EFFECT OF DEFICIT FURROW IRRIGATION ON YIELD AND WATER PRODUCTIVITY OF TOMATO (*Solanum Lycopersicum L.*) IN CENTRAL RIFT VALLEY INTENSIVE IRRIGATION SYSTEM AT EAST SHEWA ZONE, OROMIA, ETHIOPIA

MSc THESIS

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Effect of Deficit Furrow Irrigation on Yield and Water Productivity of Tomato (*Solanum Lycopersicum L.*) in Central Rift Valley Intensive Irrigation System at East Shewa Zone, Oromia, Ethiopia

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In Partial Fulfillment of the Requirement for the Degree of
MASTER OF SCIENCE IN SOIL AND WATER ENGINEERING
(IRRIGATION ENGINEERING)

Lemma Teklu Kumsa

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Haramaya University, Haramaya

HARAMAYA UNIVERSITY
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I hereby certify that I have read and evaluate this Thesis entitled: ***Effect of Deficit Furrow Irrigation on Yield and Water Productivity of Tomato (Solanum Lycopersicum L.) in Central Rift Valley Intensive Irrigation System at East Shewa Zone, Oromia, Ethiopia*** prepared under my guidance by ***Lemma Teklu***. I recommend that it be submitted as fulfilling the thesis requirement.

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As a member of the Board of the Examiner of the ***M.Sc*** **Thesis Open Defense Examination**, I certify that I have read and evaluated the Thesis prepared by ***Lemma Teklu*** and examined the candidate. I recommend that the thesis be accepted as fulfilling the Thesis requirement for the degree of *Master of Science in Soil and Water Engineering (Irrigation Engineering)*.

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Final approval and acceptance of the Thesis is contingent upon the submission of its final copy to the Council of Graduate Studies (CGS) through the candidate's department or school graduate committee (DGC or CGS).

DEDICATION

I dedicated this thesis manuscript to the memory of my sister **MESERET TEKLU** for her nursing me with affection, love and dedicate in the success of my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

The author was born on December 13, 1988 from his father Teklu Kumsa and his mother Kuni Bedada in Degamaye Selashi Kebele, Degem Woreda, North Shoa Zone, Oromia Regional State. He attended his elementary school education from Grade 1-6th and 7-8th at Kunde and Fitche Abdisa Aga Primary School respectively. He completed his Secondary and Preparatory School at Fitche Compressive and Preparatory School. After successfully passing the Ethiopian School Leaving Certificate Examination (ESLCE), He joined Mekelle University College of Agriculture in 2007 and earned Bachelor of Science degree in Soil and Water Conservation in July 3, 2010.

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WHAT CAN I SAY ABOUT MY ALMIGHTY GOD!

ACRONYMS AND ABBREVATIONS

ABA	Abscisic Acid
AFI	Alternate Furrow Irrigation
ANOVA	Analysis of Variance
AR	Advance rate
BARC	Bako Agricultural Research Center
Ca_2CO_3	Calcium Carbonate
CFI	Conventional Furrow Irrigation
CO_2	Carbon dioxide
CU	Consumptive Use of Water
CV	Coefficient of Variance
CWR	Crop Water Requirement
CWUE	Crop Water Use Efficiency
DP	Deep Percolation
DU	Distribution Uniformity
Ea	Application Efficiency
ER	Effective Rainfall
Er	Storage Efficiency
ESLCE	Ethiopian School Leaving Certificate Examination
ETc	Crop Evapotranspiration
ETo	Potential Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FC	Field Capacity
FES	Flame Emission Spectrophotometer
FFI	Fixed Furrow Irrigation
FIWUE	Field Irrigation Water Use Efficiency
HSD	Honestly Significant Different
ILRI	International Livestock Research Institute
IWMI	International Water Management Institute
IWR	Irrigation Water Requirement

LIVES	Livestock and Irrigation Value Chains for Ethiopia Smallholders Project
LSD	Least Significance Difference
LSI	Large Scale Irrigation
Mha	Million hectares
MoARD	Ministry of Agriculture and Rural Development
MoWR	Ministry of Water Resource
MS	Mean Square
MSI	Medium Scale Irrigation
Na_2CO_3	Sodium Carbonate
NO_3^-	Nitrate ion
pH	Potential of Hydrogen
PHI	Pre-Harvest Interval
PWP	Permanent Wilting Point
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis Software
SE	Standard Error
SS	Sum Square
SSI	Small Scale Irrigation
UCC	Christiansen Uniformity Coefficients
USA	United States of America
WUE	Water Use Efficiency

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ABSTRACT

This study attempted to evaluate the effects of alternative furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) systems on crop yield and water use efficiencies. The general objective were to study the effect of deficit irrigation on yield and water use efficiency for improved agricultural production, environmental sustainability and water productivity, with specific objectives of investigating the effect of deficit irrigation under different furrow irrigation systems on soil properties, yield and water use efficiency of tomato. A field experiment was designed as a two factor factorial in RCBD; with three time replicate. The two factors were irrigation systems and water application levels. Irrigation depth was monitored using a Parshall flume of an opening diameter 3 inch with discharge of 3.532 l/s at a head of 8cm. Results were compared in terms of flow parameters, water use efficiencies and yield at ($P<0.01$). Flow parameters had shown that, recession time of AFI system was highly significant from both of CFI and FFI systems and 100 % ETc from the remaining three application levels and their interaction was significant. For water use efficiency parameters; the mean results of both crop water use efficiency (CWUE) and field water use efficiency (FWUE) of AFI, FFI and CFI were 256.69, 214.77 and 130.53 kgha^{-1}mm^{-1} respectively and showing highly significant difference between them. There were highly significant differences between the mean results of irrigation systems of AFI and CFI systems on Christian's uniformity coefficient (UCC), application efficiency (Ea), storage efficiency (Er) and deep percolation losses (Dp) and Water application levels between 100% ETc and the remaining three application levels on UCC and Er, while for Ea and Dp between 85% ETc and 50% ETc and their interaction were also highly significant. There was no significant difference between the yield obtained in the AFI and CFI, However, there were highly significant difference between yield of FFI and CFI systems. In view of the results, AFI system is taken as promising for conservation of water (1232.9m^{3}/ha), time (19:22'48" hours/ha), labor (4050.93 birr/ha) and fuel (5457.18 birr/ha) saving for users diverting water from the source to canals using pump without negligible trade-off in yield.

1. INTRODUCTION

1.1. Back ground of the Study

Irrigation is an age-old art-perhaps as old as human civilization. Nevertheless, the increasing need for crop production due to the growing population in the world is necessitating a rapid expansion of irrigated agriculture throughout the world (Awulachew *et al*., 2005). This situation is not different in Ethiopia. It has been loudly stated that if our country is to feed its ever increasing population and lessen risk of drought, continuous and extensive effort needs to be made towards developing intensive irrigated agriculture. Crop and livestock production is, therefore, only possible if water is made available through either rainfall or irrigation. If rainfall is adequate to meet the total water requirements of the crop and if it occurs at the time when the crops need it, irrigation may not be as such required as supplementary and crop production can be totally rain-fed (Arora, 1996).

However, such ideal conditions are rare, particularly in any country like Ethiopia where the vagary of weather exposes primarily farmers to frequent drought. Generally water availability for crop production is highly erratic both in space and time. In some areas, there is a substantial rainfall and consequently high runoff in some months of the year, while others suffer from dry spell (Awulachew *et al*., 2007). This calls for the storage of excess rainfall and runoff that can be utilized during the dry season. Efforts to ensure food self sufficiency at house hold level requires efficient use of the stored water and appropriate water application technologies that can be adopted by small holder farmers. The traditional irrigation development effort is aiming at supplying sufficient water to crops to avoid water stress during the whole growing stage, so as to achieve maximum yield (Doorenbos and Pruitt, 1992). However, the limitation in water availability and also salinity related to over irrigation obliges to adopt alternative irrigation schedules with different frequencies of irrigation. Because of the limited water and high level of competition, most irrigators in Ethiopia, especially these at tail of a scheme, allocation of irrigation water to the field is below the maximum crop water requirement for maximum yield (Lorite *et al*., 2007).

In order to overcome the deficit in water required for crop production and minimize the impact of drought on crop performances, supplemental water has to be supplied in the form of irrigation. With irrigation, it is not only possible to avoid risk in production but also possible to grow multiple crops in a year which helps in food and nutritional security strategies. But, the question is which type of irrigation technology should be employed, from the three broad categories of irrigation: surface (flood, basin, border, and furrows), sprinkler, and drip (micro-irrigation) methods based on application of water in the field. Among the above methods, sprinkler and drip irrigation methods are known to be efficient in maximizing water utilization, but their initial investment cost is often prohibitive and not affordable by the majority of smallholders' farmers. Under such circumstances, less precise and yet least capital-intensive irrigation systems have to be considered. In this relation, furrow irrigation method is the most widely used in Ethiopia in almost all-large and small irrigation schemes. It has been reported by FAO (2001) that 97.8% of irrigation in Ethiopia is done by surface methods of irrigation especially by furrow system in farmer’s fields and majority of the commercial farms. Furrows are particularly suitable for irrigating row crops such as vegetables, cotton, sugar beet, maize, tomatoes and potatoes planted on raised beds, which are subject to injury if water covers the crown or stems of the plants (Michael, 2008).

Conventional furrow irrigation (CFI), where every furrow is irrigated during consecutive watering, is known to be less efficient particularly in areas where there is shortage of irrigation water. CFI usually causes excessive deep percolation at the upper part of the furrow, insufficient irrigation at the lower part and considerable runoff, resulting in low application efficiencies and distribution uniformities. Proper furrow irrigation practices can minimize water application and irrigation costs, save water, control soil salinity build up and result in higher crop yields (Michael, 2008).

The development towards optimum utilization of irrigation is to irrigate alternate furrows during each irrigation time (Zhang *et al*., 2000). 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. It is presumed that irrigating alternative furrows can help to save irrigation water both by minimizing evaporative loss from plant leaf due to reduced stomatal opening with absence of visible leaf water deficit and by reducing deep percolation losses at the same time (Devlin and Witham, 1986).

Different techniques of saving agricultural water use have been investigated globally. Various researchers (Hodges *et al*., 1989; Graterol *et al*., 1993; Stone and Nofziger, 1993) have used wide spaced furrow irrigation or skipped crop rows as a means of improving WUE. They selected some furrows for irrigation while other adjacent furrows were not irrigated for the whole season i.e. fixed furrow irrigation (FFI) which means that irrigation is fixed to one of the two neighboring furrows. In general, these techniques are trade-off of lower yield with maximum water saving.

Water use efficiency should be improved by reducing leaf transpiration as stomata control leaf gas exchange and transpirational water loss. Investigations have shown that stomata may directly respond to the availability of water in the soil by reducing their opening accordingly (Kang *et al*., 1998). The advantage of this type of regulation is that plants may delay the onset of serious leaf water deficit and enhance their chance of survival in times of unpredictable rainfall: the optimization of water use for CO_2 intake and survival. The recent evidence has shown that this feed-forward stomatal regulation worked through a chemical signal, i.e. increased concentration of abscisic acid (ABA), in xylem flow from roots to shoots (Kang *et al*., 2000). Part of the root system in drying soil can produce large quantity of abscisic acid while the rest of the root system in wet soil may function normally to keep the plant hydrated. The result is that plants may have a reduced stomatal opening with the absence of visible leaf water deficit.

Kang *et al*. (2000) evaluated the alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) with different irrigation amounts for maize production. They reported that yield reduction in AFI was not significant unlike FFI. Mohajer *et al*. (2004) investigated application of the saline water in furrow irrigation systems for cotton and maize productions. Water productivity in the alternate furrow irrigation was greater than that in conventional furrow irrigation. Horst *et al*. (2007) applied surge flow to alternate furrows in cotton fields. The performance of alternate furrow irrigation considerably increased and provided the highest water productivity (0.61 kg m^{-3}) and irrigation application efficiency (85%) as compared to the conventional furrow irrigation. Alternate furrow irrigation also increased water use efficiency in wheat-cotton rotation in Punjab, India (Thind *et al*., 2010). Moreover, application of the alternate furrow irrigation increased water productivity rather than conventional furrow irrigation in sugarcane fields in southern part of Iran (Sheyni *et al*. 2009). Slatni *et al*. (2011) conducted field experiment to evaluate three irrigation systems including AFI, FFI and CFI for a potato crop. Application and irrigation efficiency were the highest in FFI and lowest in CFI. Water productivity was reported to be 8.0, 8.7 and 5.9 kg m^{-3} for the AFI, FFI and CFI treatments, respectively.

Now a day's, farmers in the study area pump irrigation water from ground or lake for intensive irrigation practice. Because, poor rainfall distribution during the growing season and over application of irrigation water without determining the crop water requirement during a dry season were identified as the major problem of a crop failure in the area. Under such existing condition in the study area, irrigation is vital in improving water productivity and stabilizing agricultural production through an increased production of high value horticultural crops. This in fact increases the economic wellbeing of small holder producers. In addition to this, it also increase the knowledge and capacity of smallholder farmers involved in irrigated agriculture production and other value chain actors and service providers.

