



**EVALUATION OF ALTERNATE, FIXED AND CONVENTIONAL FURROW
IRRIGATION SYSTEMS ON TOMATO YIELD AND WATER USE EFFICIENCY
AT HUMBO WOREDA, ETHIOPIA**

MSc.THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

MAY, 2018

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IRRIGATION SYSTEMS ON TOMATO YIELD AND WATER USE EFFICIENCY
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**A THESIS SUBMITTED TO FACULTY OF BIO-SYSTEMS AND WATER
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HAWASSA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
EXAMINERS' APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by **Tamirneh Kifle** have read and evaluated his thesis entitled “**Evaluation of Alternate, Fixed and Conventional Furrow Irrigation Systems on Tomato Yield and Water Use Efficiency at Humbo Woreda, Ethiopia**”, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of science in Irrigation and Drainage Engineering.

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I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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LIST OF ACRONOMYS AND ABBREVIATIONS

ABA	Absciscic Acid
AFI	Alternative Furrow Irrigation
ANOVA	Analysis of variance
ASM	Available Soil Moisture
CFI	Conventional Furrow Irrigation
CoSEARSAR	Commission for Sustainable Agricultural and Environmental Rehabilitation in the Amhara Region
CSA	Central Statistical Authority
CIMMYT	International Maize and Wheat Improvement Center
CWR	Crop Water Requirement
CWUE	Crop Water Use Efficiency
D_{ap}	Depth of Irrigation
DMRT	Duncan's Multiple Range Test
Ea	Application Efficiency
ETc	Crop Water Requirement
ETo	Reference Crop Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
FFI	Fixed Furrow Irrigation
FWUE	Field water use efficiency
GDP	Gross Domestic Product
GPS	Geographical Positioning System

I_g	Gross Irrigation
I_n	Net Irrigation
IR	Infiltration Rate
IWMI	International Water Management Institute
K_c	Crop Characteristics
LSD	Least Significant Difference
m.a.s.l	Meter Above Sea Level
MRR	Marginal Rate of Return
P	Depletion Factor
P_e	Effective Rainfall
PWP	Permanent Wilting Point
RCBD	Randomized Complete Block Design
RZD	Maximum effective root zone depth
SNNPR	Southern Nations, Nationalities, and Peoples' Region
TAW	Total Available Water
TDR	Time-Domain Reflectometer
USAID	United States Agency for International Development
USDA	United State Department of Agriculture
WUE	Water Use Efficiency

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ABSTRACT

Water scarcity is one of the most important factors influencing sustainable agricultural production in arid and semi-arid regions. Insufficient water supply for irrigation was the norm rather than the exception, and irrigation management has been shifting from emphasizing production per unit area to maximizing the production per unit of water consumed, the water productivity. 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). The objective of this research was to evaluate the three furrow irrigation systems on tomato yield and water use efficiency and identify the furrow irrigation method which allows achieving optimum tomato yield. To achieve this, experimental design was arranged in RCBD with three treatments and four 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. There for, in area where enough water available, applying water at conventional furrow irrigation system through growing season is advisable to obtain maximum tomato yield and in water scarce area applying irrigation water through alternative furrow irrigation system in four day interval is found to be economical feasible and highest water use efficiency.

Key word: ETc, Evapotranspiration, Furrow irrigation method, Tomato, Water use efficiency.

1. INTRODUCTION

1.1 Background

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 development of agriculture particularly in arid and semiarid areas of the world. In such areas rain-fed agriculture alone may not be successful to satisfy the increasing food demand since rainfall is not adequate to meet the total water requirements of the crop and it does not occur at the time when the crops need it.

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).

Ethiopia's agriculture is also hindered by the erratic distribution of rainfall both in time and space. It is becoming risky practice due to highly erratic and uneven distribution of rain in most areas of the country. Failure of a given seasonal rain leads to severe drought conditions and widespread food insecurity (USAID, 2009).

Irrigation development is increasingly implemented in Ethiopia more than ever to supplement the rain-fed agriculture. It aims to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure that the agriculture to plays a pivotal role for driving the economic development of the country (Mekonen, 2011).

Southern Peoples, Nations and Nationalities Regional State has exuberant resource endowment with respect to natural resources for irrigation based farming that accounts an estimated irrigable area of 700,000 ha of land constituting about 19 % of the estimated total irrigable area of the country, that is 3.7 million ha (CoSEARSAR, 2000).

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 practices (Zaman *et al.*, 2001). In this regard, micro irrigation system is becoming increasingly important, and may contribute substantially to attain higher productivity and optimum use of water in various orchard crops and vegetables.

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). Other experiments on hot pepper are also reported by Owusu-Sekyere *et al.*, (2010)

who reported reduction in 20% water need has no significant effect on growth, development and fruiting of the crop. 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.

Among the surface irrigation methods, furrow irrigation technique is known to have better efficiency and can be used in situations where water shortage is critical. Recently, furrow irrigation is becoming most popular for both small and large scale irrigation schemes (FAO 2001). According to FAO (2001), 97.8 % of irrigation in Ethiopia is made by surface methods of irrigation especially by furrow system in farmer's fields and majority of the commercial farms.

Researchers have used wide spaced furrow irrigation or skipped crop rows as a means to improve water use efficiency in irrigated agriculture (Kang *et al.*, 2000). In skipped rows, some rows are fixed for irrigation while adjacent furrows are not irrigated for the whole season. In general these techniques are a trade-off: between yield and higher water use efficiency. Water is saved mainly by reduced evapotranspiration from the soil surface.

By irrigating alternative furrows, half of root is exposed to wet soil condition and the other half is exposed to dry soil condition. A drier soil condition stimulates the creation of phytohormone known as Abscisic acid (ABA) in shoots. ABA is a primary regulator of the stomatal aperture in water stressed plants. Closure of stomata in leaf associated with decrease in the evaporative water loss is initiated by ABA. The partial wetting of the soil while the other part is kept dry stimulates secretion of ABA in the roots. The presence of ABA sends water stress signal to the stomata and forces the stomata to close. This in turn reduces transpiration or water loss without affecting photosynthesis (Kang *et.al.*, 1998). Other investigations had shown that alternative

furrow irrigation which affects the stomata may directly respond to the availability of water in the soil by reducing their opening (Kang *et al.*, 1999). Evaluations of alternative furrow irrigation (AFI) have been made for Onion (Deribew, 2006), for Potato (Woldesenbet, 2005) and for Maize (Mitslal, 2008). However, there are only limited studies exist concerning the effect of alternative, fixed and conventional furrow irrigation system on tomato yield, particularly SNNPR region. Therefore, this study investigates the best furrow irrigation systems on water use efficiency and Tomato yield.

1.2 Problem statement

Most of the research results indicate that alternate furrow irrigation has the potential to save water and labor and insure high water use efficiency, although they recommended conducting similar experiments for other vegetable and food crops. Ethiopian agriculture is hindered by the erratic distribution of rainfall both in time and space. A serious of water shortage and poor water management were the most sever constraint in the study area. Application of water through water saving furrow irrigation system and its economic analysis is not commonly practiced in most water scarce areas of Ethiopia. The same is true in Humbo woreda, which is one of the water scarce areas in southern region. Farmers in study area apply much water on their farm from their limited supply that even does not correspond with the water required by the crops. This unwise use of irrigation water causes low crop water productivity and high production cost in the area. Their awareness on crops yield response to water application is limited. The problems are evolved from shortage of research and awareness on irrigation water productivity based on local climate, soil type and irrigation systems. Hence, before extension of this irrigation water management system (furrow irrigation method) in the study area it is a need to investigate its impact on crop yield and water productivity and providing practical recommendations to farmers and extension workers under various conditions of crop management system.

1.3 General objective

The general objective of this study is to evaluate the yield and water use efficiency of tomato using different furrow irrigation systems.

1.3.1 Specific objectives

- To investigate the effect of alternate, fixed and conventional furrow irrigation systems on tomato yield
- To evaluate the water use efficiency in the alternate, fixed and every furrow irrigation methods
- To determine the sensitivity of tomato to water deficit under alternative, fixed and conventional furrow irrigation systems
- To select the furrow system that allow achieving maximum crop yield and highest economic benefit

1.4 Research questions

In this research the following scientific questions was answered:

Under which type of furrow irrigation method high marginal return rate and income could be obtained?

Which type of furrow irrigation method has more water use efficiency?

Which furrow irrigation method result the highest yield?

1.5 The scope of the study

This study was focused on Humbo woreda of Woliya zone, Ethiopia on farmer field level, to evaluate the types of furrow irrigation methods on tomato yield and water use efficiency. Due to time and resource constraints, the research focuses only on evaluation of alternative, fixed and conventional irrigation method.

1.6 Significance of the study

This study was about evaluating the types of furrow irrigation system on tomato yield , water use efficiency and economic benefit. When this research is completed the society gets the best type water saving furrow irrigation systems to increase productivity of tomato, evaluate the effects of alternate, fixed and conventional furrow irrigation methods and select the furrow system that allow achieving optimum crop yield at Humbo woreda of southern Ethiopia. This study can also serve to generate base line information for further studies in related area of the study.

2. LITERATURE REVIEW

2.1. Water Scarcity and Irrigated Agriculture

Though water covers about two-thirds of the Earth's surface, it is a scarce resource as most of it is unavailable and too salty for use. Only 2.5% of the world's water is not salty, and two-thirds of that is locked up in the icecaps and glaciers. About 20% of the fresh water is not accessible, and much of it arrives at the wrong time and place, as monsoons and floods. Currently, less than 0.08% of all the Earth's water is available for human use. But, of this small proportion of available water more than two-third is used for agriculture (FAO, 2000).

With growing water scarcity in many parts of the world and projections that indicate the need to increase agricultural production and, concurrently, agricultural water use, it is increasingly advocated to focus efforts on enhancing water productivity in irrigated agriculture. Given the large quantities of water involved, and the widely-held perception that water use in agriculture is relatively inefficient, even small improvements in agricultural water productivity are believed to have large implications for local and global water budgets. Many international organizations concerned with water management are promoting increase in agricultural water productivity as an important policy goal, and significant public and private investments are being made with this in mind (FAO, 2012).

Irrigation plays the key role in the performance of agriculture, which increases income growth.

A reliable and suitable irrigation water supply can result in vast improvements in agricultural production and assure the economic vitality of the region. Income growth is essential for economic growth (Hussain and Biltonen, 2001).

2.2 Irrigation Water Demand

Agricultural production is the major user of the Earth's water resources and the water demand for this sector is increasing steadily with its root on population growth. These days about 70% of the available water we have on Earth is used for agriculture and by 2020 additional 17% more water is needed than is available now if we are to feed the world (Lascano and Sojka, 2007). In Ethiopia, total water withdrawal in 2002 was estimated to be 5.6 km³ of which 5.2 km³ (93.6%) was used for agriculture (World Bank, 2006).

