |

## 3.2 Crop and irrigation water requirements of tomato

Figure 4 shows the reference evapotraspiration (ETo) value of the study site was found to be ranged between 4.88 mm/day in January, 5.38 mm/day in February and 5.04 mm/day in march, with an average of 5.1 mm/day for the whole growth period.

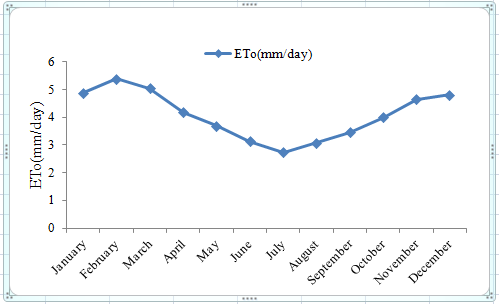


Figure 4:ETo of the experimental site

In the absence of rainfall and considering tomato (Lycopersiconlycopersci) roma VF variety with crop coefficient at initial stage 0.6, mid stage 1.15 and late stage 0.8 as shown in the Figure 5, root depth 0.7 to 1m, allowable critical depletion 40%, clay soil with total soil available moisture 206.1 mm/m, the seasonal irrigation requirement was found to be 415.7 mm. This amount needed for full irrigation throughout the growing season.

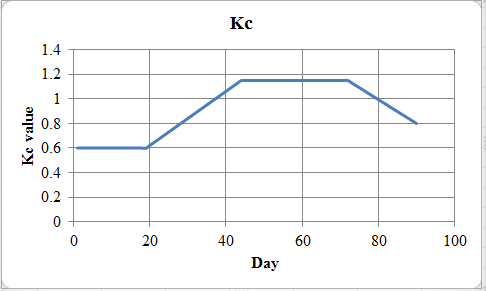


Figure 5: Crop coefficient value of Tomato

From the beginning to the middle of the period, tomatoes needed more water. In mid-March of the mid-stage, the maximum amount of irrigation water (41.2mm) was needed. The tomato reached its maximum crop coefficient at this point, and the reference evapotranspiration was high. Due to a decrease in the crop coefficient value, less water was needed at the end of the period.

Table 4: Crop and irrigation water requirement for tomato at four days interval

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Date | Stage | Kc | ETo  (mm/period) | Etc  (mm/period) | IRn  (mm) | IRg  (mm) |
| 4-Jan | Init | 0.6 | 19.52 | 11.7 | 11.7 | 19.5 |
| 8-Jan | Init | 0.6 | 19.52 | 11.7 | 11.7 | 19.5 |
| 12-Jan | Init | 0.6 | 19.52 | 11.7 | 11.7 | 19.5 |
| 16-Jan | Init | 0.6 | 19.52 | 11.7 | 11.7 | 19.5 |
| 20-Jan | Dev | 0.60 | 19.52 | 11.7 | 11.7 | 19.5 |
| 24-Jan | Dev | 0.67 | 19.52 | 13.1 | 13.1 | 21.8 |
| 28-Jan | Dev | 0.77 | 19.52 | 15.0 | 15.0 | 25.1 |
| 1-Feb | Dev | 0.85 | 21.52 | 18.3 | 18.3 | 30.5 |
| 5-Feb | Dev | 0.94 | 21.52 | 20.2 | 20.2 | 33.7 |
| 9-Feb | Dev | 1.03 | 21.52 | 22.2 | 22.2 | 36.9 |
| 13-Feb | Dev | 1.12 | 21.52 | 24.1 | 24.1 | 40.2 |
| 17-Feb | Mid | 1.15 | 21.52 | 24.7 | 24.7 | 41.2 |
| 21-Feb | Mid | 1.15 | 21.52 | 24.7 | 24.7 | 41.2 |
| 25-Feb | Mid | 1.15 | 21.52 | 24.7 | 24.7 | 41.2 |
| 1-Mar | Mid | 1.15 | 20.16 | 23.2 | 23.2 | 38.6 |
| 5-Mar | Mid | 1.15 | 20.16 | 23.2 | 23.2 | 38.6 |
| 9-Mar | Mid | 1.15 | 20.16 | 23.2 | 23.2 | 38.6 |
| 13-Mar | Mid | 1.15 | 20.16 | 23.2 | 23.2 | 38.6 |
| 17-Mar | End | 1.1 | 20.16 | 22.2 | 22.2 | 37.0 |
| 21-Mar | End | 0.98 | 20.16 | 19.8 | 19.8 | 32.9 |
| 25-Mar | End | 0.95 | 20.16 | 19.2 | 19.2 | 31.9 |
| 29-Mar | End | 0.80 | 20.16 | 16.1 | 16.1 | 26.9 |
| Total |  |  | 448.56 | 415.7 | 415.7 | 692.8 |