General Objective:

To study the effect of deficit irrigation on yield and water use efficiency for improved agricultural production, environmental sustainability and water productivity

Specific Objectives:

i**.** Evaluating the effect of deficit irrigation on soil properties

ii. Investigating the effect of different furrow irrigation methods on water use efficiency

iii. Evaluating the effect of deficit irrigation under furrow irrigation method on yield of tomato

2. LITERATURE REVIEW

2.1. Importance of Irrigation

The need for additional food supplies is necessitating a rapid expansion of irrigation throughout the world. Even though irrigation is of major importance in the arid and semi arid regions of the world, it is also becoming increasingly important in humid regions (Israelsen *et al*., 1980).

There is no single nutrient requirement for plant life, which is more vital than provision of water. Adequate quantities of water should be readily available within the root zone of all kinds of plants. When such water is not present in the soil naturally, it may be applied by irrigation or derived directly from the rainfall during the crop season. Rainfall is beyond the control of human being. It is estimated that one-third of the earth's surface receives less than 250 mm of yearly rainfall and the other one-third receives only 250 to 500 mm yearly. In the some other parts, rainfall is received only during few months during the year. This shows that we cannot afford to depend exclusively on rainfall. Irrigation is therefore, required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount to sustain crop growth (Sahasrabudhe, 1996).

A reliable and suitable irrigation water supply can result in vast improvement of agricultural production and productivity and thus ensures the economic vitality of a region. Many civilizations have been dependent on irrigated agriculture to provide the basic needs of a society and enhance their livelihood security. As little as 15-20% of the world wide total cultivated area is irrigated. Comparing yields obtained from irrigated and non-irrigated farms, relatively small fraction of irrigated agriculture is contributing as much as 30-40% of gross agricultural output (Walker, 1989).

A general comparison made by FAO (2002) between irrigated and rain-fed agriculture for food production revealed that irrigated agriculture has been an extremely important means of food production over recent decades. It was also reported that highest yields obtained from irrigation were more than double of the highest yields obtained from rain-fed agriculture.

2.2. Water Resources of Ethiopia

In Ethiopia about 80% of the total rainfall occurs between June and September. This means also many rivers in Ethiopia are seasonal. Dry season flow originates from springs, which provide base flows for small-scale irrigation. The total annual water resource is estimated at 122 km^3, of which 76.6 km^3 drain into the Nile basin. The initial estimate of ground water potential varies from 2.6-13.5 billion m^3 per year. There are numerous lakes in Ethiopia; the eleven major lakes have a total surface area of about 7000 km^2. There are also 12 major river basins that provide an estimated annual run-off of 125 billion m^3, with Abay basins (in central and northwest Ethiopia) accounting for 45% of this amount (Awulachew *et al*., 2010).

Annual rainfall varies from less than 100 mm along the border with Somalia and Djibouti to 2400 mm in the southwest highlands. The national average is estimated at 744 mm/year. In the southern and eastern highlands, there is a pronounced bi-modal rainfall distribution, with the first and generally smaller rains peaking in April, and the second in September. The main dry season extends from October to February, being longer and drier in the north. Rainfall variability is important, particularly in the lower rainfall areas of the northeast highlands (FAO, 1995).

2.3. Irrigation Development in Ethiopia

Traditional irrigation is very old in Ethiopia (Awulachew *et al*., 2007). The traditional small-scale schemes in general are simple river diversion. The diversion structures are rudimentary and subjected to frequent damage by flood. Modern irrigation was started at the beginning of the 1960s by private investors in the Middle Awash Valley, where big sugar estates, fruit and cotton farms are found (FAO, 1995).

The need for developing irrigation for crop production is getting more and more attention in Ethiopia in response to the growing demand for agricultural produce. Before 1974, private capital investment in agriculture had been increasing due to the government's policy encouraging the development of commercial farm in sparsely populated lowland areas of the country. Concessionaire farms included the Middle Awash Agricultural Estate Share Company of Melka Sedi banana farms and cotton and sugar cane plantations. The military government nationalized the rural lands and commercial farms, and changed the then commercial farms together with newly established ones (mainly rainfed ones), into state owned enterprises (Fekadu *et al*., 2000).

Ethiopia comprises 112 million hectares of (Mha) land. Cultivable land area estimates vary between 30-70 Mha. Currently, high estimates show that only 15 Mha of land is under cultivation. For existing cultivated area, the estimate is that only about 4-5 percent is irrigated; with existing equipped irrigation schemes covering about 640,000 hectares. These irrigation schemes vary widely in size and structure, from micro irrigation (rain water harvesting), to river diversion, pumping, and small or large dams (Awulachew *et al*. (2010). Based on data from IWMI (in Awulachew *et al*., 2007) and grey document from Ministry of water resource (MoWR) and ministry of agriculture and rural development (MoARD), from a total of 640,000 hectares of irrigation nationwide; 128,000 hectares from rain water harvest, 383,000 hectares from small scale irrigation (SSI), and 129,000 hectares from medium scale irrigation (MSI)/large scale irrigation (LSI). The M/LSI includes Fentale and Tibila schemes.

2.4. Advantage of Furrow Irrigation over Other Surface Irrigation Method

Furrow irrigation method is one of surface irrigation methods in which small regular channels direct water across the field. Furrow irrigation method is best suited to deep, moderately permeable soils with uniform flat or gentle slope of 0.1-0.5% for crops that are cultivated in rows such as vegetables, maize, cotton, tomato and potatoes etc (FAO, 1986). Furrows are particularly well adapted to irrigating crops, which are susceptible to fungal root rot since water ponding and contact with plant parts can be avoided (Michael, 2008).

As compared to other methods of surface irrigation, furrow method has several distinct advantages: when the available irrigation streams are small, for land of uneven topography, water in the furrows contacts only one-half to one-fifth of the land surface, using furrows irrigation necessitates the wetting of only part of the surface (20% to 50%), thus reducing evaporation losses, lessening the puddling of heavy soils, earlier cultivation is possible which is a distinct advantage in heavy soils, adapted to use without erosion on a wide range of natural slopes by carrying the furrows across a sloping field rather than down the slope, reduces labour requirements in land preparation and irrigation, no wastage of land in field ditches compared to check basin method, Nearly all row crops can be irrigated using furrow method rather than flooding (Michael, 2008).

Moderate to high application efficiency can be obtained if good water management practices are followed and the land is properly prepared. Different kinds of crops can be grown in sequence without major changes in design layout or operating procedures. The initial capital investment is relatively low on lands not requiring extensive land forming as the furrow are constructed by common farm implements (FAO, 2002). Soils, which form surface crusts when flooded, can readily be irrigated, because water moves laterally under the surface. This irrigation method is best suited to medium and moderately fine textured soils with relatively high available water holding capacity and hydraulic conductivity, which allow significant water movement in both the horizontal and vertical directions. The method is also suited to fine textured soils on level sites, where it permits water impoundment (Michael, 2008).

2.5. Different Furrow Based Irrigation Systems

2.5.1. Alternate furrow irrigation systems (AFI)

Alternate Furrow Irrigation system (AFI) is where half of root is exposed to wet soil condition and the other half is exposed to dry soil condition. It offers opportunity for reducing size of irrigation and permits irrigating a field in a shorter time with a given water supply. The reduced size of irrigation may not reduce yields appreciably and thus increase irrigation-water use efficiency (Musick and Dusek, 1974).

When the supply of water is limited, irrigation is applied through alternate furrows. Besides this, AFI system is adopted where salt is a problem. This system save quite a good amount of water and is very useful and crucial in areas of water scarcity and salt problems (Majumdar, 2002).

Alternate furrow irrigation system may supply water in a manner that greatly reduces the amount of surface wetted leading to less evapotranspiration and less deep percolation. Deep percolation can be reduced because the lower wetted surface with alternate furrow results in lower infiltration. It has been suggested that the reduced evapotranspiration in the alternate-furrow irrigation method is due to a reduction for wet soil surface compared to that in every-furrow irrigation (Stone *et al*., 1979). AFI system leads to continuous stomatal inhibition and reduced leaf transpiration. In AFI drying lead to 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).

According to Karajeh *et al*. (2000), application of alternate furrow irrigation system has improved irrigation water use. Under this furrow irrigation system, 56.7-72% of the water supply has been used to replenish soil moisture, 12-21.1% for infiltration within the temporary irrigation network and 11.3-17.8% for surface runoff. Working conditions of labors carrying out irrigation process were improved as this technology allowed them moving on the dry furrows.

Alternate furrow irrigation system has been widely used in the USA, to improve irrigation efficiency with good results in potatoes, corn, sorghum, cotton and peppermint. Large water savings (up to 50%) without a loss in yield or only slight reduction have been achieved in the USA with substantial reductions in the labor required to carry out the irrigation (Stone and Nofziger, 1993).

2.5.2. Fixed furrow irrigation (FFI)

Fixed furrow irrigation system supplies water to one side of each furrow ridge. Usually, this technique applies water to more area in a given amount of time than does irrigating conventional furrow irrigation. Benefit of irrigating every other furrow is the ability to store rainfall in a recently irrigated soil. FFI should not be used on steep slopes or on soils with low intake rates. On steep slopes, the water flowing down the furrow is in contact with only a limited amount of soil surface, causing low intake rates. Research indicates that every other furrow irrigation results in yields comparable to those achieved when every furrow is irrigated. Irrigation water application may be reduced 20 to 30 percent by implementing every other furrow irrigation (FFI). Because of increased lateral flow, infiltration is not to be reduced by one–half compared to watering every furrow (Yonts *et al*., 2003).

Many ways of conserving agricultural water have been investigated. Researchers fixed some furrows for irrigation, while adjacent furrows were not irrigated for the whole season. Water was saved mainly by reduced evaporation from the soil surface, as in the case of drip-irrigation and also used wide spaced furrow irrigation or skipped crop rows as a means to improve WUE (Kang *et al*., 2000).

2.5.3. Conventional furrow irrigation (CFI)

According to karajeh et al. (2000), under conventional furrow irrigation (CFI) option, irrigation water has been used as follows: 51-54% of the total water supply was used to moisten soil (saturation), 20-25% for infiltration within the temporary irrigation net work and in the fields, 5-6% for the evaporation from water surface, and 18-21% for surface runoff. Significant quantities of irrigation water losses by infiltration and surface runoff is about 40% of total water supply which reduced water supply to the irrigated lands and decreased the efficiency of agricultural production as well as the reliability of drainage systems. This irrigation system has speed up the processes of decomposition and removal of organic elements and mobile forms of nutrients in the root zone that eventually, brought to soil fertility losses.

As reported by Graterol *et al*. (1993), the great evapotranspiration and deep percolation in the CFI system did not increase yields. This may be so because a greater portion of the evapotranspiration and deep percolation (Dp) could be due to non-productive water losses arising from evaporation from the higher amount of wet soil surface or from deep percolation.

Mintesinot *et al*. (2004), made a comparative study that has been undertaken over two irrigation seasons (1998/1999 and 1999/2000) between the traditional furrow irrigation management and scheduling; and alternative water management options (furrows-scientific scheduling and every furrow-scientific scheduling) on maize plots in northern Ethiopia. Results were compared on the basis of yield, water productivity and economic productivity concepts. Yield-based comparison has shown that every furrow-scientific scheduling generates the highest yield levels followed by alternate furrows-scientific scheduling. The yield increase by every furrow-scientific scheduling over the traditional management was found to be 54%.Water productivity based comparison has shown that alternate furrows-scientific scheduling generates the highest water productivity values followed by every furrow-scientific scheduling. The increase by alternate furrow irrigation, scientific scheduling over the traditional irrigation management was 58%. Economic productivity-based comparison has shown that the highest economic return was obtained from every furrow-scientific scheduling followed by alternate furrows-scientific scheduling. The increase in income by every furrow scientific scheduling over the traditional irrigation management was 54%.

2.6. Crop Water Requirement (CWR)

Crops need a continuously and right amount of water from the time of sowing to maturity. The rate of use of water is not, the same for all crops. The rate of use of water varies with the kind of crop grown, time taken by the crop to mature, and the weather conditions like, temperature, wind, solar radiation and relative humidity. The same holds true for tomatoes. Over a wide range of climatic conditions, the simple product of air temperature time's radiation can be used to estimate maximum tomatoes water use (Tan, 1980).

When irrigation water is provided to the land, quantity of the water is stored in the root zone of the plant. Soil moisture should be sufficient for the period of crop growth that may vary from few days to several weeks. The length of the period between two watering is dependent on the capacity of the soil to hold the available water and the type of crop grown on that soil (Sahasrabudhe, 1996).

The amount of water used in producing a crop is commonly referred to as consumptive use or evapotranspiration. It includes the water transpired by the leaves of the plants and evaporated from the wet soil. Part of the consumptive use requirement may be satisfied by rainfall during the growing season, or precipitation prior to planting and retained in the soil. The amount of water needed in addition to effective rainfall to satisfy the consumptive use requirement of the crop is referred to as the consumptive use of applied water. This is the amount that must be supplied by irrigation (Sahasrabudhe, 1996).