Irrigated agriculture is the main user of the available water resources. Irrigation has an important role to play in contributing to food security and poverty alleviation. Of the 1,500 million ha of global cropland, only about 250 million ha (17%) are irrigated, despite this 17% irrigated agriculture provides about 40% of world food production (FAO, 2000). This contribution of irrigation in agricultural development is increasing. Irrigation in Ethiopia contributed approximately 5.7% to agricultural Gross Domestic Product (GDP) and 2.5% to the overall GDP during the 2005/2006 cropping season. Future forecast of contribution of irrigation to agricultural GDP and overall GDP by the year 2009/2010 production year was increased approximately to 8.8% and 3.7%, respectively (Hagos *et al.*, 2009).

Consequently, many countries in Sub-Saharan Africa are planning to increase irrigated agriculture as a contribution to attaining the Millennium Development Goals. For example, the Commission for Africa proposed a doubling of the area of arable land under irrigation by 2015 (Commission for Africa, 2005). In particular in developing countries, the area equipped for irrigation is expected to have expanded by 20 % (40 million ha) by 2030. This means that 20 %

of total land with irrigation potential but not yet equipped will be under irrigation, and that 60% of all land with irrigation potential (402 million ha) will be in use by 2030 (FAO, 2003).

Irrespective of the actual outcomes, it is important to highlight the fact that water allocations for agriculture will face increasing competition from other higher utility uses – municipal, industrial and other uses and calls for water to be left in the environment. During the latter half of this century, the pressure on natural water resources is increasing in the semi-arid and arid areas where demographic growth rates are greatest (FAO, 2003). These factors necessitate major changes in irrigation management and scheduling in order to increase the efficiency of use of water that is allocated to agriculture.

The efficiency of water use in most agricultural productions is low with poor management and improper designs of water application systems. Only a part of agricultural water withdrawals are effectively used in the production of food or other agricultural commodities. According to FAO (1996), of the total applied water only 40 to 60% is effectively used by the crop. The remainder of the water is lost in the system, and in the field, either through evaporation, runoff to the drainage system or by percolation into the groundwater. Perhaps that part of water lost can be recovered, but additional costs are needed to be incurred. As a step towards achieving the objective of more crops per drop of water, there is a need for irrigators to begin to adopt the use of techniques and practices that save irrigation water.

The use of efficient irrigated farming practices with the most economical exploitation of the water resources is an issue as far as irrigation water saving is concerned. Based on the actual crop need, the irrigation management has to be improved so that the water supply to the crop can be reduced while still achieving a high yield. At the same time, water leakage and

evaporation from storage facilities and in transport have to be reduced to the minimum (Perera, 2002).

2.3 Water Use Efficiency

Water-use efficiency (WUE) is generally defined in agronomy as the ratio of crop yield (usually economic yield) to water used to produce the yield. WUE is a measure of the productivity of the water consumed by the crop. In areas with limited water resources, where water is the greatest limitation to production, WUE is the main criterion for evaluating the performance of production systems (FAO, 2002).

Samson and Ketema (2007) indicated that deficit irrigation increased the water use efficiency of onion from 6% by stressing the crop during the initial stage to 13% by partially stressing the crop at 75% of crop evapotranspiration compared to the optimum application throughout the growing season. Similarly, Brewster (1990a) and Shock *et al.*, (1998) reported that irrigation water use efficiency was higher at the irrigation treatment at 50% available soil moisture (ASM) than at 25 or 75% (ASM). Best irrigation water use efficiency was also obtained with irrigation at 50% available soil moisture than at 75% and 25% available soil moisture (Kebede, 2003). On the contrary, high water use efficiencies were observed with increasing level of irrigation, or no irrigation in the vegetative period (Kadayifci *et al.*, 2004).

2.4 Crop Water Requirement

The term crop water requirement is defined as the amount of water required to compensate the evapotranspiration loss from the cropped field. Crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al.*, 1998).

For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ET_o) and the effect of crop characteristics (K_c) are important (Doorenbos and pruit, 1977).

Reference evapotranspiration (ET_o) has been estimated using different methods, Including Priestley and Taylor, Hargreaves & Samani, Blaney & Criddle, Penman, ASCE Penman-Monteith and Penman-Monteith. The first two methods are energy based, BLANEY & CRIDDLE is temperature based, Penman was mass transfer based, ASCE Penman-Monteith and Penman-Monteith were combined based (Gotardo *et al.*, 2016).

The growth and yield of any crop is related to the amount of water used. The variable amount of water contained in a soil and its energy state are important factors affecting growth of plants (Hillel, 2004). The accuracy of determination of crop water requirements will be largely dependent on the type of the climatic data available and the accuracy of the method chosen to estimate the evapotranspiration (Nuha and Henery, 2000).

Based on the comparative studies of the reference evapotranspiration methods and recommendations of a panel of experts and researchers organized in FAO, Rome, in 1990, the Penman Monteith equation has been adopted as the globally best performing method of estimating reference evapotranspiration (Smith *et al.*, 1991). The calculation can be done using CROPWAT model. Reference evapotranspiration (ET_o) is calculated based on the FAO Penman-Monteith method (Allen et al., 1998) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \text{-----} 2.1$$

where, ET_o = reference evapotranspiration (mm/day),

Rn = net radiation at the crop surface (MJ/m²/day),

G = soil heat flux density (MJ/m²/day),

T = mean daily air temperature at 2 m height (°C),

U2 = wind speed at 2 m height (m/s),

e_s = saturation vapor pressure (kPa),

e_a = actual vapor pressure (kPa),

e_s - e_a = saturation vapor pressure deficit (kPa),

Δ = slope of vapor pressure curve (kPa/°C) and

γ = psychrometric constant (kPa/ °C).

The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water. The updated values of crop coefficients are determined from Allen *et al.* (1998).

$$ET_c = ETo \times Kc \text{-----} 2.2$$

A procedure for calculation of crop evapotranspiration for well-watered conditions using the reference crop approach is recommended by Allen *et al.* (1998).

Reference evapotranspiration (ETo) can be estimated using the Penman-Monteith equation.

Various crop growth stages and their respective lengths are identified for the locations of

interest, and then Kc for the various stages of the crop is determined. Kc values are then adjusted for frequency of wetting condition for rain or irrigation. Then crop coefficient curves are developed to determine Kc values for periods of any length, e.g. monthly or daily periods. Crop ET is then calculated for well-watered conditions for each period of interest as the product of ETo and Kc. Having ETc and all necessary meteorological data, crop water requirement can be computed with the aid of CROPWAT program. The gross water requirement will then be computed assuming 60% of application efficiency as suggested by FAO (1989).

2.5 Irrigation Requirement (IR) and Effective Rain Fall

Irrigation requirement refers to the water that must be supplied through irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the CWR (Yonas, 2012).

Computation of irrigation water requirement (IR) requires long-term rainfall data from each study site. Long-term monthly rainfall data will be obtained from the study sites and probability analysis is used to establish the dependable rainfall occurrence at 20, 50 and 80% probability levels representing wet, normal and dry seasons, respectively. The values obtained are used during the computation of CWR. The net irrigation requirement is calculated using the CROPWAT computer program based on Allen et al. (1998) as follows:

$$IR = CWR - \text{Effective rainfall} \text{-----} 2.3$$

where, IR = irrigation requirement in mm,

CWR = crop water requirement in mm and

Effective rainfall which is part of the rainfall that entered into the soil and made available for crop production in mm.

Different formulae are available to compute effective rainfall; these are fixed percentage, dependable rain, empirical formula and USDA Soil Conservation service method (Ali et al 2017).

2.6 Measurement of Soil Moisture

According to Hansen, *et al.* (1979) in irrigated regions, the capacity of the soil to store available water for use of growing crops is of special importance and interest, because the depth of water to apply in each irrigation and the interval between irrigation are both influenced by storage capacity of the soil. Therefore, measuring soil moisture helps to detect if there is a water shortage that can reduce yields or if there is excessive water application that can result in water logging or leaching of nitrates below the root zone.

There are different soil moisture measuring methods available including gravimetric method, tensiometer, electrical porous blocks, neutron probe and TDR. The gravimetric soil moisture content is typically determined directly. Soil samples was taken from the field with the best available tools (shovels, spiral hand augers, bucket augers, perhaps power-driven coring tubes), disturbing the sample soil structure as little as possible (Dirksen, 1999).

Gravimetric soil analysis is the most trusted one. In this method soil samples are taken with soil auger and weighed and dried in an oven at 105°C for about 24 hours, until all the moisture is driven off. After removing from oven they are cooled slowly at room temperature and weighed again. The difference in weight is the amount of moisture lost from the soil (Michael, 1978).

Soil water content most commonly is expressed as percent water by weight, percent water by volume, or millimeters of water per meter depth of root zone.

2.7 Concept of Alternate, Fixed and Conventional Furrow Irrigation Systems

Furrow irrigation water application system is most popular form of surface irrigation, as it requires a smaller initial investment compared to other types of irrigation water application systems. This type of irrigation method is the most widely used in our country in almost all-large and small irrigation schemes. Apart from the conventional method the use of furrow irrigation can be modified to alternate or fixed furrows so that it can maintain relatively drier soil condition.

2.7.1 Alternate furrow irrigation systems

Alternate furrow irrigation (AFI) is the technique of irrigation water application in which one of the two neighboring furrows alternately irrigated during consecutive watering. This system saves quite a good amount of 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). The water saving property of this system arises from the reduced surface wetting that leads to less evaporation.

Research results indicate that soil evaporation of alternate-furrow irrigation is lower than that of conventional furrow irrigation for the same treatment. The difference in soil evaporation between alternate-furrow irrigation and conventional furrow irrigation would become smaller and smaller with the increase of the lower limit value of soil moisture (Majumdar, 2002).

According to Zhang *et al.* (2000), alternate furrow irrigation method uses less irrigation water but can maintain the same grain yield production as that of conventional furrow irrigation with high irrigation amounts. This is believed to be because of continuous regulation by root drying signal on stomatal inhibition and reduced leaf transpiration. When roots are in drying soil, even in a situation where only part of the root system is dry, substantial ABA is produced in the roots and transported through the xylem to the shoots where stomatal opening is regulated. AFI takes advantage of this physiological response and exposes part of the root system alternatively to the drying soil. This method of watering can lead to continuous stomatal inhibition and reduced leaf transpiration. Photosynthesis and dry matter accumulation are less affected by such partial stomatal closure because photosynthesis and stomatal opening have a saturation relationship. Maximum stomatal opening does not necessarily lead to maximum photosynthesis, and transpiration and stomatal opening, however, have a linear relationship (Zhang and Davies, 1991).