ETo = reference evapotranspiration, ETc = crop water requirement, IRn = net irrigation requirement, IRg = gross irrigation requirement, kc = crop coefficient, Init = initial stage, Dev = development stage and Mid = middle stage.

## 3.3 Effects of furrow irrigation systems of tomato yield

The result in the Table shows that marketable yield was significantly affected by the amount of water applied to the crop and the methods of furrow irrigation systems. The highest marketable yield (24 ton/ha) was obtained from CFI while the minimum marketable yield (14.4 ton/ha) was obtained from FFI. The decrease in the yield is directly related to the variation of types of furrow irrigation systems. Marketable fruit numbers also showed significant differences between the treatments and had consistency with marketable yield. The maximum (448958 ) and minimum(296250) fruit number was recorded in CFI and FFI systems, respectively. AFI gives a

relatively better yield than fixed furrow irrigation systems. In this research, unmarketable yield means that the fruits that were affected by pest attack, bird attack, rotten, and size. The result revealed that unmarketable yield was statistically non-significant between the treatments. The unmarketable yield of 8.1 ton/ha, 7.9 ton/ha, and 7.0 ton/ha was obtained from CFI, FFI, and AFI systems, respectively. Total yield is the sum of marketable and unmarketable fruit yield. The result also showed that the highest total fruit yield (32 ton/ha) was obtained from CFI system and the minimum total yield (22.3 ton/ha) was gained from FFI.

Table 5: Water use efficiency and Tomato response to furrow irrigation system

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| TRT | MY(ton/ha) | MFNO | UY(ton/ha) | UMFNO | TY(ton/ha) | WUE(kg/m3) |
| AFI | 18.3b | 353125ba | 7.0 | 193125.0 | 25.4b | 8.82a |
| FFI | 14.4c | 296250b | 7.9 | 214166.7 | 22.3b | 6.91b |
| CFI | 24.0a | 448958a | 8.1 | 242916.7 | 32.0a | 5.76b |
|  |  |  |  |  |  |  |
| CV(%) | 11.5 | 18.0 | 19.0 | 19.8 | 12.8 | 12.5 |
| MS error | 4.7 | 4.4 | 2.2 | 1.8 | 11.6 | 1.7 |
| LSD(0.05) | 3.8 | 114648 | NS | NS | 5.9 | 1.15 |

TRT = treatment, MY = marketable yield, MFNO = marketable fruit number, UY = unmarketable yield, UMFNO = unmarketable fruit number, TY = total yield, WUE = water use efficiency.

## 3.4Water use efficiency

The analysis of variance indicated that the types of furrow irrigation systemswere significantly (p<0.05) affected the irrigation water use efficiency of tomato. The result in the table: shows that highest and the lowest mean value of irrigation water use efficiency for AFI was observed to be 8.82 kg/m3 and 5.76 kg/m3 for CFI. The water use efficiency of CFI and FFI was statistically non-significant, but FFI saved more water. This is because of the difference in percentage of wateractually converted to evapotranspiration out of the total amount applied. This is consistent withthe significant improvements in CWUE that have been associated with AFI (Zhang et al., 2000). As indicated in Table 8 the yield reduction at alternative furrow irrigation was 23.5% and 39.9% at alternative furrow irrigation.