Water requirement of crop is the total amount of the water required to sustain the normal growth of plant. This includes the amount of water required to meet; losses through evaporation, losses through transpiration, plant metabolism needs, application losses and special needs. Water requirement of crops can be expressed mathematically as (Sahasrabudhe, 1996):

$$CWR = CU + \text{application losses} + \text{special} \quad (1)$$

Alternatively, in relation to source it can also be expressed as:

$$CWR = IWR + ER + S \quad (2)$$

where

CWR= crop water requirement

CU = Consumptive use of water (evapotranspiration)

IWR = Irrigation requirement of a crop at field head

ER= Effective rainfall

S = Soil moisture contribution

Other important factors to be considered during calculating the soil water balance of the root zone on daily basis in tomatoes production include rooting depth, growth stage as affected by soil moisture deficit, and the yield threshold depletion or allowable soil water depletion. Transplanted tomatoes are a relatively shallow-rooted crop. Although roots may penetrate beyond 1 m in depth, the greatest concentration of roots is in upper 30 cm. Water use by irrigated tomatoes varies with the crop development stage. The peak water use periods occur during fruit set and fruit development. Irregular and inadequate water supply during these periods can result in poor fruit set and blossom-end rot. Optimizing both yield and quality is accomplished by matching water application to peak crop water use rate. The yield threshold depletion or allowable soil water depletion is the percentage of available water that can be depleted from the soil before there is an adverse effect on yield and quality of the crop. The allowable soil water depletion value for tomatoes is about 50% (Tan, 1980). To avoid deep percolation losses that may leach essential nutrients out of root zone, the net irrigation depth should be smaller than or equal to the root zone depletion (Sahasrabudhe, 1996).

2.7. Plant Response to Water Stress and Implication for Irrigation Water Saving

Stomata of plant leaf close when the leaf potential declines below a threshold value. This is manifestation of the development of plant water deficit. Stomatal closure can cause marked but indirect effect on cell metabolism; changes in CO_2 influx, water loss, leaf temperature and solute transport within the plant (Zhang *et al*., 1990).

Evidences show that, stomatal regulation process works through a chemical signal; the increased concentration of abscisic acid (ABA), in the xylem flow from roots to shoots controlling transpiration (Zhang *et al*., 1989, 1990, 1991). Reduction of evapotranspiration to decrease crop water requirement or reducing irrigation requirement has been a long-standing goal in arid and semi-arid regions. In this regard, much of the research work has been directed toward modifying canopy resistance through the use of chemical, anti-transparent. Several of the suggested chemicals, however, are toxic to plants and animals. In some cases, the reduction of transpiration is accompanied with a reduction in photosynthesis; the water use efficiency of the plant is, therefore, unaffected (Zhang *et al*., 1989, 1990, 1991).

A naturally occurring plant hormone, abscisic acid (ABA) has shown promise to be a nontoxic anti-transparent. Abscisic acid content tend to increase in leaves, which are exposed to water stress and has the effect of reducing stomatal aperture in opening. An exogenous application of ABA lowers the magnitude of transpiration in the plants. Approximately there is a linear relationship between transpiration rate and the logarithm of the concentration of exogenously applied ABA. The magnitude and persistence of the effect was related to ABA concentration. However, a later study on plants subjected to water stress, indicated that once a sufficient concentration of endogenous ABA has been built up in the stressed plants, no further reduction of transpiration could be expected by additional exogenous applications of ABA. Thus, ABA might be most effective anti-transparent at intermediate soil water potentials. The effectiveness of ABA applications in reducing transpiration seems to be related to plant species and variety. A single exogenous application of ABA has been reported to reduce transpiration for several hours in wheat plants to 21 days in young seedlings. However, the ABA content of water stressed plants has been observed to fall rapidly to the pre-stress level upon watering while stomatal resistances remain high. Thus there seems to be no direct correlation between residual ABA and the delayed recovery of transpiration rate (Zhang *et al*., 1989, 1990, 1991).

The early release of abscisic acid (ABA) in to the apoplast appears sufficient for rapid stomatal closure furthermore, there is evidence that ABA produced by roots in drying soil moves up through the stem and accumulates at or near guard cells with concomitant decrease in leaf conductance (Zhang *et al*., 1987). Stomata control the opening of plant gas exchange and transpiration water loss. Recent investigations have shown that stomata may directly respond to the level of available water in the soil by regulating their size of openings (Davies *et al.*, 1991).

The advantage of such regulation is that the plant may delay the onset of an injurious leaf water deficit and enhance its chance of survival under unpredictable rainfall conditions; the so called optimization of water use for CO_2 intake and then survival (Jones, 1980; Cowan, 1982).

2.8. Advance Rate Condition

Advance rate in the furrow is a function of soil texture and furrow design. In soils that are fine in texture, water is absorbed slowly and higher advance rates are observed. Where soils are quite permeable, more water is infiltrated and advance rates are lower. Furrows that are narrow and deeper exhibit lower amount of water infiltration and faster advance rate. This configuration is used to discourage excessive percolation at the upper end. On the contrary, shallow and wide furrows leave more wet area for the water to infiltrate resulting in lower advance rate (Michael, 2008).

The performance of furrow irrigation can be improved by measuring furrow irrigation advance rate, from which optimized values for irrigation parameters can be determined and implemented in subsequent irrigations (McCarthy, 2004). Rates of advance of water down the furrow in every-furrow irrigation system have been estimated to be from 1.23 to 1.48 times greater than in the alternate furrow irrigation depending upon soil type and slope (Hodges *et al*., 1989).

According to Graterol *et al*. (1993), advance ratios were, 1.97 and 0.91 for AFI and CFI respectively. This indicates that water in alternate furrow irrigation system reached the first half and the end of the furrow length more lately when compared to the CFI system due to deep percolation caused by poor uniformity and lower runoff in AFI.

In a field experiment on irrigated maize plants for two consecutive years to determine soil water distribution, uniformity and water-use efficiency under alternate furrow irrigation in arid areas, water advance time did not differ between AFI, FFI and CFI at all distances monitored. Water did not advance more slowly in AFI than in FFI and CFI under a covering of plastic film over the soil surface (Zhang *et al*., 2000).

2.9. Water Distribution Uniformity, Application and Storage Efficiency

Among the factors used to judge the performance of an irrigation system or its management, are distribution uniformity, application efficiency and storage efficiency (James, 1988). A reduced amount of water applied does not consistently reduce yields because water use efficiency may be increased. The uniformity of soil water distribution in the AFI and FFI treatments did not change noticeably when irrigation amount was reduced. Maize plants grown under conditions of AFI succeeded in taking up more applied irrigation water because of larger and deeper root system than that found under CFI. The deep percolation found in CFI was larger than in AFI. Plants took up therefore more irrigated water with alternate furrow irrigation than with conventional furrow irrigation (Zhang *et al*., 2000).

2.9.1. Irrigation water distribution uniformity (UCC)

When a field with a uniform slope, soil and crop density receives steady flow at its upper end, a waterfront will advance at a monotonically decreasing rate until it reaches the end of the field. If it is not dyked, runoff will occur for a time before recession starts following shut-off inflow. Application uniformity concerns the distribution of water over the actual field, divided by the average infiltrated depth over the whole field. Two of the most commonly used uniformity indices in surface irrigation application are distribution uniformity (DU) and Christian's uniformity coefficient (UCC). UCC is defined as the ratio of the difference between the average infiltrated amount and the average deviation from the average infiltrated amount (Zerihun et al., 1997).

Application uniformity concerns the distribution of water over the actual field. A number of technical sources suggest the Christian's Coefficient as a measure of uniformity. Others argue in favor of an index more in line with the skewed distribution. Distribution uniformity is defined as the average infiltrated depth in the low quarter of the field, divided by the average infiltrated depth over the whole field. This term can be represented by the symbol, DU and same authors also suggest an 'absolute distribution uniformity', DU which is the minimum depth divided by the average depth (Walker, 1989).

According to Zhang *et al*. (2000), using UCC to evaluate irrigation distribution uniformity of the soil, there was no significant difference among the treatments although irrigation water use in AFI and FFI was smaller than that in CFI, possibly, because water flow was increased in the furrows by covering the surface with plastic film.

Christian's developed UC to measure the uniformity of sprinkler systems, and it is most often applied in sprinkler irrigation situations. UC has been occasionally applied to other forms of irrigation, though DU has been applied to all types of irrigation systems. These two uniformity measures are approximately related by the equations (Solomon, 1988).
UC = (0.63) (DU) + 37 and DU = (1.59) (UC) – 59)

2.9.2. Application efficiency (Ea)

Application efficiency can be defined as the ratio of the volume of water stored in the subject region to the volume of water diverted into the subject region (Zerihun, *et al*., 1997).

$$E_a = \frac{\int_0^L Zdx - \int_0^{L_{ov}} Zdx + Z_r L_{ov}}{\int_0^t Q_o dt} \times 100 \qquad (3)$$

where

Ea = application efficiency in (%)
Z = Cumulative infiltration expressed as a function of distance, (m^3m^{-1})
L = channel length, (m)
Lov = the length over which the infiltered amount equals or exceeds the requirement, (m)
Zr = net irrigation requirement or the perceived requirement, (m^3m^{-1})

Zdx = volume of water infiltrated over the entire reach of the subject region, (m^3m^{-1})

$\int_0^L Zdx =$Total volume of water infiltrated over that part of the channel, which receive irrigation amounts at least equal to the perceived requirement, (Z_r)

$\int_0^{L_{ov}} Zdx =$Volume of water retained in the subject region over the reach that excess irrigation received, and

$\int_0^t Q_o\, dt$ = Total volume admitted in to the subject region. In practice, inlet flow rate does not vary continuously with time, but rather in a step wise fashion.

Exact expression therefore can be proposed for the denominator as follows:

$$\int_0^{t_{co}} Q_{oi}\, dt = \sum_{i=1}^{I} Q_{oi}\, \Delta t_i \tag{4}$$

where

i = time index

I=the total number of time interval, (t_i)

t_i = the i^{th} time interval during which the inlet flow rate is set at, Q_{oi}, and

Q_{oi} = inlet flow rate during time period $_{ti}$

Case 2 (Zmin < Z_r < Zmax): all the three terms in the numerator of Equation (3) have to be evaluated using numerical integration as Simpson's Rule of Equation (5).

$$\int_0^L Zdx = \frac{\Delta L}{3}\left[Z_0 + 4\,Z_1 + 2Z_2 + 4\,Z_3 + 2Z_4 + \cdots + 4Z_{n-1} + Z_n\right] \tag{5}$$

where

ΔL = Constant distance interval between computational nodes or observation station (ΔL=L/n)

n = Number of intervals (must be even number), and

Zi = infiltrated amount at station i, ($m^3\, m^{-1}$)

The second term in the numerator of Equation (3) can also be evaluated using Equation (5), only by changing the upper limit of integration from L to L_{ov}. Note that the distance, from the upstream end, of a station with a Z_i value nearest to Z_r can be taken as an approximate value of L_{ov}.

Often considerably more water is applied to the soil than it possibly holds. The concept of water application efficiency can be applied to a project, a farm, or a field to evaluate irrigation practice. Irrigation efficiencies can vary from extremely low values to values approaching 100%. However, in normal irrigation practice, surface irrigation efficiencies of application are in the range of 60%. Sprinkler irrigation had the highest application efficiency of 70% while basin irrigation of rice had the lowest of 30%. Wild flooding had low which is 45% (Bakker *et al*., 1999).

Walker (1989) reported that irrigated agriculture faces a number of difficult problems in the future. One of the major concerns is the generally poor efficiency with which water resources have been used. A relatively safe estimate is that 40% or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff. These losses may not be lost when one views water use in the regional context, since return flows become part of the useable resource elsewhere. However, these losses often represent foregone opportunities for water because they delay the arrival of water at downstream diversions and because they bear almost universally poorer quality water.

According to Israelsen *et al*. (1980) the common sources of loss of water from the farm during irrigation application are, surface runoff from the farm and deep percolation below root zone. Neglecting evaporation losses during the time water is being applied and immediately after, water delivered to the farm is calculated as:

$$Wf = Er + Rf + Df \tag{6}$$

where

Wf = Water applied to the farm, (mm)
Er = Storage efficiency (%) or Water stored in the root zone, (mm)
Rf = Surface runoff, (mm)
Df = Deep percolation, (mm)

Many variable factors such as land uniformity, irrigation method, and size of irrigation stream, soil texture, permeability and depth influence the time the irrigator keeps water running on his farm and hence the depth he applies. Losses from the field occur as deep percolation and as field tail water or runoff. To compute Ea, it is necessary to identify at least one of these losses as well as the amount of water stored in the root zone. This implies that the difference between the total amount of root zone storage capacity available at the time of irrigation and the actual water stored due to irrigation be separated, i.e. the amount of under irrigation in the soil profile must be determined as well as the losses (Walker, 1989).

Feyen and Zerihun (1999) assessed the performance of border and furrow irrigation systems and the relation between performance indicators and system variables. For border and furrow irrigations; software tools BORDEV and FURDEV were used to facilitate quantification of the performance terms. The values of performance indices were plotted as a function of the system variables. From this plot when discharge to the furrow (Q_o) is 0.94 l/s application efficiency (E_a) is 55-60% for furrow irrigation, and when furrow length is 50 m deep percolation (Df) is 20-25%.