Alternative drying of part of the root system is better than the drying of fixed part of the root zone. This is because alternative drying substantially stimulates more roots growth. In addition, alternate drying favors an even distribution of the root system in the soil, while drying of the fixed root zone resulted in more roots in the wet and less in the dried zone (Kang *et al.*, 1998). Plant water uptake rate is enhanced after re-watering in water stress condition compared to full irrigation. This is obtained due to improvement of hydraulic conductivity of root systems that is subjected to water stress. This compensation in root hydraulic conductivity might be explained by new secondary roots and changes in the old roots when exposed to rewetting (Kang and Zhang, 2004).

AFI is beneficial in minimizing nutrient leaching from the plant root zone. This is due to, on one hand, less water application that can favor nutrient movement within the plant root zone. The significant lateral water movement, on the other hand, helps in keeping nutrient in the root zone rather than leaching it down (Skinner *et al.*, 1999).

AFI can avert severe leaf water deficit, which may develop in the shoots when irrigation is drastically reduced. Evidence for this conclusion is that the AFI treatments show no significant reduction in terms of shoot height and dry matter accumulation when irrigation was reduced. It is well known that leaf growth and shoot elongation are inhibited when shoot water deficit develops and turgor is reduced as a result (Hsiao, 2000).

2.7.2 Fixed furrow irrigation

Fixed furrow irrigation (FFI) means that irrigation is fixed to one of the two neighboring furrows. Usually, this technique applies water to more area in a given amount of time than does irrigating conventional furrow irrigation (Yonts *et al.*, 2003).

FFI do not similarly respond with respect to water use efficiency. The water use efficiency of sugar beet was determined using FFI irrigation in Shiraz and Iran. Due to FFI the water use efficiency has been significantly increased (Sepaskhah and Kamgar-Haghighi, 1997). However, the result of Samadi and Sepaskhah (1984) for dry bean indicated a significant yield reduction. The reduction of yield was due to the smaller amount of applied water.

2.7.3 Conventional furrow irrigation

Conventional furrow irrigation (CFI) or traditional irrigation means irrigating all furrows during consecutive watering. Frequent irrigation under CFI may result in higher evaporation

from the soil surface, especially during the early growing season with incomplete ground cover (Sepaskhah and Kamgar-Haghighi, 1997). This irrigation system is speeding up the processes of decomposition and removal of organic elements and mobile forms of nutrients in the root zone that eventually, brings to soil fertility losses (Karajeh *et al.*, 2000).

2.8 The Tomato plant

According to Shankara *et al.* (2005) Tomatoes are normally transplanted because much better results are gained when seedlings are raised in a nursery. According to Workafris (2009), Tomato has different varieties, including Marglove, Meni-Maker, Roma VF, Melkassa and Melkashola. Areka Agricultural Research Center conducted research on Tomato response to deficit irrigation that shows Roma VF variety was more adapted than the other variety and its elliptical shape was selected by the farmer in Humbo Woreda. The soil type of the study area was clay and rocky after one meter, Due to this reason effective root depth tomato grow up to one meter.

Tomato is rapidly growing crop with a growing period of 90-150 days. Optimum daily temperature for growth is 18-25⁰c with night temperature between 10-20⁰c (Doorenbos and Kassam, 1979). Maximum effective root zone depth (RZD) of tomato ranges between 0.7-1.5m and has allowable soil water depletion fraction (P) of 0.40 (Andreas *et al.*, 2002).

2.9 Experimental design

Experimental design is the manner in which the experimental units are arranged or grouped, and how the treatments are assigned to them. There are three basic types of research design; these include completely randomized design, randomized complete block design and the latin square design. Completely randomized design treatments are assigned randomly to the experimental subjects without restriction and experimental subjects should be homogenous with respect to all other factors which could affect the treatment being compared if they were not controlled. Randomized complete block design divides the experimental subjects into more or less homogenous groups called blocks. Blocking is done to make sure that the experimental subjects in a group have similar characteristics so that observed differences among the groups will be largely due to the treatments (Clewer *et al.*, 2001).

2.10 Economic analysis

According to CIMMYT (1988), the first step in doing an economic analysis of on-farm experiments is to calculate the costs that vary for each treatment. Costs that vary are the costs (per hectare) of purchased inputs, labor, and machinery that vary between experimental treatments. Farmers want to evaluate all the changes that are involved in adopting a new practice. It is therefore important to take into consideration all inputs that are affected in any way by changing from one treatment to another. These are the items associated with the experimental variables. They may include purchased inputs such as chemicals or seed, the amount or type of labor, and the amount or type of machinery. These calculations should be done before the experiment is planted, as part of the planning process, to get an idea of the costs of the various treatments that are being considered for the experimental program.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted at Humbo woreda, woliyta zone of southern nation nationality and peoples of Ethiopia. Humbo Woreda is located 327 km south of Addis Abeba and 15 km from south of the Wolaita Sodo town following the tarmac road that passes through the town to Arbaminch. The Woreda has a total area of about 866 Km² and is composed 42 rural kebeles. The population of Humbo Woreda is about 155,495 of which 49.8% are male and 51.2% are female (CSA, 2007). The study site is geographically located at latitude 06⁰44'N, longitude 037⁰48'E and an altitude 1611m.a.s.l.

3.1.2 Climate

According to the long-term (1995 – 2017) record of meteorological data, the mean annual rainfall in the area is 1001 mm. The mean maximum and minimum monthly rainfall values are 142 mm and 21.7 mm occurring in the month of August and January, respectively. The 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, with the average value of 20.55 °C. The experimental site is in the semiarid climate with mean relative humidity of 62 % and average sunshine hour of 8.2 hrs.

3.1.3 Soil and agronomic practices

In the study area farmers mainly grow Tomato (*Lycopersicon esculentum* Mill.), Onion (*Allium cepa* L.), Pepper (*piper nigrum*), Pigeon pea (*cajanuscajan*), Ginger

(*Zingiberofficinale*), Maize (*Zea may*), Haricot-bean, sorghum, Teff, Sesame and Cabbage, are also among the widely cultivated crops in the area (Alemayehu *et al.*, 2016).

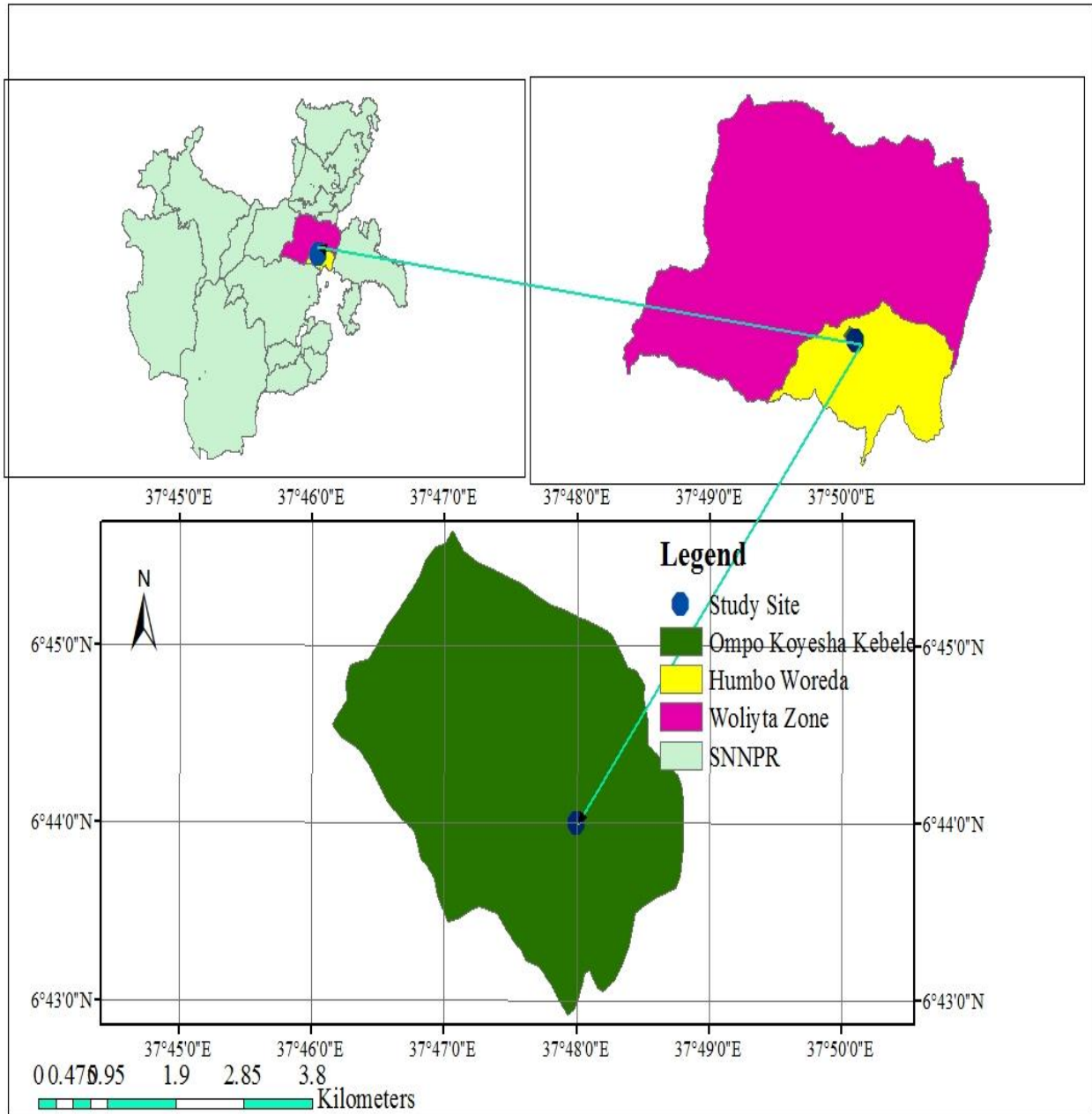


Figure 1: Location Map of Ompokoyesha Kebele of HumboWoreda

3.2 Methods

3.2.1 Experimental design and treatments layout

The experiment had one factor that is variation in types of furrow irrigation methods. The three irrigation methods were Alternate furrow irrigation (AFI), Fixed furrow (FFI) and Conventional furrow irrigation (CFI). Full irrigation requirement, i.e., the amount of irrigation water to satisfy the crop water requirement was computed using CROPWAT model. The experiment was laid out in a RCBD consisting of three treatments. Each treatment had four replications making a total of 12 experimental plots. Based to the dimension used by Areka Agricultural Research Center, each plot had 20 m² (5.0 m x 4.0 m) areas, the space between plots and replications were 1 m and 1.5 m respectively, each plot has six furrows with five ridges and single row tomato with spacing of 30cm between plants and 90cm between rows and a single ridge had 60 cm wide and a single furrow had 30cm wide. Experimental treatments were assigned to the plot by randomizing them within each block. Each plot had 5 rows of tomato plants and 13 plants in each row with a total plant population of 65 in each plot .The experimental site total area was 24.5 m * 14 m = 343 m². The designations for the experimental treatments were:

- T1 = Alternative furrow irrigation (AFI) with 100 % ET_c
- T2 = Fixed furrow irrigation (FFI) with 100 % ET_c
- T3 = Conventional furrow irrigation (CFI) with 100 % ET_c

Where, Conventional furrow irrigation with 100 % ET_c = all furrow get full water requirement, Fixed furrow irrigation with 100 % ET_c = fixed open furrow get full water

requirement and Alternative furrow irrigation with 100% ETc = alternate open furrow get full water requirement.