Table 6: Water useefficiency and amount of water saved

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| TRT | MY(kg/ha) | CWR(mm) | AW(mm) | Saved water(mm) | Yield reduction (%) | WUE(kg/m3) | Rank in WUE |
| CFI | 23958 | 415.7 | 415.7 | 0 | 0 | 5.76 | 3 |
| AFI | 18333 | 415.7 | 207.85 | 207.85 | 23.5 | 8.82 | 1 |
| FFI | 14375 | 415.7 | 207.85 | 207.85 | 39.9 | 6.91 | 2 |

TRT= treatment, CWR = crop water requirement AW= applied water and WUE = water use efficiency

**3.5Yield response factor**

Table indicates that the yield of tomato was not sensitive to water deficit that happen in alternative and fixed irrigation systems, since yield response factor (ky) is less than one. That is tomato tolerate some degree of water stress through growing season.

Table 7:Yield response factor (ky)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trt | Actual yield in kg/ha | Maximum  yield in kg/ha | Actual Eta (mm) | Maximum ETm (mm) | Yield response factor (ky) |
| CFI |  | 23958 |  | 415.7 |  |
| AFI | 18333 |  | 207.85 |  | 0.5 |
| FFI | 14375 |  | 207.85 |  | 0.8 |

ETa=actual evapotranspiration, ETm=maximum evapotranspiration

## 4.7 Economic analysis

The application of water in a water-saving irrigation system could be economically attractive to minimize drought hazards in water-shortage areas.

At the time of harvest, the market price of tomato was 10 birr per kg and the cost of irrigation water was 7 birr/m3 (by considering the cost of drinking water as the cost of irrigation water). To analyze by the producer of dominance analysis, the treatments were set in their sort of increasing variable cost, and their equivalent benefits were put aside. FFI and CFI showed the minimum and maximum variable costs respectively. Based on the current prices of tomato yield produced and input costs required for production, the economic analysis was carried out. The highest net income (193,081 birr/ha) was obtained under CFI and the least net income (111,801 birr/ha) was obtained under FFI. However, as indicated in Table 8, the largest MRR (3858 %)was acquired under AFI and the smallest MRR (315.14%) was obtained under CFI. Therefore, the highest economic return was observed at AFI with a net income of 150,381 birr/ha and MRR of 3858 %. The MRR tells us the amount of additional income obtained for every 1 birr spent. Hence, AFI acquired an additional 38.58 birr for every 1 birr spent.

Table 8: Economic analysis

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TRT | AW | OY | GI | FC | VC | TC | NI | MRR |
| (m3/ha) | (kg/ha) | (birr/ha) | (birr/ha) | (birr/ha) | (birr/ha) | (birr/ha | (%) |
| FFI | 2078.5 | 14375 | 143750 | 17400 | 14549.5 | 31949.5 | 111801 | 0 |
| AFI | 2078.5 | 18333 | 183330 | 17400 | 15549.5 | 32949.5 | 150381 | 3858 |
| CFI | 4157 | 23958 | 239580 | 17400 | 29099 | 46499 | 193081 | 315.14 |

TRT= treatment, AW= Applied water, OY=Observed Yield, GI=Gross income, FC= Fixed cost, VC=Variable cost, TC=Total cost, NI=Net income, MRR=Marginal rate of return

1. **Conclusion and recommendation**

Maximum fruit yield of 32 tons/ha and the highest economic return with net income of 193081 birr/ha was obtained under conventional furrow irrigation i.e., irrigating all furrows during consecutive watering. Irrigation water application in which one of the two neighboring furrows alternately irrigated during consecutive watering gives a relatively better yield i.e. 25.4 ton/ha than irrigation fixed to one of the two neighboring furrows through the growing season that yields 22.3 ton/ha. The highest water use efficiency (8.82 kg/m3) was obtained under alternative furrow irrigation and saved 50 % water and the minimum water use efficiency (5.76 kg/m3) was obtained during the conventional furrow irrigation system. Alternative furrow irrigation was also economically feasible because of its higher return rates. In areas where enough water is available, applying water to a conventional furrow irrigation system through the growing season is advisable to obtain maximum tomato yield. However, in water-scarce areas, applying irrigation water through an alternative furrow irrigation system is advisable with a minimum reduction of yield.

**Competing interests**

We confirm that the manuscript has been read and approved by authors and that there are no other persons who fulfill the criteria for authorship but are not listed. We further confirm that we have approved the order of authors listed in the manuscript. We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions, and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author.

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