According to Kassa (2001) evaluation of the performance of surface irrigation methods at Melka-Werer, middle awash valley, indicated that the maximum possible application efficiency (E_a) for furrow irrigation computed was 64.5% for inlet flow rate 2.5 l/s and 0.8 m furrow spacing. Whereas the total irrigation- water losses due to deep percolation and runoff was 56-62%. Water application efficiency gives a general sense of how well an irrigation system performs its primary task of getting water to the plant roots. However, it is possible to have a high Ea but have the irrigation water so poorly distributed that crop stress exists in areas of the field. It is also possible to have nearly 100 percent Ea but have crop failure if the soil profile is not filled sufficiently to meet crop water requirements. It is easy to manipulate water delivered to field (Wf) so that Ea can be nearly 100 percent. Any irrigation system from the worst to the best can be operated in a fashion to achieve nearly 100 percent Ea if water delivered to field (Wf) is sufficiently low. Increasing Ea in this manner totally ignores the need for irrigation uniformity. For Ea to have practical meaning, water available for use by the crop needs to be sufficient to avoid undesirable water stress. Determination of application efficiency of a specific irrigation system is generally time consuming and often difficult. One difficulty is that efficiency varies in time due to changing soil, crop and climatic conditions. Reported ranges of application efficiency (E_a) for furrow irrigation are from 50-70% (Rogers *et al.*, 1997).

2.9.3. Storage efficiency (Er)

Storage efficiency can be defined as the ratio of the volume of water actually stored in the subject region to the volume of water that can be stored (Zerihun *et al.*, 1997).

$$E_r = \frac{\int_0^L Zdx - \int_0^{L_{ov}} Zdx + Z_r L_{ov}}{Z_r L} \times 100 \quad (7)$$

where

Er = Storage efficiency (%)

Z = Cumulative infiltration expressed as a function of distance, (m^3m^{-1})

L = Channel length, (m)

Lov, Zr and Zdx = are as defined in equation 3

The adequacy of irrigation is the percent of the field receiving sufficient water to maintain the quantity and quality of crop production at a “profitable” level. Storage efficiency (Er) is the measure of adequacy when the desired depth of irrigation fills the soil to field capacity (James, 1988).

The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of Er is important either when the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs. This parameter is the most directly related to the crop yield since it will reflect the degree of soil moisture stress. Usually, under-irrigation in high probability rainfall areas is a good practice to conserve water but the degree of under-irrigation is a difficult question to answer at the farm level (Walker, 1989).

2.10. Irrigation Water Loss Indicators

Surface irrigation losses include runoff, deep percolation, ground evaporation and surface water evaporation. Runoff losses can be significant if tail water is not controlled and reused. Although use of tail water reuse pits could generally increase surface application efficiency, many surface irrigators use a blocked furrow to prevent runoff. Usually the lower portion of the field is leveled to redistribute the tail water over that portion. While runoff may be reduced to near zero, deep percolation losses may still be high with this practice (Hansen, 1960).

Efficient furrow irrigation requires reducing deep percolation and surface runoff losses. Water that percolates below the root zone (deep percolation) is lost and not available to the crop production, although deep percolation may be necessary to control salinity when required. Improving the evenness of the applied water and preventing over irrigation can reduce deep percolation. Surface runoff can be captured with a tail-water recovery system and used on lower lands or re-circulated on the field being irrigated (Blaine, 1993).

2.10.1. Deep percolation fraction (Df)

Deep percolation fraction, an index used to quantify the irrigation water loss by irrigation water percolating below the root zone (Feyen and Zerihun, 1999).

Deep percolation fraction (Df) is defined as the ratio of the volume of water percolated below the bottom boundary of the subject region to the total volume admitted into the subject region (Zerihun *et al*., 1997).

$$\mathrm{Df} = \frac{\int_0^{L_{ov}} Zdx - Z_r L_{ov}}{\sum_{i=1}^{L} Q_{oi} \Delta t_i} \tag{8}$$

where

Df = Deep percolation fraction

Zr, Zdx, Lov, Q_{oi} and t_i are as defined in equation 3 and 4

= the i^{th} time interval during which the inlet flow rate is set at Q_{oi},

= inlet flow rate during time period t_i

Zmin = minimum infiltrated amount

Zmax = the maximum infiltrated amount

Case 1 ($Z_r <$ Zmin): in this case $L_{ov} =$ L. The integral expression in the numerator can be solved using the procedure outlined in equation 3.

Case 2 (Zmin $< Z_r <$ Zmax): Equation (7) is directly applicable. The integral expression in the numerator can be evaluated using the procedure described in connection with Equation 3.

Case 3 (Zmax $< Z_r$): this implies that $L_{ov} = 0$, therefore Df = 0

High deep percolation losses aggravate water logging and salinity problems, and leach valuable crop nutrients from the root zone. Depending on the chemical nature of the ground water basin, deep percolation can cause a major water quality problem of a regional nature. These losses can return to receiving streams heavily laden with salts and other toxic elements and thereby degrade the quality of water to be used by others (Walker, 1989).

2.10.2. Runoff fraction (Rf)

The runoff fraction can be defined as the ratio of the volume of run off to the volume of water diverted into the subject region (Zerihun *et al*., 1997).

$$Rf = 100 - E_a - Df \qquad (9)$$

where

Rf= runoff fraction (%)
Df and Ea as defined in equation 8 and 3 respectively

Run off fraction is an index used to quantify the irrigation water loss by surface run off (Feyen and Zerihun, 1999).

Runoff losses pose additional threats to irrigation systems and regional water resources. Erosion of the top soil on a field is generally the major problem associated with runoff. The sediments can then obstruct conveyance and control structures downstream, including dams and regulation structures (Walker, 1989).

2.11. Concepts in Water Use Efficiency

The term water use efficiency is used to describe the relation between growth and water use (Gregory, 1988). Water Use Efficiency (WUE) is expressed as the crop dry matter or yield production per unit of water used by the plant.

Increasing the amount of water used by the plant or increasing the growth and yield of the plant can change water use efficiency. Soil management practices like, tillage and residue management, and plant nutrient practices like, addition of nitrogen and phosphorous have a positive impact on water use efficiency (Stewart *et al*., 1981; Jones, 1980).

Crop producers in water-limited areas have used water use efficiency as a method of comparing farming systems. In the higher rainfall areas, water use efficiency can be used to improve nutrient management practices across fields. A survey of literature around the world indicates that, the potential that exists to increase crop yield per unit of water used (Hamblin *et al*., 1987).

The agronomic definition of water use efficiency involves two major terms: a biological component also called transpiration efficiency, which specifies the amount of dry matter produced per unit of water transpired, and a management component, which specifies the fraction of the total water supply used for transpiration. Thus, water use efficiency is usually a seasonal value defined as yield in an area per water used to produce the yield. Yield is frequently expressed as grain yield. But in many dry land areas, the straw has an economic value as great as that of the grain because it is used to sustain livestock. In dry land agriculture, yield is expressed as the total shoot mass (Gregory *et al*., 1984; Gregory, 1988).

2.12. Tomato Agronomic Principles and Growth Requirements

The aim of any producer is a high yielding, high quality crop that satisfies the end user. There are a large number of agronomic factors which can influence this, many are within the control of the grower, under given growing systems and climatic and soil conditions.

Plant may be either indeterminate or determinate type. Indeterminate type is the one which when side shoots are removed, produce a continuously growing single stem and also continue to produce flowers. They ideally suit greenhouse production and can grow over 10 m in height after 9 to 10 months. Staking, while expensive, helps increase yield and maximizes quality potential in both indeterminate and determinate crops. Determinate type is ending in the formation of a flower cluster and a bush-like structure. It is usually earlier to mature, because, once flowers are formed they divert all energy into filling and producing a uniform crop. They are more often used where seasons are shorter and just one crop is produced. They are bushy in character with a short main stem, and ideal for mechanical harvesting of processed crops and field cultivation of fresh tomatoes (http://www.yara.us/agriculture/crops/tomato/key-facts/agronomic-principles/).

Tomatoes are warm-season crops and sensitive to frost at any stage of growth. If subject to temperatures below 50°F, crops suffer from delayed seed germination and slow early growth. Low temperature will also reduce fruit set and delay maturity. Similarly, temperature extremes of over 95°F will reduce fruit set and restrict red coloration. If water stress and high temperatures occur together the plant will produce soft fruit.

The optimum temperature range for tomatoes is between 64.4 and 80.6°F. Above 80.6°F, flower formation is adversely affected. For this reason, most outdoor crops are grown in temperate climates, between the 30th and 40th parallels in both the northern and southern hemisphere. However, with the introduction of modern varieties, tomatoes are increasingly grown in higher temperature, tropical conditions. Optimum relative humidity in glasshouse crops range from 60-80%. Under hydroponics, 75% and 85% respectively are typical night and daytime relative humidity.

Maturity dates range from around 60-75 days for determinate varieties grown in more northerly latitudes to more than 95 days where a longer, single season harvest period is used.

Tomatoes are sensitive to low light conditions, requiring a minimum of 6 hours of direct sunlight to flower. However, if the intensity of solar radiation is too high, cracking, sunscald, and uneven coloration at maturity can result. For this reason, under greenhouse conditions, shading of fruit is essential. Day length is not critical to the production of tomatoes and so greenhouses occur across a very wide range of latitudes.

Tomatoes can be produced across a wide range of soils as long as drainage and physical soil structure is good. The plant produces a fibrous root mass, which can exploit the subsoil given the absence of cultivation pans. Most of the root mass though, is normally concentrated in the cultivated zone, or top 23.6 inch and 70% of the total root volume is in the top 7.9 inch of topsoil. Tomatoes require good nutrition. Thus, the best crops are on the more fertile soils.

Optimum soil pH is between 6.0-6.5, but crops are grown in soils with a pH of 5.0-7.5. When pH drops below 5.5, magnesium and molybdenum availability drops and above 6.5, zinc, manganese and iron become deficient, (http://www.yara.us/agriculture/crops/tomato/key-facts/agronomic-principles/).

3. MATERIALS AND METHODS

3.1. General Description of the Study Area

The experiment was carried out at Dugda district irrigation scheme, which is located in East Shoa Zone, Oromia Regional State. The experiment was conducted from mid January to mid April 2016. The site is situated at 130 km away from Addis Ababa, the capital city of Ethiopia on the way to Ziway. The study site is located in South East direction from Meki town at an altitude of 1685 m a s l and lies in $08^{0}00'$-$8^{0}20'$N and $38^{0}30'$-$39^{0}00'$E longitude and latitude respectively (figure 1).

The study area has mild, and generally warm temperate climate with an average annual temperature of 18.4^{o}C. April is the hottest month of the year with an average temperature of 19.7^{0}C, while the lowest average temperatures of 17.0^{o}C occur in December. The area receives an annual precipitation of 1009 mm. Rain fall is the minimum in December, with an average of 6mm. The maximum amount of rainfall occurs in July with an average rainy season of 185 mm. The precipitation differences between the driest and wettest months are 179 mm, while the variation in temperatures throughout the year is 2.7^{o}C (en.climate-data.org/location/54437/).

The area is known for its mixed crop livestock farming system. Cultivated and grazing lands of the woreda accounts 30.9% and 8.7%, respectively. The major rain fed crops grown in the area includes wheat, teff, barley, bean and field pea, while onion, tomato, water lemon, hot pepper, cabbage, papaya are grown in irrigation. Forest and shrubs lands accounted about 9.6% of the district, while swampy and marshy land covered 0.4%. Degraded and others accounted 44.3% of the district. The area is characterized by sandy and clay soil type. Sub-tropical grass lands are the dominant vegetation cover of the district (BoANRD, 2004).