Layout of Experimental treatment

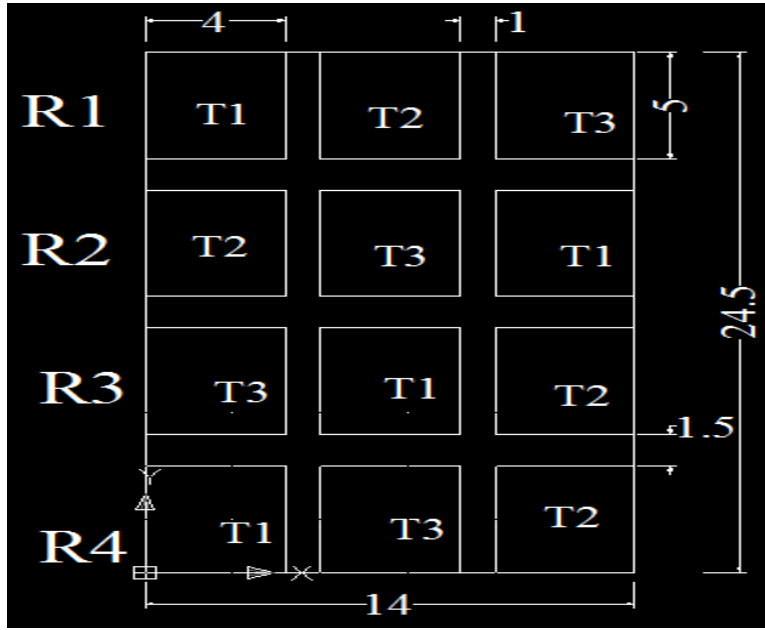


Figure 2: Layout of Experimental treatment

Where, R1, 2, 3, 4 are the four replications respectively

3.2.2 Crop establishment and management practices

Tomato (*Lycopersicon lycopersci*) seeds variety of roma VF was selected based on farmer interest and market acceptability. The selected variety seed was sown on 03 Dec 2017 on a bed 1m width and 10 m length. 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 3 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 1 January 2018 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 100 kg/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. All other agronomic practices other than treatment variables were done in accordance with prevailing local condition.

3.3 Soil data collection

3.3.1 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 first, second, third and forth soil samples were taken at 5 meter diagonally from the corners of the experimental field and the fifth sample was taken from the center of experimental field. Physical and chemical properties of the soil were analyzed. The analysis was carried out at Areka Agricultural Research Center department of soil laboratory. 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).

$$\rho_b = \frac{W_s}{V_c} \text{-----} (3.1)$$

where ρ_b is soil bulk density (g/ cm³), W_s is mass of dry soil (g) and V_c is volume of soil in the core (cm³)

The pH of the soil was measured by means of pH meter in the supernatant suspension of 1:2.5, soil: liquid mixture as described by (Batjes. 1995). Electrical conductivity (EC) of 1:5 soils to water ratio extracts was carried out with a conductivity meter (Yangbo *et al.*,2012).

To determine 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 analyzed 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 point was 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).

$$TAW = \frac{(Fc - PWP)}{100} * BD * Dz \quad \text{-----} \quad (3.2)$$

where, FC and PWP in % on 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.

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 content was determined using the following equation (Cuenca, 1989). The gravimetric water content was calculated by the equation:

$$\theta m = \frac{W_{ws} - W_s}{W_s} * 100 \quad \text{-----} \quad (3.3)$$

where, θm = water content expressed on weight basis in (%), W_{ws} = weight of wet soil (g) and W_s = weight of dry soil (g).

Volumetric water content

$$\theta v = \frac{\rho b}{\rho w} * \theta m \quad \text{-----} \quad (3.4)$$

Where, θ_v = volumetric moisture content in (%), ρ_b = soil bulk density (gcm^{-3}) and ρ_w = water density (gcm^{-3}).

3.3.2 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 ground and 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 water inside the outer ring was avoid lateral movement of water from the inner ring. 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).



Figure 3: Measuring Soil Infiltration Rate and Soil Sampling

3.4 Climate data

Twenty two years (1995-2017) of climate data such as maximum and minimum air temperature, relative humidity, wind speed, sunshine hours, and rainfall were collected from Hawassa Branch of National Meteorological Agency for determination of reference evapotranspiration (ET_o), planning irrigation schedule and crop water requirement. The daily weather data during the growing period were collected from Woliyta Sodo Meteorological Station. Plastic rain gauge was installed to measure rainfall in the experimental field.

Table 1: Average climate data of the study site

Climate	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	22	22	68	122	136	100	141	142	93	77	48	30
Max.temp	29	30	30	28	26	24	23	24	25	26	27	28
Min.temp	14.8	14.8	14.7	14.0	14.2	14.1	14.2	14.4	14.0	14.1	15.1	15.3
Sunshine hr	8	8	7	6	6	4	3	4	5	7	8	8
Wind speed	2.0	2.1	1.8	1.4	1.2	1.4	1.1	1.1	1.1	1.4	2.1	2.2
Relative humidity	48	43	50	64	73	74	78	76	71	65	53	49

Max.temp = maximum temperature (0_C), Min.temp = minimum temperature (0_C), Rainfall (mm),

Wind speed (m/s) and Relative humidity (%).

3.5 Determination of reference evapotranspiration

As indicated in section 2.4 periodic reference evapotranspiration (ET_o) for each day of climatic record was calculated based on the modified FAO Penman-Monteith equation (Allen et al., 1998) using FAO CROPWAT software. The input data for the CROPWAT software include geographical location that is longitude, latitude and altitude of the study site, daily

values of maximum and minimum air temperatures, air humidity, sunshine duration and wind speed.

3.6 Crop data

As indicated in Table 2, 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 2: Crop data required for CWR determination

Crop data	Growth stage			
	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 () data were from Areka agricultural research center

3.7 Crop and irrigation water requirement

The amount of water needed (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires reference evapotranspiration (ETo) and tomato crop coefficient (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 season stage. 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:

$$IR = CWR - Pe \text{ -----(3.5)}$$

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.

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

$$Pe = 0.6 * P - 10 \text{ For } P_{\text{month}} \leq 70 \text{ mm -----(3.6)}$$

$$Pe = 0.8 * P - 24 \text{ For } P_{\text{month}} > 70 \text{ mm -----(3.7)}$$

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

However, since there was no rainfall during the experimental period, Pe is equal to zero and net irrigation requirement (IRn) was taken to be equal to the crop water requirement (ETc).

3.8 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:

$$I_g = \frac{I_n}{E_a} \text{ -----(3.8)}$$

where, Ig = the gross 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):

$$t = \frac{I_g * l * w}{6 * Q} \text{-----(3.9)}$$

where, I_g = 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.

3.9 Agronomic data collection

During harvesting Stand count, weight and fruit number of marketable yield, weight and fruit number of unmarketable yield were measured from the net harvested area of each plot. The data were taken from the central three plant rows and the net area of each plot is 4 m by 3 m. This was done to avoid border effects. Unmarketable fruit yield was obtained from the fruit that were affected by pest, bird attack, rotten and under size. The weight of total (marketable and unmarketable) fruit yields per plot at harvesting from the net area were recorded and summed up to estimate yield per hectare.

The results were converted to hectare basis using the following formula:

$$\text{Yield obtained per ha} = \text{Yield obtained per square meter} \times 10^4 \text{ ----- (3.10)}$$

3.10 Water use efficiency

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

$$WUE = \frac{Y}{ETc} \text{ ----- (3.11)}$$

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

3.11 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(ET_a). A standard formulation equation relates these four parameters (Y_a , Y_m , ET_a , ET_m) to K_y , which links relative yield decrease to relative evapotranspiration deficit (Vaus and Pruitt, 1983):

$$k_y = \frac{(1 - \frac{y_a}{y_m})}{(1 - \frac{ET_a}{ETM})} \text{-----}3.12$$

where, Y_a = actual yield (kg/ha), Y_m = maximum yield (kg/ha), ET_a = actual evapotranspiration (mm), ET_m = maximum evapotranspiration (mm), K_y = yield response factor.

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

3.12 Economic 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. Economic data includes input cost like cost for water (water pricing), seeds, fertilizers, fuel and labor. However, cost of water price and labor are the cost that varies between treatments. The net income (NI) treatments were calculated by subtracting total cost (TC) from gross income (GI) and were computed as:

$$NI = GI - TC \text{3.13}$$

The difference between net income of a treatment and its next higher variable cost treatment termed as change in net income (ΔNI). Higher net benefits may not be attractive if they require very much higher costs (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:

$$MRR = \frac{\Delta NI}{\Delta VC} \text{3.14}$$

Where, MRR= marginal rate of return, ΔNI = change in net income, ΔVC = change in variable cost

3.13 Statistical Analysis

The collected data were analyzed using Statistical Agricultural Software (SAS 9.0) and least significance difference (LSD) was employed to see a mean difference between treatments and the data collected was statistically analyzed following the standard procedures applicable for RCBD with single factor. The treatment means that were different at 5% levels of significance were separated using LSD test. Appendix Table 6 syntax was used to analyze the data in SAS system and mean value with the same letter are not significantly different.

The randomized complete block design (RCBD) is perhaps the most commonly encountered design that can be analyzed as a two-way ANOVA. In this design, a set of experimental units is grouped (blocked) in a way that minimizes the variability among the units within groups (blocks). The objective is to keep the experimental error within each block as much as possible. Each block contains a complete set of treatments, therefore differences among blocks are not due to treatments, and this variability can be estimated as a separate source of variation. The removal of an appreciable amount of this source of variation reduces experimental error and improves the ability of the experiment to detect smaller treatment differences (Jiju, 2003).