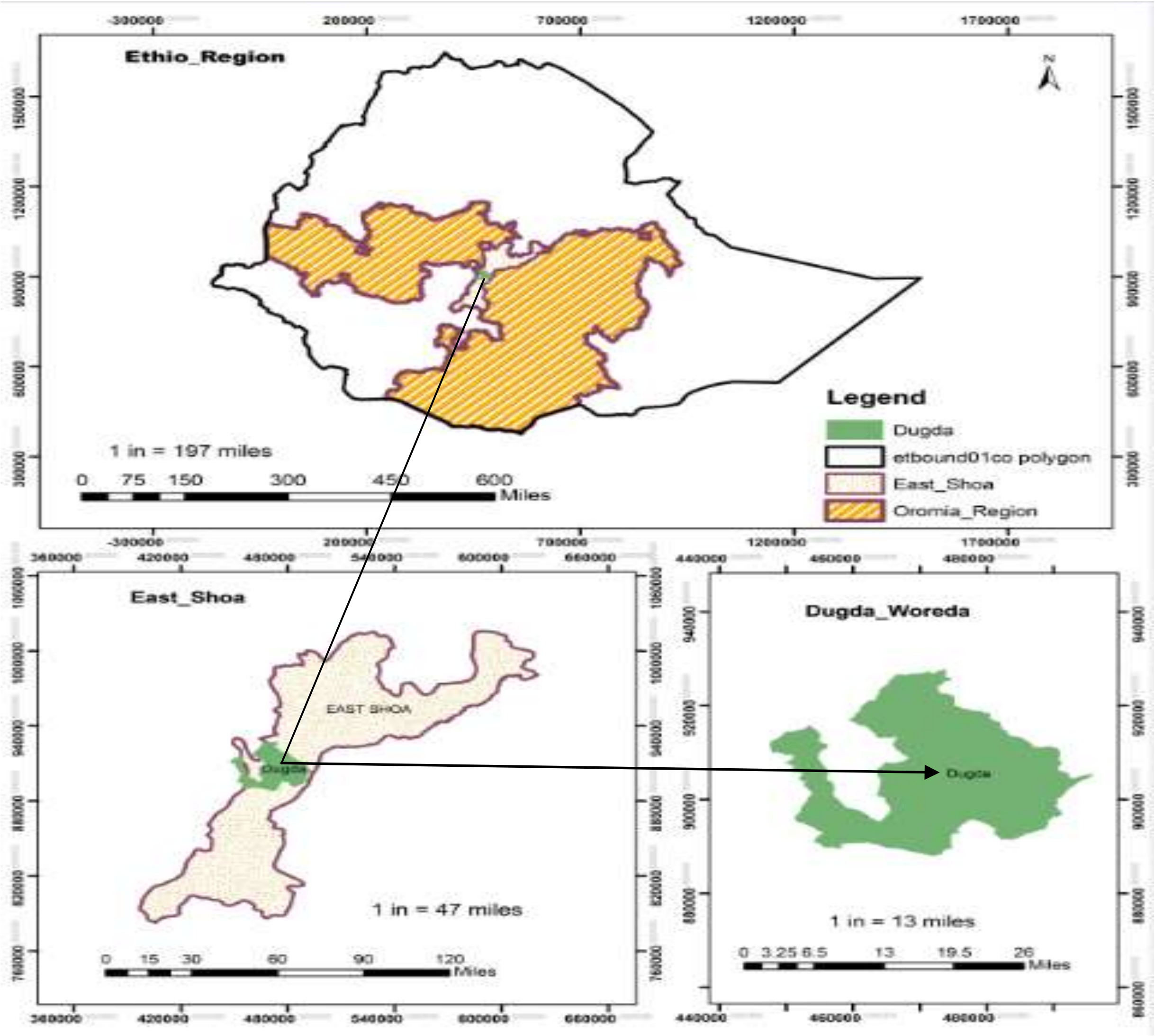


Figure 1. Map of study area (Dugda district)

3.2. Pre-experimental Activities

Before the start of the experimental activities, different field and laboratory materials: tensiometer, Parshall flume, soil auger, core samplers, plastic bag and double ring infiltrometers were collected from Haramaya University, Melkassa, Ziway Soil and Bako Research Centers. The collected materials were used for different purposes such as pipette method for soil texture analysis, Walkley and Black (1934) method for organic matter content determination, pressure plate apparatus for soil moisture contents determination at FC and PWP, plastic bag for soil sample collection, double ring infiltrometer for measuring of soil infiltration rate, parshall flume for water flow rate calibration and measurement, soil auger and core sampler for taking disturbed and undisturbed soil sample respectively. About 0.1298 hectare (59 m wide and 22 m long) of land was used for a total of 36 plots and ploughed using animal drawn implements. Each plot contained four ridges and four furrows. Each bed had 1m width and 6m length. The U shape furrow was prepared with an average depth of 25 cm and width of 35 cm. Furrow that enables to receive irrigation water from secondary canal to the experimental plot was prepared by using local plough and blockage materials. Plot designing, furrow slope aligning and all specification was accomplished using string, water level, meter and pegs. Parshall flume was installed at 7m away from the experimental plots to control the flow rate at different water head. Once it installed, water was released through it for calibration purpose by uniform velocity and constant head. Then, the water pass through it was collected into a graduated cylinder and the time required was also recorded. The total collected water was divided by a total recorded time to know the discharge rate. The calibration was done three times and the average flow rate is almost similar with the standard table on FAO irrigation and drainage_56. The end of each furrow was blocked to prevent the out flow of tail water and also to maintain the required depth of water within the furrow. Appropriate slope was selected for water flow along the advance.

3.2.1. Climatic characteristics and evapotranspiration of the area

The average of twenty two year's maximum and minimum temperature, rainfall, wind speed, 12 years relative humidity and 1 year sunshine climatic data on monthly bases were collected from National Meteorological Service Agency (NMSA). The mean daily reference evapotranspiration were computed using CROPWAT version_8 program from the monthly total rainfalls and the result is presented as (Appendix Table1 and Figure 1).

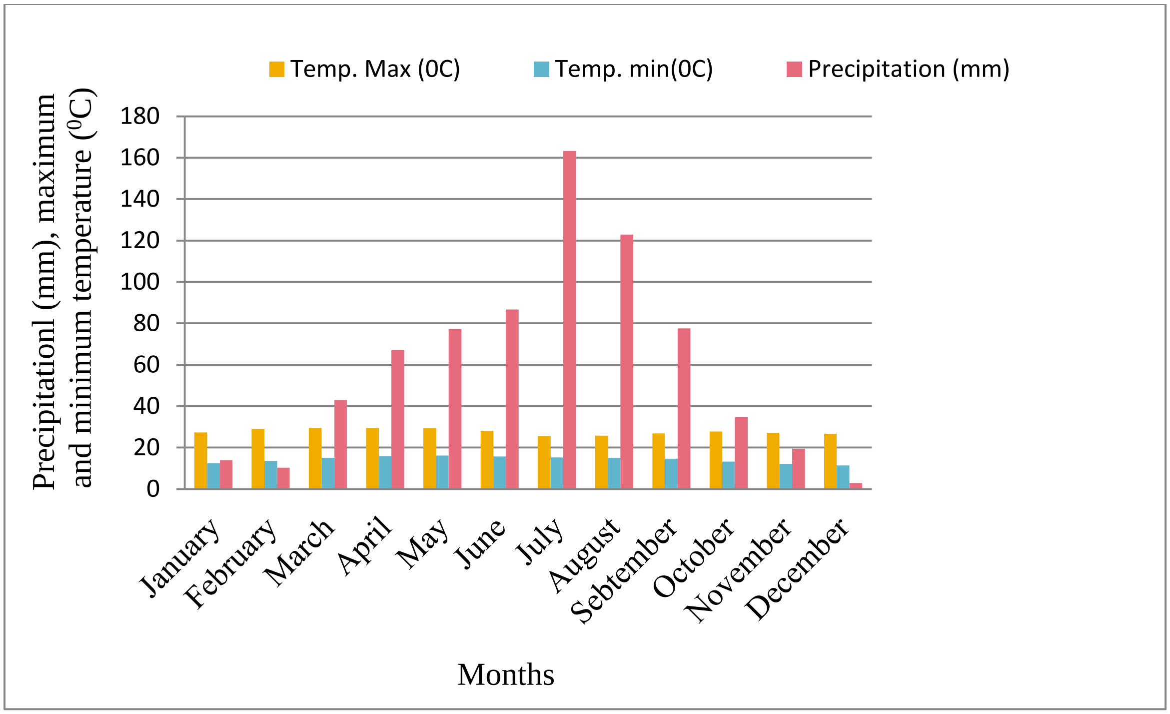


Figure 2. Precipitation, maximum and minimum temperature of the study area

3.2.2. Calculation procedure of the crop water requirement

Crop water requirement is determined by multiplying the ETo with the crop coefficient (Kc) values estimated by Allen *et al.* (1998) for each of the four growth stages of tomato viz., initial, development, mid season and late season. Through estimates of effective rainfall, crop irrigation water requirements were calculated assuming optimal water supply. Different inputs on soil texture, maximum infiltration rate, maximum root depth, yield response factor, crop growth stage length, total and initial available moisture were needed and their result were presented in (Appendix Tables 2 and 3). Then, a daily soil water balance was calculated with the model, predicting water content in the soil root zone by means of a water balance equation, which takes into account the incoming and outgoing flow of water.

3.3. Experimental Treatments and Design

The experiment was implemented in two factorial combination namely, three irrigation systems and four irrigation water levels. The three irrigation systems are AFI, FFI and CFI and the four levels of irrigation included 100% ETc, 85% ETc, 70% ETc and %50% ETc of the irrigation requirement.

AFI means one of the two neighboring furrows is alternately irrigated during consecutive irrigation events. FFI means that irrigation fixed to one of the two neighboring furrows. CFI or traditional irrigation means irrigating all furrows during consecutive watering.

With 100% ETc (full irrigation) implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of CROPWAT program. 85% ETc, 70% ETc and 50% ETc means 85%, 70% and 50% of full irrigation requirement, respectively. Each experimental plot was 4 m × 6 m with 1 m free space between plots and 2m wide spacing between blocks. Each treatment was replicated three times and the plots were laid by Randomized Complete Block Design (RCBD) in factorial arrangement as follows.

The experimental treatments were:
AF100% ETc = Alternative furrow with 100% ETc
AF85% ETc = Alternative furrow with 85% ETc
AF70% ETc = Alternative furrow with 70% ETc
AF50% ETc = Alternative furrow with 50% ETc
FF100% ETc = Fixed furrow with 100% ETc
FF85% ETc = Fixed furrow with 85% ETc
FF70% ETc = Fixed furrow with 70% ETc
FF50% ETc = Fixed furrow with 50% ETc
CF100% ETc = Conventional furrow with 100% ETc
CF85% ETc = Conventional furrow with 85% ETc
CF70% ETc = Conventional furrow with 70% ETc
CF50% ETc = Conventional furrow with 50% ETc

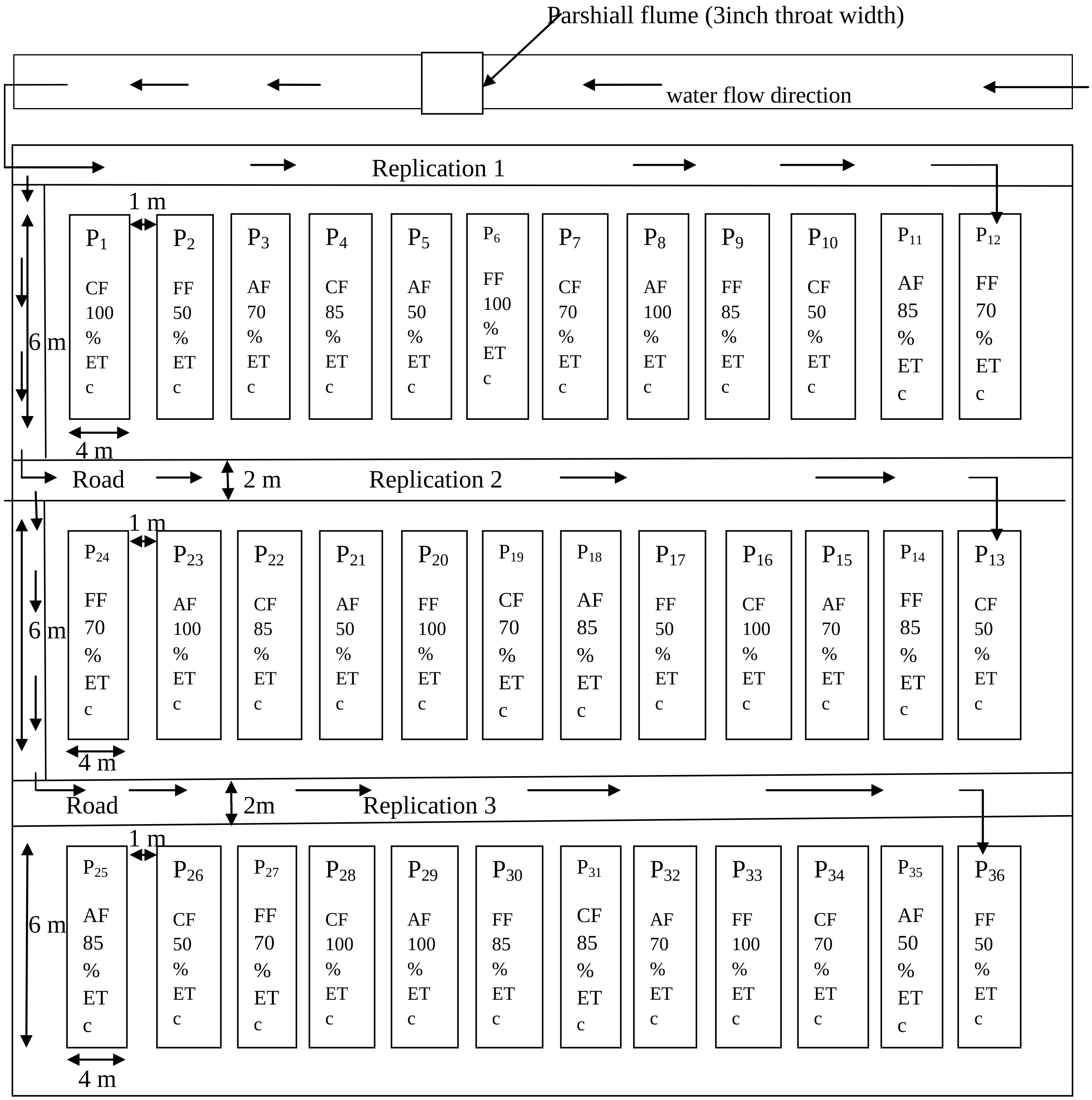


Figure 3. Experimental plot layout configuration

3.4. Soil Analysis

Depending on the requirement of each parameters and also considering the greatest concentration of root depth which is 30cm for transplanted tomatoes, the disturbed and undisturbed composite soil sample before planting and after harvest from each treatment at a depth of 0-20 and 20-40 cm were collected and analyzed for different soil physical properties such as bulk density, texture, field capacity and permanent wilting point and also for chemical properties such as soil pH, organic matter content, total nitrogen, available phosphorus and potassium at Ethiopian Water Works and Design Enterprise, Bako and Ziway Research Center Soil Laboratory.

3.4.1. Soil Physical Properties

Soil texture was determined using pipette method. This is based on direct sampling of the density of the solution. Using a pipette, samples of the suspension (usually 20 cm^3) was withdrawn at a given depth after various periods have elapsed after initiation of sedimentation. As per Stoke's law at a depth 'L' below the surface of the suspension and at time 't', all particles whose terminal velocity 'v' is greater than was passed below this level example silt passes through but clay remains.

The soil bulk density is defined as the oven dry weight of undisturbed soil in a given volume, as it occurs in the field. It was determined by core sampler method by taking undisturbed soil sample at a depth of 0-20 and 20-40cm. After weighing the soil sample, it was placed in an oven dry at 105^0c for 24 hours. After drying, the soil was weighed again for dry mass and the bulk density was calculated by using the following formula.

$$\rho b = \frac{W_d}{V_c} \tag{10}$$

where

ρb= soil bulk-density, (g/cm^3)
Wd = weight of dry soil, (g)
Vc = volume of core sampler, (cm^3)

Double ring infiltrometers were used to measure infiltration rate of the soil. The tests were done at five randomly selected points in the experimental site and the average result was taken.

The Water content field capacity (FC) and permanent wilting point (PWP) were determined at Ethiopian Water Works and Design Enterprise using a pressure plate apparatus by applying a suction of 1/3 and 15 bars to a saturated soil sample and when water is no longer leaving the soil sample, the soil moisture was taken as FC and PWP respectively. The moisture content of the soil samples on volume basis was determined by multiplying the gravimetric water content on weight basis by the bulk density.

3.4.2. Soil Chemical Properties

pH was measured in 1:1 soil: water mixture by using a pH meter. Distilled water was used as a liquid in the mixture. 10 g air dried < 2 mm soil was weighed into 100 ml beakers and 10 ml distilled water was added to 1:1 soil/water suspension and transferred to an automatic stirrer, to be stirred for 30 minutes and pH on the upper part of the suspension was measured.

Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H_2SO_4) digestion according to Walkley and Black (1934) method.

Total nitrogen was determined by micro Kjeldahl procedure (Kjeldahl, 1883). The soil sample was digested in sulphuric acid and hydrogen peroxide with selenium as catalyst and whereby organic nitrogen is converted to ammonium sulphate. The solution is then made alkaline and ammonia was distilled. The evolved ammonia is trapped in boric acid and titrated with standard acid. This procedure determines all soil nitrogen including adsorbed NH_4^+ except that in nitrates.

For non acidic soil, available phosphorus was determined by Olsen method (Olsen *et al.*, 1954). The readily acid soluble form was extracted by combination of HCl and NH_4F. Phosphorus in extract was determined calorimetrically with the blue ammonium molybdate method by flame emission spectrophotometer (FES) at a wavelength of 766.5.

Available potassium was determined by flame photometer method (Reed and Scott, 1961). Potassium was converted to a water-soluble form by heating the tetraphenylborate salt for 20 minutes in a furnace at 350^0C or in boiling aqueous solution of mercuric chloride. Then, it was separated from the mineral residues by adding acetone to the aqueous system and filtering. The potassium in the filtrate was then determined by flame photometry after the tetraphenylborate salts have been destroyed with aqua regia.

3.5. Crop Agronomy Practice and Disease Control

Tomato improved *Galilea* varieties having a total growing period of 75 days after transplanting was grown in a modern green house for 21 days and transplanting on experimental plot on 26 January, 2016. The total Recommended fertilizer rate of 200 kg/ha DAP and 50% of 150 kg/ha Urea were applied during transplanting time, while the remaining 50% of the Urea was applied at 21 days after transplanting on each seed bed to increase the fertilizer use efficiency by minimizing the leaching loss.

There is no single chemical product that is effective against all important foliar diseases. For example Mancozeb give good control but, Chlorothalanil gives fair control of early blight. Therefore, it is necessary to use a combination of different chemicals such as Ridomil Gold MZ WG, Mancozeb 80WP[4], Modan 5% E.C and Profit turn by turn in a spray program to optimize disease management. Ridomil Gold MZ WG was applied at a rate of 2.5kg in 500-700 liter water/ha to control early leaf blight (*Alternaria solani)* and late leaf blight fungal diseases. A maximum of 3 applications at 10 to 14 days intervals was done during the period of active growth. The first application was done when the crop has fully emerged and before disease has occurred. Shorter spray interval was used as a weather conditions favors the diseases occurrences especially during active crop growth in the period prior to flowering. Mancozeb 80WP[4] (Wettable Powder) was applied at a rate of 500g/ha in 600ml of water per ha to control powdery and fungal diseases such as early blight (*Alternaria solani)*, late blight (Irish blight), anthracnose leaf mould (*fulvia fulva*) and grey leaf spot. First application was done at the time, when disease symptoms first appear and then, repeated at 7 days intervals at higher rate with shorter spray interval as the weather condition was favorable to disease development. Modan 5 EC and Profit were applied at a rate of 100-150ml/ha in 200-500 liter of water per ha and 750ml/ha in 400-500 liter of water per ha to control white fly (aphid) insects respectively.

Under chemical uses, one important consideration is that products have different pre-harvest interval (PHI). So, a chemical product with a PHI greater than 2 days such as ridomil (7 days), mancozeb (5 days), Modan 5 EC (4 days) and profit (7) cannot be used, when the growers harvest 2 or more times per week.

The recommended spacing of 60 cm between plants and 100 cm between rows was used. Irrigation water was applied according to treatments arrangement and calculated irrigation interval. All needed management aspects was done according to the agronomic recommendation of the crop. Tomato yield was harvested from the two center ridges of all plots to minimize the border effects on yield.

3.6. Soil Moisture Determination

Soil moisture were monitored both at field condition by installing a tensiometer at different depth of 30, 40 and 60 cm and laboratory by taking undisturbed soil sample. Soil samples were taken at 11 and 15 days interval for the initial and remaining three growth stage respectively depending on irrigation interval from the third furrow of each plot at depths of 0-20 and 20-40 cm at locations of 3m from a head of furrow. This was provided a total of 2 samples from each plot, 24 from a block and 72 out of the experimental field. The collected soil samples were placed in an oven set at a temperature of 105^0C and dried for 24 hrs. Its gravimetric water content was then determined using the expression (Cuenca, 1989).

$$\theta_{dw} = \left\lceil \frac{W_{ws} - W_{ds}}{W_{ds}} \right\rceil \times 100 \tag{11}$$

where

Ws= weight of wet soil, (g)

θ_{dw} = water content expressed on weight basis in (%)

W_{ds} = weight of dry soil, (g)

And the volumetric water content was calculated from the gravimetric water content using the following expression.

$$\theta_v = \frac{\rho_b}{\rho_w} \times \theta_{\mathrm{dw}} \times 100 \quad (12)$$

where

θ_v = Volumetric moisture content in (%)

ρ_b = Soil bulk density, (g/cm^3)

ρw = Water density g/cm^3, (1g/cm^3)

θ_{dw} = as expressed in equation 11

3.7. Depth and Discharge Measurement

The total amount of water requirement estimated using the CROPWAT version_8 program was diverted to the furrow with calibrated parshall flume having appropriate opening diameter of three inch (3") with a length of 2 m and its appropriate head ranges from 3-33cm. Water flow to each furrow was controlled by the difference in depth between the water level in the feeder canal and free water level at the outlet at the furrow head. It was calculated as suggested by Michael, (1997):

$$Q = 0.1771h^{1.55} \quad (13)$$

where

Q = discharge from parshall flume, (l/s)

h = effective head of Parshall flume causing flow, (cm)

The time required to deliver the desired depth of water into each furrow was calculated using the equation recommended by Israelsen (1980).

$$t = \frac{d \times w \times l}{360 \times q} \quad 14$$

where

d= gross depth of water applied, (cm)

t= application time, (hr)

l= furrow length in, (m)

w= furrow spacing in, (m)

q= flow rate (discharge), (l/s)

The depth of irrigation was divided by value of Ea which is 60% for different loss compensation.

3.8. Flow Time Measurement

The setting time, advance time, time of application and recession time was monitored using stopwatch during each irrigation water application in order to assess the treatment effects on advance and recession rates. Data on water volume and length of irrigation time was taken during all irrigation events from discharge of the parshall flume.

3.9. Calculation and Analyses of Basic Parameters

3.9.1. Advance rate computation

Advance rate (AR) is the ratio of the length that the waterfront travels to the time required to cover the same length. Its comparisons were made using two parameters i.e. the recorded advance time and the total length that the water travels. It is computed using the equation (Israelsen, 1980).

$$\mathrm{AR} = \frac{\mathrm{LT}}{\mathrm{AT}} \tag{15}$$

where

AR= is Advance rate, (m/s)

LT = is Length travelled by water, furrow length, (m)

AT= is the time taken by water to travel from head to the tail of furrow, (s)

3.9.2. Distribution uniformity

Comparison between the irrigation methods was made on basis of the infiltration distribution uniformity. The soil samples were taken at a depth of 0-20 and 20-40cm before irrigation and after irrigation from all plots. The tool used to evaluate irrigation distribution uniformity was Christian's Uniformity Coefficient, which is given as:

$$\mathrm{UCC} = \left[1 - \frac{\sum_{i=1}^{n} \left|\theta_i - \bar{\theta}\ \right|}{\bar{\theta}\ \mathrm{N}}\right] \times 100 \tag{16}$$

where

UCC= Christian's uniformity coefficient, in %

θ_i = the observed water content for the i^{th} point, in cm^3 (from gravimetric moisture determination). It is the moisture content after oven dry of each of the soil sample from a plot

N = number of points where samples was taken. N is 1, 2, 3 ... 36, because uniformity was computed for each treatment

$\bar{\theta}$= the mean water content

Mean water content is determined by:

$$\bar{\theta} = \frac{\sum_{i=1}^{n} \theta_i}{N} \tag{17}$$

3.9.3. Application efficiency

Application efficiency is defined as the ratio of water stored in the root zone to water applied to the farm during irrigation Israelsen (1980).

$$E_a = \frac{W_s}{W_f} \times 100 \tag{18}$$

where

Ea = Application efficiency (%)

Ws= Water stored in the root zone, (mm)

Wf = Water applied to the field, (mm)

Water application efficiency can be estimated from the amount of water diverted into the furrow at a given irrigation (Wf), the amount deep percolated (Df) and runoff collected as a tail water at the end of the furrow at that specific irrigation (Israelsen, 1980).

Hence

$$E_a = \frac{W_f - (R_f + D_f)}{W_f} \times 100 \tag{19}$$

where

Rf= is the amount of runoff during irrigation, (mm)

Df= is the amount of water deep percolated during irrigation, (mm)

Runoff fraction (Rf) is an index used to quantify the irrigation water loss by surface runoff. Runoff fraction was computed from the volume of tail water collected at the end of the furrows using the following expression:

$$\mathrm{Rf} = \frac{\mathrm{Runoff}}{\mathrm{W_f}} \tag{20}$$

Deep percolation fraction (Df), is an index used to quantify the irrigation water loss by irrigation water percolating below the root zone. It was determined by:

$$\mathrm{Df} = 100\text{-}\mathrm{E_a}\text{-}\mathrm{Rf} \tag{21}$$

where

Rf and Ea as defined in equation 19 and 3 respectively

3.9.4. Storage efficiency

Storage efficiency (Er) was calculated using the following formula:

$$Er = \frac{\mathrm{W_S}}{\mathrm{W_n}} \times 100 \tag{22}$$

Where

Er = storage efficiency (%)

Ws = water stored in the root zone during irrigation, (cm)

Wn = water needed in the root zone prior to irrigation, (cm)

3.9.5. Yield assessments (y)

In order to assess the overall effect of treatments on crop yield, the amount of tomato produced was harvested from the central ridges only; this is to avoid boarder effects. The results were then converted to hectare basis using the following formula:

Yield obtained per ha = y × 10^4

where

y = is yield obtained per square meter

3.9.6. Water use efficiency

The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water (kg/m^3). Two kinds of water use efficiencies namely total water use efficiency (CWUE) and net irrigation water use efficiency (FWUE) was calculated.