4. RESULTS AND DISCUSSIONS

To identify the response of tomato to alternate, fixed and conventional furrow irrigation systems a number of direct and indirect measurement were made. This includes analysis of physical and chemical properties of experimental site soil, yield response, crop water use, economic water productivity and water use efficiency.

4.1 Physical and Chemical properties of Soil

In order to characterize soils of the study site, soil physical and chemical parameters were measured in the field and laboratory. The results are presented as follows.

4.1.1 Physical properties

The laboratory results of the mean soil physical properties of the experimental site are presented in Table 3. The result of the soil analysis from the experimental site showed that the mean composition of sand, silt and clay percentages were 24.5%, 9% and 66.5%, respectively. Thus, according to the USDA soil textural classification, the percent particle size determination for experimental site revealed that the soil texture could be classified as clay soil. The top soil surface had slightly lower bulk density (1.15 g/cm^3) than the subsurface (1.34 g/cm^3). 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/cm^3 tend to restrict root growth (McKenzie et al., 2004). In general, the average soil bulk density of the experimental site is 1.27 g/cm^3 which falls in clay soil ranges and was suitable for crop root growth.

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 total average available 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 3: 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/cm ³)		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 data collected at the field from double ring infiltrometer on infiltrated depth and time taken is presented in Appendix Table 3. This data was used to generate the cumulative infiltration and the infiltration rate curves as shown in Figure 4.

The basic infiltration rate in this experiment was found to be 4.8 mm/hr which is in the lower range of clay soil (1-5mm/hr) (Hillel, 2004). This means that a water layer of 4.8 mm on the soil surface was take one hour to infiltrate.

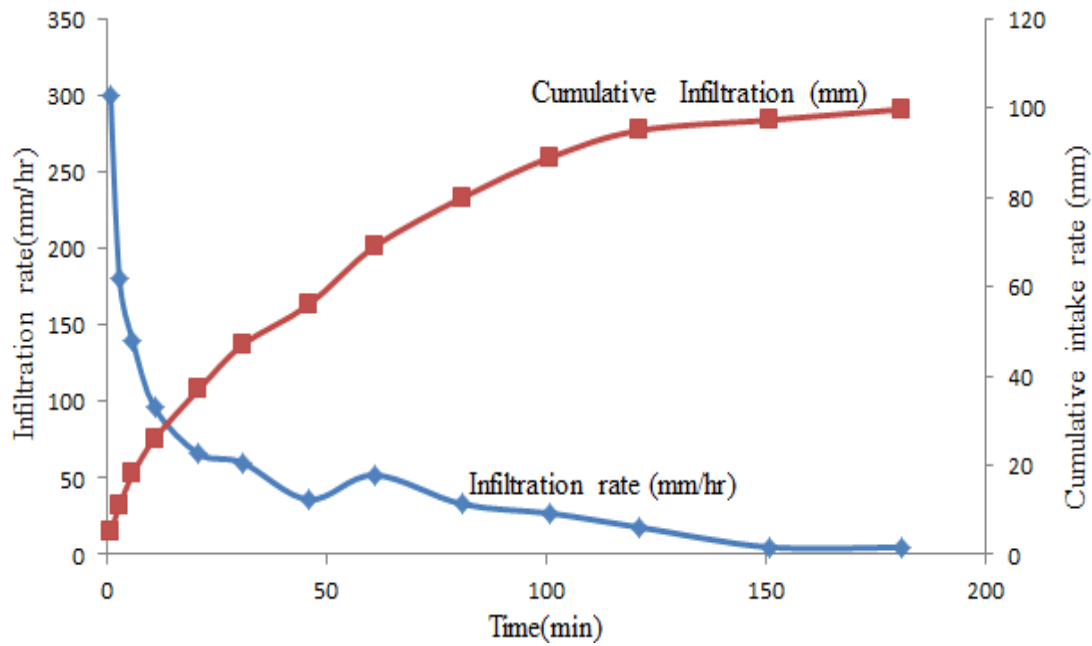


Figure 4: Cumulative Intake Depth and Cumulative Infiltration Rate of Experimental Soil

4.1.2 Chemical properties

As indicated in Table 4, 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 1.1 dS/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 4: 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

4.2 Crop and Irrigation Water Requirements of Tomato

Figure 5 shows the reference evapotranspiration (ET_o) 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.

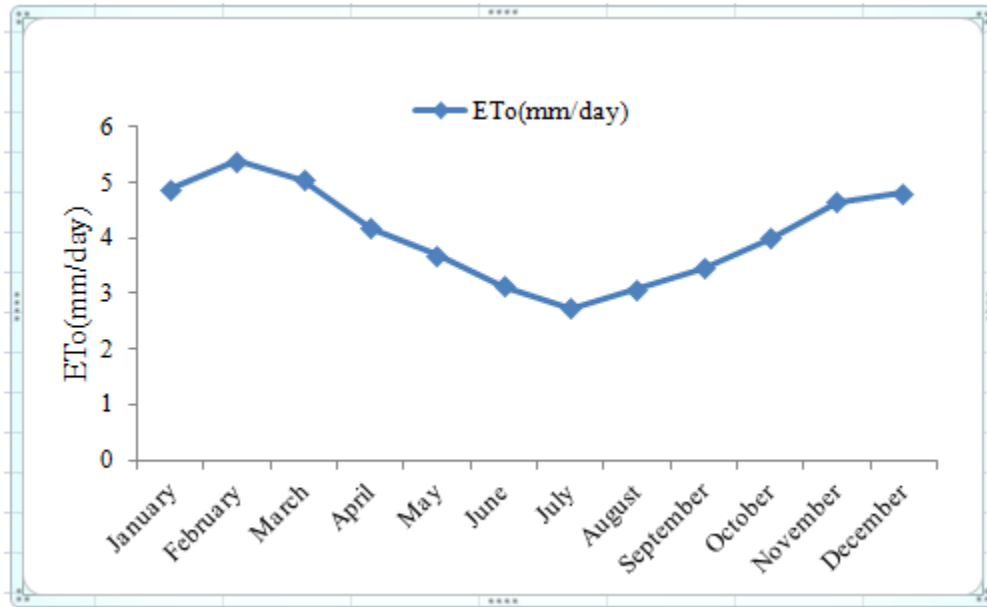


Figure 5: ET_o of the experimental site

In the absence of rainfall and considering tomato (*Lycopersicon lycopersci*) 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 6, 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.

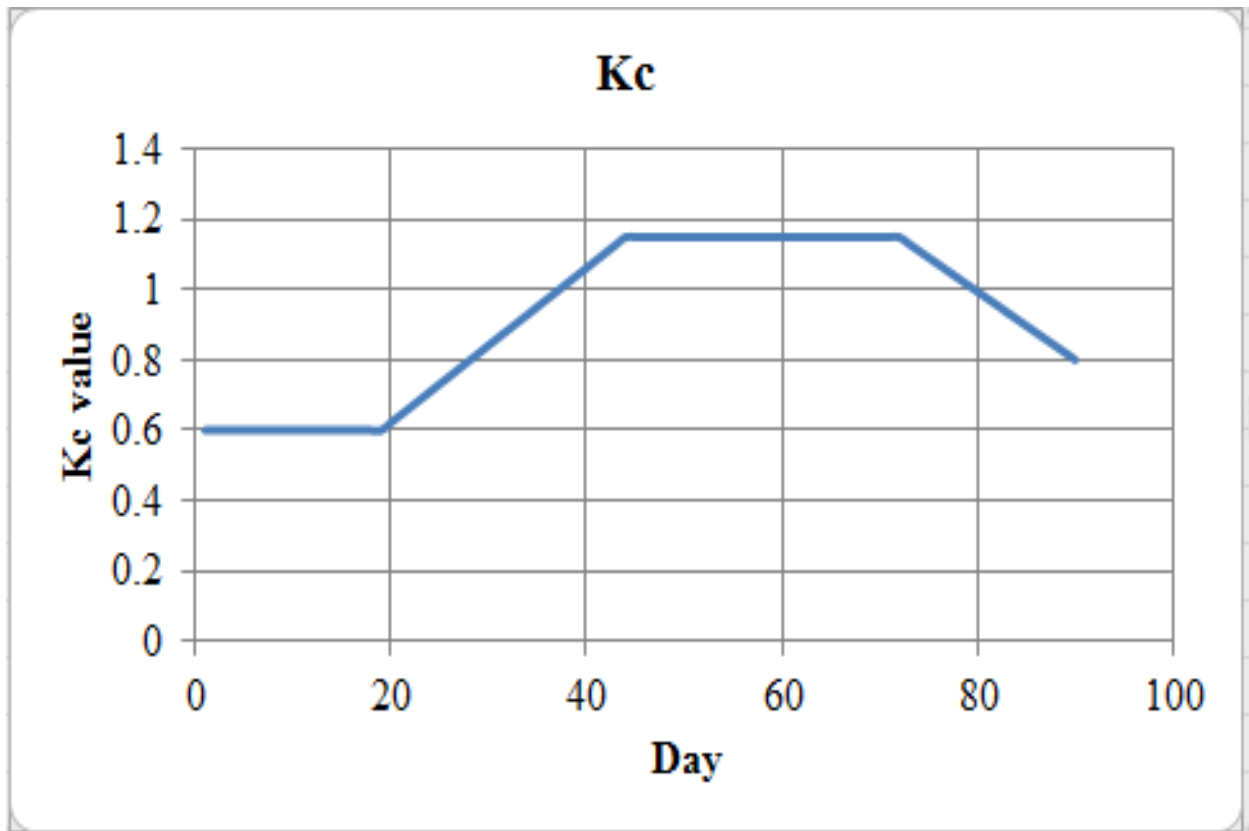


Figure 6: Crop coefficient value of Tomato

The amount of water required by tomato was increasing from initial period to mid period. The maximum irrigation water (41.2 mm) was required at mid-March of mid stage. In this stage tomato was attained its maximum crop coefficient and there was high reference evapotranspiration. At late period the water required was reduced due to reduction crop coefficient value.

Table 5: 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.

As shown in Table 5, total amount of water required by tomato crop through the growing period was 415.7mm. Similarly, the net irrigation requirement was 415.7 mm which the same as the crop water requirement. This is due to the absence of rainfall during the experimental period. Assuming the irrigation efficiency of surface irrigation to be 60 %, gross water requirements of tomato in the study site was 692.8 mm. The seasonal evapotranspiration was the highest (448.56 mm).