3.9.6.1. Crop water use efficiency

Total water use efficiency is the yield harvested per ha-mm of total water used.

$$\mathrm{CWUE} = \frac{\mathrm{y}}{\mathrm{ETc}} \qquad (23)$$

where

CWUE = crop water use efficiency (kg/ha-mm)

Y = yield in kg ha^{-1} and

ETc = evapotranspiration in mm

3.9.6.2. Field water use efficiency

Field water use efficiency is the yield harvested per ha-mm of net depth infiltered.

$$\mathrm{FWUE} = \frac{\mathrm{y}}{\mathrm{Net\ irrigation}} \qquad (24)$$

Where

FWUE = field water use efficiency (kg/ha-mm)

Y= yield in (kg/ha)

Net irrigation is in (mm)

3.9.7. Statistical Analysis

The collected yield, irrigation systems and depth of applied water levels data during the field studies were compared using SAS, ANOVA and least significance difference (LSD) was used for mean comparisons.

4. RESULTS AND DISCUSSION

Irrigation system performance indicators such advance rate, recession time, distribution uniformity, application efficiency, storage efficiency, yield assessment and water use efficiency (water productivity in terms of total water use efficiency and net irrigation water use efficiency) were measured to evaluate the performance of AFI, FFI and CFI under deficit irrigation system. The results obtained were presented and discussed in the following sections.

4.1. Crop Water Requirement of Tomato

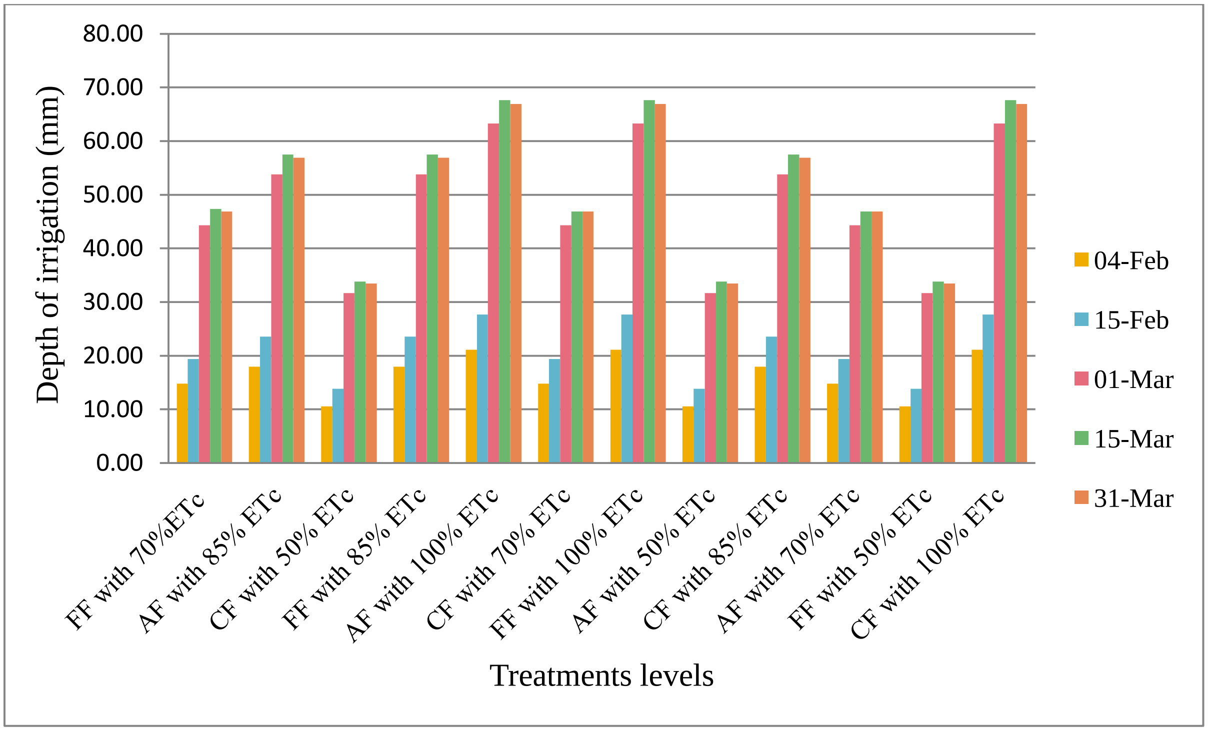
Crop water requirement is the quantity of water, regardless of its source, required by a crop in a given period of time for its normal growth under field conditions at a place. Estimation of the water requirement of a crop is one of the basic needs for irrigated crop production planning.

The net crop water requirement was computed by deducting effective rainfall from ETc. The gross water requirement was computed by adopting a field application efficiency of 60%. In fact furrow irrigation efficiencies vary from 45-60% (Bakker *et al.*, 1999). However, in this experimental set up, where water was applied more accurately and there was no runoff, a higher value of Ea (60%) was adopted.

The values of ETo estimated using CROPWAT model based on climate parameters need to be adjusted for actual crop ET. The crop water requirement of the tested crop is calculated by multiplying the reference ETo with crop coefficient (Kc) as presented (Appendix Table 4).

According to Appendix Table 4, the seasonal irrigation water requirement of tomato was found to be 246.58 mm. This amount of water was needed for 100% ETc with CFI, AFI, FFI (full irrigation) level treatments. Accordingly, 85%, 70% and 50% of full irrigation (100% ETc) with CFI, AFI, and FFI level were 210 mm, 173 mm and 124 mm, respectively.

The CROPWAT model predicted effective rainfall depth of about 68mm during the growing season. But, there was no rainfall during the experimental period. The depth of irrigation water applied during each irrigation event and water application level is presented (Appendix Table 5 and Figure 4).The result indicates that, the maximum depth of water was applied during mid of March which is the mid development stage of tomato. Sahasrabudhe, (1996) suggested that this is the time when the crop needs high amount of water. Maximization of crop yield and quality can be achieved through meeting crop water requirement during this critical period, given all other factors are met. Probably the high tomato water requirement during this stage of development can be accounted for development of flowers and fruit which is high energy demanding and peak physiological phase for the crop growth. It should be noted also that development stage is also the time during which the plants achieve higher canopy coverage and undergoing higher transpiration rate. By sufficiently supplying water to the plant, during such critical time and ensuring its uptake, it is possible to improve crop water productivity.



* FF with 100%, 85% 70% and 50% ETc is fixed furrow with 100%, 85% 70% and 50% crop water requirement. AF with 100%, 85% 70% and 50% ETc is alternative furrow with 100%, 85% 70% and 50% crop water requirement. CF with 100%, 85%, 70% and 50% ETc is conventional furrow with 100%, 85% 70% and 50% crop water requirement.

Figure 4. Irrigation interval and depth of applied water

4.2. Soil of the Experimental Area

To characterize the soil in the experimental site in terms of infiltration characteristics, texture, FC, PWP, organic matter content, pH, total nitrogen, available phosphorus and potassium, field tests and soil analyses at laboratory were undertaken and result were presented (Appendix Figure 1 and Appendix Tables 6, 7 and 8).

According to appendix table 6 and appendix figure 1, the basic infiltration rate was about 28.2 mm/hr. It was consistent with the basic infiltration rate of sandy loam soil which ranges from 20 to 30 mm/hr as reported by different researchers (Haider, 1986; Scherer et al., 1996).

Result of soil textural analysis as depicted on Table 1 and Appendix Table 7 showed that, the composition of sand, silt and clay percentage were 71, 8 and 21 and 69, 17 and 14 for a depth of sampling 0-20cm and 20-40cm respectively. The result indicates that, there is a significant textural change with depth and thus according to the USDA soil textural classification, the soil is classified as sandy clay loam and sandy loam for a depth of 0-20 and 20-40cm respectively. The overall mean result indicates sandy loam with textural composition of sand, silt and clay percentage 70, 11 and 19 respectively.

As indicated on Table 1 and Appendix Tables 7 and 8, the analysis results of soil pH before irrigation were 7.15 and 7.55 for a sampling depth of 0-20 and 20-40cm respectively. This shows that, there was soil pH variation with depth, though not exaggerated. The mean soil pH result of 7.35 before irrigation shows that, the soil of the experimental site is nearly neutral and suitable for crop production. The mean soil pH value has changed from 7.35 to 7.76, 8.06 and 8.09 for AFI, CFI and FFI systems respectively after implementation of the irrigation. While, it was changed from 7.35 to 8.11, 7.97, 8.07 and 7.72 after application of water levels 100% ETc, 85% ETc, 70% ETc and 50% ETc respectively.

According to Brady (2000), the pH range from 7.4-7.8 and 7.9-8.4 indicates moderately and strongly alkaline respectively. The results of AFI system and 50% ETc of water application levels were changed from neutral to moderately alkaline, while the results of FFI, CFI and water application levels of 100% ETc, 85% ETc and 70% ETc were changed from neutral to strongly alkaline. Because, the lake water used for irrigation has pH (8.7), ESP (60.42%) and EC (0.64ds/m) which is categorized under sodic and with high application of irrigation water 100% ETc, 85% ETc and 70% ETc and also in CFI and FFI systems, the amount of sodium cation added to the soil from the irrigation water increases the soil pH. According to Cruz-

Romero and Coleman (1975), Exchangeable sodium and calcium carbonate (Ca_2CO_3) react in low carbon dioxide and low neutral salt environments to produce high pH and appreciable concentration of sodium carbonate (Na_2CO_3). Since the soil of arid and semi-arid regions nearly always contain some $Ca_2CO_{3,}$ a build up in the exchangeable sodium in the absence of an appreciable quantity of neutral soluble salts will always result in high pH. That is why the soil pH increases after the implementation of irrigation.

According to Appendix Table 7, the bulk density result of 0-20cm and 20-40cm of soil of the area were 1.32 and 1.34 g/cm^3 respectively. This indicates that, the top surface soil has slightly lower bulk density than the subsurface.

As indicated in the mean results of (Table 1, Appendix Tables 7 and 8), the organic matter content of the soil of the experimental site before and after irrigation were less than 2% which is very low (Landon, 2014). But, after implementation of the experiment the organic matter content of the soil increases from 1.15% to 1.20%, 1.25% and 1.38% for FFI, AFI and CFI systems and from 1.15% to 1.22%, 1.39%, 1.32% and 1.18% for water application levels of 100% ETc, 85% ETc, 70% ETc and 50% ETc respectively. This is consistent with the report of an increased trend in soil organic matter content was observed as the water deficit level of 85% ETc which further decreasing consistently (Abu and Malgwi, 2012). This clearly shows that, the organic matter in the soil stayed without decomposed and then, it was decomposed after the soil gets moisture through irrigation. There is also a variation with depth of sampling, which shows the top soil contain higher organic matter than the subsurface. This is match with the concept of soil having high organic matter is lower in weight and bulk density.

According to Table 7, the moisture content at field capacity varies with depth between 23.77% and 20.10% on volume basis. The top 0-20 cm has a larger field capacity value of 54.18% while the subsurface 20-40 cm has a lower value of 45.82% and the moisture content at permanent wilting point also shows variation with depth, having 12.28% at the top (0-20 cm) and 11.89% at 20-40cm.This variation is because of the decreases in composition of clay and sand contents with depth, especially clay contents as clearly seen from the analysis results of soil texture.

From Table 1, the mean results of total nitrogen content of the soil before and after irrigation were less than 0.15% which is low (Havelin *et al*., 2013). However, the total nitrogen content in the soil increases after irrigation from 0.08% to 0.1075%, 0.1128% and 0.1075% for FFI, AFI and CFI systems and from 0.08% to 0.11%, 0.1167%, 0.11% and 0.10% for irrigation water application levels of 100% ETc, 85% ETc, 70% ETc and 50% ETc respectively. According to Richard and Michael (2012), a conversion factor of 4.43 multiplied with the results of total nitrogen before and after irrigation, the results were changed to nitrate (NO_3^-) form which is the water soluble form of nitrogen. This helps us to judge how the solubility and availability of the nitrogen increases after it gets moisture through irrigation.

As described on Table 1 and Appendix Tables 7 and 8, the mean results of available phosphorus before and after irrigation were between 30-80mg/kg of soil which is optimum (Karltun et al., 2013). After irrigation, it was increases from 44.19 mg/kg of soil to 46.89, 46.02 and 46.96 mg/kg of soil and 46.45, 45.95, 47.07 and 47.03 mg/kg of soil for FFI, AFI, CFI and 100% ETc, 85% ETc, 70% ETc and 50% ETc respectively. Similar trends for organic matter and total nitrogen was observed and similar pedogenic process given for organic matter and total nitrogen makes differences may explain this.

Another inference from Table 1 and Appendix Tables 7 and 8 were the degree of decreases in available potassium. As already indicated, the available potassium content of the soil was decreased to some extent after irrigation on both irrigation systems and water application levels. As a result, it was decreases from 306.29 mg/kg of soil to 257.87, 274.88 and 304.61 mg/kg of soil for FFI, AFI and CFI systems, while it was decreased from 306.29 mg/kg of soil to 254.25, 284.15, 284.81 and 293.26 mg/kg of soil for 100% ETc, 85% ETc, 70% ETc and 50% ETc respectively. These results show that, when the soil gets enough moisture from irrigation, the plant uptake rate of the potassium is increased, while its content in the soil decreases. In addition to uptake, it is well established that potassium is liable to leaching and thus this might have also decrease its content in the soil. This situation was mostly pronounced in moisture stress area where soil moisture is a limiting factor. Experiment undertaken in the middle Awash reported by Haider (1986) is in agreement with the results obtained in the present study.