4.3 Irrigation Water Application on the Experimental Plots

All plants were initially well watered as pre-irrigation for the first irrigation events to ensure a good establishment of seedlings and subsequent plant growth. Based on CROPWAT model output there is 2% and 1% yield reduction at 6 and 5 day irrigation interval. But, in 4 day irrigation interval, there was no yield reduction. Therefore irrigation water was applied in a 4 days interval. The field irrigation application efficiency was assumed to be 60 % for furrow irrigation. The different irrigation treatments were (1) Alternate furrow irrigation (AFI): irrigation water applied to neighboring furrow alternately during consecutive watering. (2) Fixed furrow irrigation (FFI): crop water requirement applied to three opened furrows. The other three neighboring furrows closed and did not watering through the season. (3) Conventional furrow irrigation (FI): 100% crop water requirements applied uniformly to all furrows. The amount of water applied to each plot was measured via a three inch throat width Parshall flume installed at the inlet of the experimental field. The amount of water applied and time of application required for alternative and fixed furrow irrigation in each plot was half of the full irrigation. At 5 cm head three inch throat width Parshall flume has discharge of 1.7 liter per second (Kandiah, 1981).

Table 6: Irrigation Water Management

Date	T3	T2	T1	Area (m ²)	Dischare at 5 cm head(l/s)	T3	T2	T1	
	IRn (mm)	IRg (mm)	IRg (mm)			IRg (mm)	Time (min)	Time (min)	Time (min)
4-Jan	11.7	19.5	9.8	9.8	20	1.7	3.8	1.9	1.9
8-Jan	11.7	19.5	9.8	9.8	20	1.7	3.8	1.9	1.9
12-Jan	11.7	19.5	9.8	9.8	20	1.7	3.8	1.9	1.9
16-Jan	11.7	19.5	9.8	9.8	20	1.7	3.8	1.9	1.9
20-Jan	11.7	19.5	9.8	9.8	20	1.7	3.8	1.9	1.9
24-Jan	13.1	21.8	10.9	10.9	20	1.7	4.3	2.1	2.1
28-Jan	15.0	25.1	12.5	12.5	20	1.7	4.9	2.5	2.5
1-Feb	18.3	30.5	15.3	15.3	20	1.7	6.0	3.0	3.0
5-Feb	20.2	33.7	16.8	16.8	20	1.7	6.6	3.3	3.3
9-Feb	22.2	36.9	18.5	18.5	20	1.7	7.3	3.6	3.6
13-Feb	24.1	40.2	20.1	20.1	20	1.7	7.9	3.9	3.9
17-Feb	24.7	41.2	20.6	20.6	20	1.7	8.1	4.0	4.0
21-Feb	24.7	41.2	20.6	20.6	20	1.7	8.1	4.0	4.0
25-Feb	24.7	41.2	20.6	20.6	20	1.7	8.1	4.0	4.0
1-Mar	23.2	38.6	19.3	19.3	20	1.7	7.6	3.8	3.8
5-Mar	23.2	38.6	19.3	19.3	20	1.7	7.6	3.8	3.8
9-Mar	23.2	38.6	19.3	19.3	20	1.7	7.6	3.8	3.8
13-Mar	23.2	38.6	19.3	19.3	20	1.7	7.6	3.8	3.8
17-Mar	22.2	37.0	18.5	18.5	20	1.7	7.3	3.6	3.6
21-Mar	19.8	32.9	16.5	16.5	20	1.7	6.5	3.2	3.2
25-Mar	19.2	31.9	16.0	16.0	20	1.7	6.3	3.1	3.1
29-Mar	16.1	26.9	13.4	13.4	20	1.7	5.3	2.6	2.6
Total	415.7	692.8	346.5	346.5					

T1=Alternative furrow irrigation (AFI) with 100%ETc, T2=Fixed furrow irrigation (FFI) with 100%ETc, T3=Conventional furrow irrigation (CFI) with 100%ETc, IRn = Net irrigation, IRg = Gross irrigation

4.4 Effects of Furrow Irrigation Systems of Tomato Yield

The result in Table 7 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 conventional furrow irrigation systems while, the minimum marketable yield (14.4 ton/ha) was obtained from fixed furrow irrigation system. The decrease in the yield is directly related with the variation of types of furrow irrigation system. Marketable fruit number also showed significant difference between the treatments and has consistency with marketable yield. The maximum and minimum fruit number (448958, 296250) was recorded in conventional and fixed furrow irrigation systems, respectively. Alternative furrow irrigation gives 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 under size. The result revealed that unmarketable yield was statistically non-significant between the treatments. 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 highest total fruit yield (32 ton/ha) was obtained from conventional furrow irrigation system and the minimum total yield (22.3 ton/ha) was gained from fixed furrow irrigation systems.

Table 7: Water use efficiency and Tomato response to furrow irrigation system

TRT	MY(ton/ha)	MFNO	UY(ton/ha)	UMFNO	TY(ton/ha)	WUE(kg/m ³)
AFI	18.3 ^b	353125 ^{ba}	7.0	193125.0	25.4 ^b	8.82 ^a
FFI	14.4 ^c	296250 ^b	7.9	214166.7	22.3 ^b	6.91 ^b
CFI	24.0 ^a	448958 ^a	8.1	242916.7	32.0 ^a	5.76 ^b
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.

4.5 Water use efficiency

The analysis of variance indicated that the types of furrow irrigation systems were significantly ($p < 0.05$) affected the irrigation water use efficiency of tomato. The result in the table 7: 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 water actually converted to evapotranspiration out of the total amount applied. This is consistent with the 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 8: Water use efficiency and amount of water saved

TRT	MY(kg/ha)	CWR(mm)	AW(mm)	Saved water(mm)	Yield reduction (%)	WUE(kg/m ³)	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

4.6 Yield response factor

Table 9 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 9: 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, CFI= conventional

4.7 Economic analysis

The application of water in water saving irrigation system could be economically attractive to minimize drought hazards in water shortage areas. Cost benefit ratio for each treatments were analyzed and income was computed based on the current local market price of tomato at Humbo Woreda.

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 cost of drinking water as the cost 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 it is indicated in table 10, 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 net income of 150,381 birr/ha and MRR of 3858 %. The MRR tell us that the amount of additional income obtained for every 1 birr spent. Hence, AFI acquired additional 38.58 birr for every 1birr spent.

Table 10: Economic analysis

TRT	AW	OY	GI	FC	VC	TC	NI	MRR
	(m ³ /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

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Most of the farmers in Humbo Woreda depend on rain-fed agriculture. However, rainfall is very erratic, and drought occurs very frequently. Humbo Woreda is one of the drought-prone woreda in Woliya Zone. However, proper management of irrigation water has received inadequate attention, while the cost incurred for constructing small-scale irrigation schemes is much more. Therefore, efficient use of irrigation water using appropriate irrigation system and management is an important consideration in the drought prone areas of the region for improved crop production.

One of the main challenges facing both rain fed and irrigated agriculture is to improve WUE and sustainable water use for agriculture. Appropriate irrigation system and management in agriculture adopted to have significant impact on water saving. This strategy is introduced primarily to save water and improve WUE for consumption of less water. However, it also delivers many other economic and social benefits to the society.

The following conclusions are drawn from this research:

- A maximum fruit yield of 32 ton/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.
- Alternative furrow irrigation (irrigation water application in which one of the two neighboring furrows alternately irrigated during consecutive watering) gives relatively better

yield i.e 25.4 ton/ha than fixed furrow irrigation (irrigation is fixed to one of the two neighboring furrows through the growing season) that yield (22.3 ton/ha).

- The highest water use efficiency (8.82 kg/m^3) was obtained under alternative furrow irrigation and save 50 % water and the minimum water use efficiency (5.76 kg/m^3) was obtained during conventional furrow irrigation system.
- Alternative furrow irrigation was also economically feasible because of its higher return rates. Therefore, it could be concluded that increased water saving and water productivity through AFI would ensure the scope of further irrigation development so as to alleviate food insecurity issues that emanate from water shortage. Significant amount of water ($2078.5 \text{ m}^3/\text{ha}$) was saved by AFI system while it also maintains an acceptable tomato yield and quality.
- In area where enough water is available, applying water at conventional furrow irrigation system through growing season is advisable to obtain maximum tomato yield. However, in water scarce areas like Humbo woreda, applying irrigation water through alternative furrow irrigation system is advisable with a minimum reduction of yield.

5.2 Recommendation

- Alternative furrow irrigation system is the best technology among the tested furrow irrigation technologies to be recommended for the communities of the study area, because of its high water application efficiency in addition to saving time, labor and irrigation.
- The test crop considered here is tomato, but other crops like Potato, Onion, Cabbage, and Maize are also growing under the study area. Hence water saving furrow irrigation system should also be tested for other crops.
- The only tomato variety in this research used was Roma VF, so additional research work is necessary for other variety like Marglove, Meni-Maker, Melkassa and Melkashola.
- As the experiment was carried out only in one season and one place, repeating the experiment in space and time is important to improve the validity of the finding.
- Due to resource constraint, this experiment evaluates the furrow irrigation systems in saving the applied water. So, future research work carried out considering different furrow irrigation system and different water application levels.

6. REFERNCES

- Alemayehu,A., Derib,W. and Taye, B.,(2016).Onion Market Chain Analysis in Humbo District of Wolaita Zone, Southern Ethiopia. *International Journal of Scientific Research & Engineering Trends*, 2(1), 9.
- Ali,M.H., and Mubarak,s.,(2017). Effective Rainfall Calculation Methods for Field Crops: An Overview, Analysis and New Formulation. *Asian Research Journal of Agriculture*, 7(1), 1-12. DOI: 10.9734/ARJA/2017/36812.
- Allen, R.G. (2010). Reference evapotranspiration calculator. Software for FAO and ASCE Standardized Equations. University of Idaho Versão 2.01.17 Disponível em: <http://www.kimberly.uidaho.edu/ref-et>.
- Allen, .R., Pereira, L.A., Raes, .D. and Simth, M., (1998). Crop Evapotranspiration Guidelines for Computing Crop Water Requirement. FAO Irrigation and Drainage Paper Number 56, FAO, Rome, Italy.
- Andreas, P. and Karen, F., (2002). Crop Water Requirements and Irrigation Scheduling. Irrigation Manual Module 4. Harare, 86p.
- Batjes, N. H.,(1995). A global data set of soil pH properties. international soil reference and information center. Technical paper 27.
- Bauder ,J. W., Bauder ,T., Cardon, G. and Schneekloth. J., (1988). Guide to choosing crop well-suited to limited irrigation. Montano State University, Colorado State University and Utah State University.

- Bianchi, S.R., Miyazawa, M., Iveira, E.L. and Pavan, M. A. (2008). Relationship between the Mass of Organic Matter and Carbon in Soil. *An international journal of Brazilian Archives of Biology and Technology*, 51(2), 263-269.
- Brewster, J.L, (1990a). Physiology of crop growth and Blubbing, pp53-88: In: ItaimD.Rabinowitch and J.L.Brewster(eds). Onions and Allied crops. Volume I, Botany, physiology, and genetics. CRC press. Boca Raton, Florida. 3p.
- Brouwer, C. and Prins, K., (1989). Irrigation Water Management: Irrigation Scheduling. Training manual no. 4. FAO. Rome, Italy.
- Brouwer, C., Goffeau, A. and Heibloem, M., (1985). Irrigation Water Management: Introduction to irrigation. Training manual no. 1. FAO. Rome, Italy.
- Cimmity (International Maize and Wheat Improvement Center). 1988. From Agronomic data to Farmer Recommendations: An Economics Training Manual. Completely Revised Edition. Mexico. D.F.
- Clewer, A. G., and Scarisbrick, D. H., (2001). Practical statistics and experimental design for plant and crop science. John Wiley & Sons Ltd., New York.
- Commission for Africa (2005). Report of the Commission for Africa. Commission for Africa. London.
- Co-SAERSAR (2000) Maintenances and Rehabilitation Strategies for Small Scale Irrigation Projects. Awassa.
- CSA (Central Statistical Authority), (2007). Area and Production of Major Crops. Sample Enumeration Survey. Addis Ababa, Ethiopia. 122p.

Cuenca, R.H., 1989. Irrigation system Design: An Engineering Approach. Prentice-Hall Inc. NJ. 552p.

Derek G. G., Ferre, T. P.A. , Thorp ,K.R. and Rice, A.K.,(2015). Hydrologic-Process-Based Soil Texture Classifications for Improved Visualization of Landscape Function. doi:10.1371/journal.pone.0131299

Deribew Shanko, (2006). Performance evaluation of alternate, fixed and conventional furrow irrigation systems for onion production. MSc Thesis Presented to the School of Graduate Studies of Haramaya University, Harer, 103p.

Dirksen, C., (1999). Soil Physics Measurements. Catena Verlag, Reiskirchen, Germany, 154 p.

Doorenbos J. and Kassam, A.H., (1979). Yield response to water. FAO Irrigation and Drainage Paper Number 33. Rome, Italy. 193P.

Doorenbos, J. and Pruitt, W.O., (1977). Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper Number 24. Rome, Italy. 179 p.

Einsenhaver, D.E. and Youth, C.D., (1992). Managing Furrow Irrigation System. Central Plains Irrigation. Nebraska, USA.

English M (1990). Deficit irrigation I: Analytical framework. *J. Irrigation Drainage Eng.*, 116(3), 399-411.

English, M.J., Solomon, K.H. and Hoffman, G.L., (2002). A Paradigm Shift in Irrigation Management. *J. Irrig. Drain. Eng.*, 128, (5), 267–277.

- Fabeiro C, Olalla, F.J. and Opezurrea, R. L., (2003). Production of garlic (*Allium sativum* L.) under controlled deficit irrigation in a semi-arid climate. *Agricultural Water Management*, 59 (2), 155–167.
- FAO (Food and Agriculture Organization), (1989). Guidelines for Designing and Evaluating Surface Irrigation Systems. Irrigation and Drainage Paper Number 45, Rome, Italy.
- FAO (Food and Agricultural Organization), (1996). Irrigation Scheduling: From theory to practice. Water Reports 8. Food and Agricultural Organization of the United Nations. Rome, Italy.
- FAO (Food and Agricultural Organization), (2000). The state of food security and agriculture. World water development report. Food and Agricultural Organization of the United Nations. Rome, Italy.
- FAO (Food and Agricultural Organization), (2001). AQUASTAT-FAO's information systems on water and agriculture. http://www.wcaifonet.org/cds_static/en/qstat_fao_information_system_water_ethiopia_en_569_14376 (Online 5/24/2012).
- FAO (Food and Agricultural organization), (2002). Deficit irrigation practices. Water reports 22. Food and Agricultural Organization of the United Nations. Rome, Italy.
- FAO (Food and Agricultural organization), (2003). Food Agriculture and Water. World water development report. Food and Agricultural Organization of the United Nations. Rome, Italy.

FAO (Food and Agricultural Organization), (2005). AQUASTAT.FAO's Information System on Water and Agriculture.

<http://www.fao.org/ag/agl/aglw/aquastat/countries/ethiopia/index.stn>.

FAO (Food and Agriculture Organization of the United Nations), (2012). Coping with Water Scarcity: An Action Framework for Agriculture and Food Security. Water Reports 38, Rome, Italy.

Fereres, E. and Soriano, M.A. (2007). Deficit irrigation for reducing agricultural water use. *Journal Experimental Botany*, 58 (2), 147–159.

Gijón, M.C., Guerrero, J., Couceiro, J.F., Moriana, A., (2007). Deficit irrigation without reducing yield or nut splitting in pistachio (*Pistaciavera* cv. Kerman on *Pistaciaterebinthus* L.). *Agricultural Water Management*, 96 (1), 12-22.

Gotardo, J.T., Rodrigues, L.N., Gomes, B.M., (2016). Comparison of Methods For Estimating Reference Evapotranspiration: An Approach to the Management of Water Resources Within an Experimental Basin in the Brazilian Cerrado. *Journal of the Brazilian Association of Agricultural Engineering*. Doi:<http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v36n6p1016-1026/2016>.

Hagos, F., Makombe, R.E. and Awulachew, S.B., (2009). Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation. IWMI Research Report 128. International Water Management Institute. Colombo, Sri Lanka. 37p.

Hansen V.E., Israelson O.W. and Stringham, G.E., (1979). Irrigation principles and practices. John Wiley and Sons, Newyork.

Hillel, D., (2004). Introduction to environmental soil physics. University of Massachusetts, *ELSEVIER Academic Press*. New York. 493p.

Hsiao, T. C., (2000). Leaf and Root Growth in Relation to Water Status. *Hortcul.Sci.*, 35,1051-1058.

Hunt, N. and Gilkes, R., (1992) Farm Monitoring Hand Book. The University of Western Australia: Nedlands, WA.

Hussain, I. and Biltonen, E. (2001). Irrigation against Rural Poverty: An Overview of Issues and Pro-Poor Intervention Strategies in Irrigated Agriculture in Asia; Proceedings of National Workshops on Pro-Poor Intervention Strategies in Irrigated Agriculture in Asia Bangladesh, China, India, Indonesia, Pakistan, and Vietnam. International Water Management Institute; Colombo, Sri Lanka

Langan, S.; Kebede, H.; Tadesse, D.; Terefe, B. (Eds.). (2015). Proceedings of the Launching Workshop of the Agricultural Water Management Platform, Addis Ababa, Ethiopia, 15-16 January 2015. Colombo, Sri

Lanka: International Water Management Institute (IWMI). 56p. doi: 10.5337/2015.210 Jiju Antony, (2003). Design of Experiments for Engineers and Scientists

Kadayifci A., Tuylu, G.I., Ucar, Y., and Cakmak, B.G.I., (2004). Crop water use of Onion (*Allium Cepa L.*) in Turkey. *Agricultural Water Management*, 72, 59-68.

Kandiah, A., (1981). Guide for Measurement of Irrigation Water Using Parshall Flumes and Siphons, Technical Bulletin Number 1, Irrigation Agronomy Section, Melka Werer Research Station, Institute of Agricultural Research, Ethiopia, Addis Ababa

- Kang S., Liang, Z., Hu, W., and Zhang, J., (1998). Water use efficiency of controlled root division alternate irrigation on maize plants. *Jornal of Agricultural Water Management*, 38, 69-76.
- Kang, S., Liang, Z., Pan, Y. and Zhang, J., (2000). Alternate furrow irrigation for maize production in an arid area. *Jornal of Agricultural Water Management*, 45, 267-274.
- Kang, S.Z., and Zhang, J.H., (2004). Controlled alternate partial root-zone irrigation: its Physiological consequences and impact on water use efficiency. *Journal of Experimental Botany*, 55, 2437-2446.
- Karajeh, F., Mukhamedjanov, V. and Vyshepol'skiy, F., (2000). On-farm water and drainage management strategy in Kazakhstan's Arys-Turkestan area. Taraz, Kazakstan.
- Kebede Woldetsadik, (2003). Shallot (*Allium cepavar, ascolonicum*) Responses to Plant Nutrients and Soil Moisture in a Sub- humid Tropical Climate. PhD Thesis on Agricultural Science. Swedish University, 311P.
- Kirda, C, R. Kanber and K. Tulucu, (1999). Yield response of cotton, maize, soybean, sugar beet, sunflower and wheat to deficit irrigation. In: C. Kirda, P. Moutonnet, C. Hera and D.R. Nielsen, (eds). Crop yield response to deficit irrigation. Kluwer Academic Publishers. Dordrecht, The Netherlands.
- Kirda, C.2002. Deficit irrigation scheduling based on plant growth stages showing water stress
- Lorite, I.J., Mateos, L., Orgaz, F. and Fereres, E., (2007). Assessing deficit irrigation strategies at the level of an irrigation district. *Agricultural water management*, 91, 51 – 60.

- Majumdar, D. K., (2002). Irrigation Water Management, Principles and practice. New Delhi, India. 487p.
- McKenzie, N., Coughlan, K. and Cresswell, H., (2002). Soil Physical Measurement and Interpretation for Land Evaluation. CSIRO Publishing. Collingwood, Victoria.
- Mekonen Ayana. (2011). Deficit irrigation practices as alternative means of improving water use efficiencies in irrigated agriculture: Case study of maize crop at Arba Minch, Ethiopia. *African Journal of Agricultural Research*, 6(2), 226-235.
- Michael, A. M., (2008). Irrigation theory and Practice, Second edition VIKAS Publishing house Pvt Ltd. India. 768p.
- Mitslal Gebreslassie, 2008. Performance of alternate and conventional furrow irrigation methods on maize (*Zea mays* L.) production. MSc Thesis Presented to the School of Graduate Studies of Alemaya University, Harer, 86p.
- Moutonnet, P., (2002). Yield response factors of field crops to deficit irrigation. International Atomic Energy Agency, Joint FAO/IAEA Division, Vienna, Austria; In: Deficit irrigation practices. FAO water report 22. Food and Agricultural Organization of the United Nations. Rome, Italy.
- Olalla, FJ., Dominguez-Padilla, A., and Lopez, R. (2004). Production and quality of the onion crop (*Allium cepa* L.) cultivated under deficit irrigation conditions in a semi-arid climate. *Agric. Water Manage.*, 68, 77-89.

- Owusu-Sekyere, J.D., Asante, P., and Osei-Bonsu, P. (2010). Water requirement, deficit irrigation and crop coefficient of hot pepper (*Capsicum frutescens*) using irrigation interval of four days. *ARPJ. Agric. and Biol. Sci.*, 5 (5), 72-78.
- Peirce, L.C., (1987). *Vegetables characteristics, production and marketing*. John Wiley and Sons.Inc. Toronto, Canada.
- Pereira, L.S., Owes,T., and Zairi,A., (2002). Irrigation management under water scarcity. *Agric.Watermanag. J.*, 57, 175-206.
- Samson Bekele and Ketema Tilahun. (2007). Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. *Agricultural water management*, 89,148-152.
- Sepaskhah, A.R., and Kamgar-Haghighi, A.A., (1997).Water use and yield of sugar beet grown under every-other furrow irrigation with different irrigation intervals. *Agricultural Water Management*, 34, 71-79.
- Sezen, S. M., Yazar, A., Akyildiz, A., Dasgan, H. Y., and Gencel, B., (2008). Yield and quality response of drip irrigated green beans under full and deficit irrigation. *Scientia Horticulturae*, 117(2), 95-102.
- Shankara.N., Lidetde,J., Goffau, M., Hilmi, M. and VanDam B.,(2005). Cultivation of Tomato Production, Processing and Marketing. *Agrodok-series*, 17, 93p
- Shock, C.C., Feibert, E.B.G., and saunders, L.D., (1998). Onion yield and quality affected by soil water potentials as irrigation threshold. *Horticultural Science*, 33, 1188-1191.
- Sijali, I. (2001). *Drip irrigation: Options for smallholder farmers in Eastern and southernAfrica*. *RELMA Technical Hand Book Series*, Nairobi, Kenya, 24p.

- Skinner, R.H., Hanson, J.D. and Benjamin, J.G., (1999). Nitrogen uptake and partitioning under alternate- and every-furrow irrigation. *Plant and Soil*, 210, 11–20.
- Sleper, D.A., Fales, S.L., and Collins, M.E., (2007). Foreword In: Irrigation of agricultural crops (Lascano R.J. and Sojka, R.E. eds.). 30, 2nd edition. Agronomy Monograph. ASACSSA-SSSA publishing, 664p.
- Smith, K.A. and Mulins, C.E., (1991). Soil analysis, physical methods. Edinburgh school of Agriculture, Edinburgh, Scotland, Marcel Dekker, INC, 111p.
- Soil Feasibility and Agronomy Report (2007). Report on Mydum Dam. Western Zone of Tgiray.34p.
- Steduto P, Hsiao TC, Raes D, Fereres E .2012.Crop yield response to water. Food and agricultural organization of the united nations, Rome, Italy
- USAID. (2009). East Africa Regional Food Security Outlook. Famin Early Warning System. www.fews.net/east/africa/ethiopia.
- Vaus H.J., Pruit, W.O., (1983).Crop water production functions. In: Hillel D. (Ed.) advance in irrigation. Academic Press New York, 2: 61-97
- Walker, W. R., (2003). Guidelines for Designing and Evaluating Surface Irrigation Systems. FAO Irrigation and Drainage Paper Number 45. Food and Agricultural Organization of the United Nations. Rome,Italy.
- Werner, H., (2002). Measuring Soil Moisture for Irrigation Water Management. <http://agbiopubs.sdstate.edu/articles/FS876>.

- Woldesenbet Gebre. (2005). Evaluating Alternate furrow irrigation for potato production in sub-humid area of east gojam. Degree of master of science in soil and water engineering. Alemaya University, Alemaya, 92p.
- World Bank Water Resource Assistance Strategy for Ethiopia, (2006). Managing Water Resources to Maximize Sustainable Growth: Agriculture and Rural Development Department, World Bank. 119p.
- Yangbo,H., DeSutter, T., Prunty,L., Hopkins, D.(2012). Evaluation of 1:5 soil to water extract electrical conductivity methods. DOI: 10.1016/j.geoderma.2012.03.022.
- Yonas Zeleke. (2012). Optimizing water productivity and cropping pattern using linear programming model: a case study for amibara irrigation scheme in afar region, Ethiopia. Degree of Master of Science in Irrigation Engineering. Ale maya University, Alemaya, 86p.
- Yonts, C.D., Eisenhauer, D.E. and Varner, D. (2003). Managing furrow irrigation system. Cooperative extension, Institute of Agriculture and Natural Resources. University of Nebraska, Lincoln.
- Zaman W.U., Arshad M, and Saleem K., (2001). Distribution of nitrate-nitrogen in the soil profile under different irrigation methods. *International, J. Agri. Biol.*, 2, 208-9.
- Zhang, B., Li, F.M., Huang, G., Cheng, Z. and Zhang, Y., (2006). Yield performance of spring wheat improved by regulated deficit irrigation in an arid area. *Agricultural Water Management*, 79, 28–42.

Zhang, J. and Davies, J.W., (1991). Antitranspirant activity in the xylem sap of maize plants. *J. Exp. Bot.*, 42, 317 – 321.

Zhang, J., Kang, S., Liang, Z., Pan, Y.Z., Shi, P., Pan, Y. H., Liang Z. S. and Hu, X. T. (2000). Soil water distribution, uniformity and water use efficiency under alternate furrow irrigation in arid areas. *Irrigation Science*, 19, 181-190.

Zhang, Y., Kendy, E., Qiang, Y., Changming, L., Yanjun, S. and Hongyong, S., (2004). Effect of soil water deficit on evapotranspiration, crop yield, and water use efficiency in the North China Plain. *Agricultural Water Management*, 64, 107–122.

7. APPENDICES

Appendices tables

1. Meteorological data of the study area

Month	Rainfall (mm)	Min. temp °C	Max. temp °C	Relative humidity (%)	Wind speed (km/day)	Sunshine hour(hr)
Jan	22	14.8	29	48	173	8
Feb	22	14.8	30	43	181	8
Mar	68	14.7	30	50	156	7
Apr	122	14.0	28	64	121	6
May	136	14.2	26	73	104	6
Jun	100	14.1	24	74	121	4
Jul	141	14.2	23	78	95	3
Aug	142	14.4	24	76	95	4
Sep	93	14.0	25	71	95	5
Oct	77	14.1	26	65	121	7
Nov	48	15.1	27	53	181	8
Dec	30	15.3	28	49	190	8

2. Reference evapotranspiration (ET_o) by Penman-Monteith method

Month	Min. Temp(°C)	Max. Temp(°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad (MJ/m ² /day)	ET _o (mm/day)
January	14.8	29	48	173	8	20	4.88
February	14.8	30	43	181	8	21	5.38
March	14.7	30	50	156	7	20.3	5.04
April	14	28	64	121	6	18.7	4.18
May	14.2	26	73	104	6	18.1	3.7
June	14.1	24	74	121	4	14.7	3.13
July	14.2	23	78	95	3	13.4	2.74
August	14.4	24	76	95	4	15.3	3.09
September	14	25	71	95	5	17	3.46
October	14.1	26	65	121	7	19.6	4
November	15.1	27	53	181	8	20.1	4.65
December	15.3	28	49	190	8	19.6	4.81
Average	14.5	26.7	62	136	6.2	18.1	4.09

3. Average infiltration rate of the experimental field soil

Time	Time difference(min)	Cumulative Time (min)	Average Reading (mm)	Average Difference (mm)	Average infiltration rate(mm/min)	Average infiltration rate(mm/hr)	Average Cumulative Intake (mm)
4:00	0	0	185	0	0	0	0
4:01	1	1	180	5	5	300	5
4:03	2	3	174	6	3	180	11
4:06	3	6	167	7	2.3	140	18
4:11	5	11	159	8	1.6	96	26
4:20	10	21	148	11	1.1	66	37
4:31	10	31	138	10	1	60	47
4:46	15	46	129	9	0.6	36	56
5:01	15	61	116	13	0.9	52	69
5:21	20	81	105	11	0.55	33	80
5:41	20	101	96	9	0.45	27	89
6:01	20	121	90	6	0.3	18	95
6:31	30	151	87.6	2.4	0.08	4.8	97.4
7:01	30	181	85.2	2.4	0.08	4.8	99.8

4. Irrigation water requirement of tomato in the study area

Date	Stage	Kc	ET _o (mm/period)	ET _c (mm/period)	IR _n (mm)	IR _g (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
			448.56	415.7	415.7	692.8

5. Free flow discharge values for different size of Parshall flumes

Head (cm)	Through width (inches)				
	1	2	3	6	9
	Discharge (l/s)				
2	0.140	0.281			
3	0.263	0.526	0.772	1.496	2.504
4	0.411	0.822	1.206	2.357	3.889
5	0.581	1.162	1.705	3.354	5.471
6	0.771	1.541	2.261	4.473	7.232
7	0.979	1.957	2.872	5.707	9.155
8	1.205	2.407	3.532	7.047	11.231
9	1.446	2.889	4.239	8.489	13.448
10	1.702	3.402	4.991	10.027	15.801
11	1.973	3.943	5.786	11.656	18.281
12	2.258	4.513	6.621	13.374	20.885
13	2.557	5.109	7.496	15.177	23.605
14	2.868	5.731	8.408	17.062	26.440
15	3.191	6.377	9.358	19.027	29.383
16	3.527	7.048	10.342	21.070	32.433
17	3.875	7.743	11.361	23.188	35.585
18	4.234	8.460	12.413	25.38	38.837
19	4.604	9.200	13.499	27.643	42.186
20	4.985	9.961	14.616	29.976	45.630
21	5.376	10.744	15.764	32.379	49.167
22		11.547	16.942	34.848	52.794
23			18.151	37.384	56.510
24			19.389	39.984	60.312

6. Synthax for analyze the data in RCBD design

<pre>proc print data = work.furrow ;run; proc glm data = furrow ; class rep trt; model my umy ty wue = rep trt/ss3; means rep trt/lsd; lsmeans trt; run;</pre>	<p>Where, furrow = the name of the data, rep = replication, trt = treatment, my =marketable yield, umy = unmarketable yield, total yield, wue = water use effieency, lsd = list significant difference, lsmeans = list significant mean</p>
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7. Total cost of item and labor in birr per hectar

Types of cost	Activities and items	Cost(birr)
	Farm land preparation	1880
	Seed bed preparation	580
	Transplanting	1480
Fixed cost		
	Watering	4960
	Weeding and cultivation	1680
	Harvesting	2020
	Transportation	2000
	Seed	1000
	Urea	800
	Dap	800
	Chemical	200
Total		17400

Appendices figures



1. Infiltration Rate Test and Soil Sampling



2. Soil Sample Analysis, Land Preparation and Layout



3. Seedling, 25 day seed plant and Transplanting



4. Tomato at Development Stage, Measuring Irrigation and Rain Water



5. Tomato at fruit stage and Harvesting Stage