Table 1. Mean value of soil parameters of the experimental sites as from laboratory results

Irrigation system	Water application levels	pH in water	OM (%)	Total N (%)	Available P_2O_5 (mg/kg of soil)	Available K_2O (mg/kg soil)	FC % by vol.	PWP % by Vol.	Bd (g/cm^3)	Sand %	Silt %	Clay %	Textural class
Composite sample		7.35	1.15	0.08	44.19	306.29	21.94	12.09	1.33	70	11	19	Sandy loam
FFI	100%ETc	8.26	1.10	0.11	46.68	238.33							
	85%ETc	8.08	1.43	0.12	46.69	225.42							
	70%ETc	8.14	1.16	0.10	48.27	279.96							
	50%ETc	7.87	1.20	0.10	45.93	287.75							
AFI	100%ETc	7.73	1.33	0.11	47.81	234.28							
	85%ETc	8.13	1.34	0.11	44.85	291.75							
	70%ETc	7.99	1.12	0.13	45.04	265.85							
	50%ETc	7.17	1.35	0.10	46.38	307.64							
CFI	100%ETc	8.33	1.40	0.11	44.85	290.15							
	85%ETc	7.70	1.50	0.12	46.31	335.29							
	70%ETc	8.09	0.10	0.10	47.89	308.62							
	50%ETc	8.11	1.25	0.10	48.78	284.39							

*OM-organic matter, FC- field capacity, PWP- permanent wilting point, Bd- bulk density, N- nitrogen, P_2O_5-phosphorus penta oxide, K-potassium.

4.3. Flow Performance Results

To measure inflow rate to each furrow of the treatments, Parshall flume was calibrated at different head for discharge and results were presented in Appendix Table 9 and Figure 6.

The effective head of 8cm was calibrated and hence the resulting discharge out of the Parshall flume was 3.532 liters per second. Advance rate, infiltration distribution uniformity and water application efficiency were some of flow characteristics used to measure the effects of the treatments.

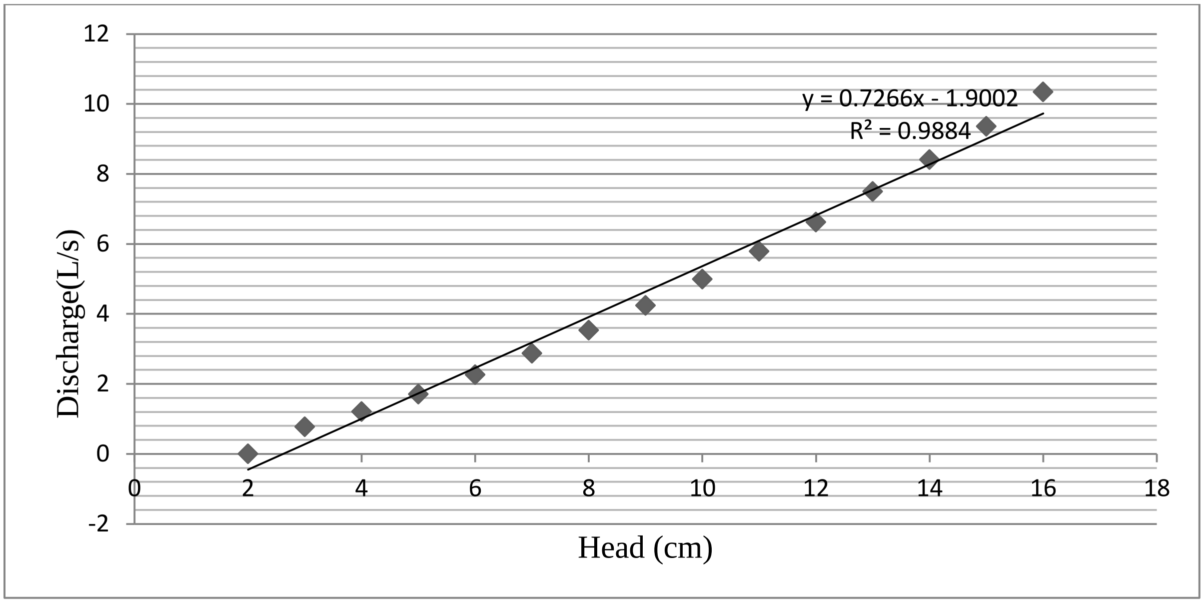


Figure 5. Parshiall flume head and discharge relationship

4.3.1. Advance rate

The time required for the water to advance to the end of the field length or to cover the field completely is an important consideration in managing surface irrigation systems. The advance time dictates in large measure when the inflow must be terminated and it provides the time when field tail water begins flowing from the field or when the field begins to pond.

To evaluate the effect of FFI, AFI and CFI systems and water application levels on advance rate, advance time was recorded and computed using the expression discussed in section 3.9.1 and results are presented in Appendix Table 10.

According to analysis of variance (Table 2), there is no significant difference between the three irrigation systems at ($p<0.05$) in terms of advance rate. However, the maximum and minimum mean values were observed from CFI (0.370) and AFI (0.35) system. Water advances more slowly in an alternate furrow irrigation system due to the greater potential for lateral movement (Musick and Dusek, 1974). The probable reason for the non significance of the irrigation systems on advance rate was the shortness of the furrow length of the experimental plot.

As clearly seen from the analysis of variance (table 2), advance rate of water application levels were also not significantly different at ($p<0.05$). However, the maximum and minimum mean values were observed for irrigation water application levels of 100% ETc (0.374) and 85% ETc (0.360) respectively.

Regarding to advance time, as indicated in analysis of variance (Table 2), there were no significant interaction between irrigation systems and water application levels. None of alternate, fixed and conventional irrigation systems accelerated or slowed down any of irrigation levels significantly on advance rate.

Table 2. Analysis of variance for advance rate

Source of variation	SS	df	MS	F computed	F-tab	
					(0.05)	(0.01)
Blocks	0.0035	2	0.0017	1.34	3.44	5.72
Treatments	174.0289	11				
Systems	0.0024	2	0.0012	0.94	3.44	5.72^{NS}
Levels	0.0033	3	0.0011	0.83	3.05	4.82^{NS}
System x levels	0.0070	6	0.0012	0.89	2.55	3.76^{NS}
Error	0.0286	22	0.0013			
Total	174.0737	46				

NS-non significant

4.3.2. Recession time

To observe the infiltration opportunity time of irrigation water for AFI, FFI and CFI systems with water application levels, recession time were recorded during experimental period and results were presented in Appendix Table 11.

As indicated on analysis of variance (Appendix Table 12), there were highly significant difference among the three irrigation systems at ($p<0.01$) in terms of recession time. As it is clearly seen from Table 3, recession time of AFI system was significantly different from both CFI and FFI systems, but there were no significant difference between CFI and FFI systems. The probable reason for this could be the difference in soil-water potential between the three irrigation systems which makes the recession time different. The water suction of CFI may be smaller and need longer recession time than AFI and FFI. In an AFI, soil desiccations was higher with low soil water potential due to alternate wetting of neighboring furrows and the recession time is shorter. In FFI system, the neighboring furrow stays dry during the whole irrigation period and the lateral movement subsequently higher than the rate of infiltration. This is consistent with the results of slower recession time that have been associated with AFI and FFI (Hodges et al., 1989; Musick and Dusek, 1974; Woldesenbet, 2005).

Table 3. Effect of irrigation systems on recession time

Irrigation systems	Recession time (min)
CFI	83.36^{a}
FFI	77.10^{a}
AFI	70.44^{b}
Mean	76.97
CV	4.90%
$LSD_{0.05}$	6.40
SE	3.09

* Mean of twelve treatments observation

Looking into the effect of irrigation water application levels from the accompanying analysis of variance (Appendix Table 12), there were highly significant difference at ($p<0.01$) among the water application levels on recession time. As indicated on Table 4, the significant difference in recession time were observed between 100% ETc and the remaining three application levels, 85% ETc and 50% ETc and 70% ETc and 50% ETc. But, no significant difference between water application levels of 85% ETc and 70% ETc. This result indicates that, the time needed for recession depends on the levels of irrigation water applied.

Table 4. Effect of water application levels on recession time

Water application levels	Recession time (min)
100% ETc	87.33^a
85% ETc	80.33^b
70% ETc	74.33^b
50% ETc	66.89^c
Mean	77.22
CV	4.90%
$LSD_{0.05}$	6.40
SE	3.09

* Mean of twelve treatments observations

As depicted from the analysis of variance (Appendix Table 12), there were significant interactions at ($p<0.05$) between irrigation systems and water application levels. As indicated on two ways Table 5 and Appendix Figure 2, recession time of CFI and FFI systems were significantly different between 100% ETc and the remaining three application levels, 85% ETc and 50% ETc and also between 70% ETc and 50% ETc for CFI system. This indicates that, the recession time of CFI and FFI systems were affected by water application levels. But under AFI system, recession time of water application levels at 50% ETc was significantly different from the three application levels, while there were no significant difference among 85% ETc, 70% ETc and 50% ETc.

Table 5.Two-way table of mean recession time (min)

Irrigation systems	Water application levels				Mean
	100%ETc	85%ETc	70%ETc	50%ETc	
FFI	86.78^{a}	78.27^{b}	73.44^{cb}	69.89^{dc}	77.01
AFI	76.11^{a}	74.00^{a}	71.22^{a}	60.44^{b}	70.44
CFI	99.11^{a}	84.33^{b}	78.34^{cb}	71.67^{d}	83.36
Mean	86.91	78.45	73.91	68.47	76.94
$LSD_{0.05}$	6.40				

4.3.3. Distribution uniformity

The Christian's Uniformity Coefficient (UCC), equation 16, was used to evaluate irrigation water distribution uniformity. Soil moisture content was computed using equation 11 and used as an input data for UCC determination. The calculated mean values for the treatments were presented in Appendix Table 13.

According to the analysis of variance (AppendixTable14), there were highly significant difference at ($p<0.01$) among the three irrigation systems in terms of UCC. As indicated on Table 6, UCC of CFI system was significantly different from AFI, but no significant difference between CFI and FFI, AFI and FFI systems. This is not consistent with Woldesenbet, (2005) who reported that UCC is not affected by irrigation systems rather than application levels. According to Hanson (2005), a uniformity of 100% means the same amount of water infiltrates everywhere in a field. Practically, no irrigation systems, however, can apply water at 100% uniformity. Regardless of the irrigation systems, some parts of a field infiltrate more water than other areas.

Table 6. Effect of irrigation systems on UCC

Irrigation systems	UCC (%)
FFI	80.21^{ab}
AFI	79.01^{a}
CFI	81.75^{b}
Mean	80.32
CV	1.77%
$LSD_{0.05}$	2.40
SE	1.16

* Mean of twelve treatments observation

Another inferences that can be drawn from the results of analysis of variance (Appendix Table 14) was the comparison among irrigation water application levels which is highly significant at ($p<0.01$) in terms of UCC. As clearly observed from Table 7, UCC of 100% ETc is significantly different from 85% ETc, 70% ETc and 50% ETc application levels, while there were no significant differences between the remaining three levels. This difference came from the difference in intake opportunity time for water distribution. At large water application levels, the tail end furrows get comparable opportunities for water infiltration as that of furrow heads (Walker, 1989).

Table 7. Effect of water application levels on UCC

Application levels	UCC (%)
100% ETc	82.68^{a}
85% ETc	80.09^{b}
70% ETc	79.34^{b}
50% ETc	79.18^{b}
Mean	80.32
CV	1.77%
$LSD_{0.05}$	2.40
SE	1.16

* Mean of twelve treatments observations

From the analysis of variance (Appendix Table 14), interaction between irrigation systems and water application levels were highly significant at ($p<0.01$) on UCC. As indicated on two ways Table 8 and Appendix Figure 3, the water UCC of FFI, AFI and CFI systems depends on the application levels. But, the degrees of the effect of water application levels for the three irrigation systems were different. As a result, UCC of FFI system at water application level of 50% ETc was significantly different from 100% ETc, 85% ETc and 70% ETc. Moreover, CFI system is better in UCC at 100% ETc which is significantly different from the remaining three application levels. While in AFI system, UCC at 70% ETc was significantly different from water application levels of 100% ETc, 85% ETc and 50% ETc. UCC in AFI system increases from 70% ETc to 50% ETc water application levels. This is because of the soil-water potential difference and suction force of the soil, as the lateral flow to the dry area is greater than the rate of infiltration in this case.

Table 8.Two-way table of mean UCC (%)

Irrigation systems	Water application levels				Mean
	100%ETc	85%ETc	70%ETc	50%ETc	
FFI	82.32^{a}	80.04^{a}	80.91^{a}	77.57^{b}	80.21
AFI	80.67^{a}	79.60^{a}	76.05^{b}	79.69^{a}	79.00
CFI	85.04^{a}	80.62^{b}	80.07^{b}	80.26^{b}	81.50
Mean	82.68	80.09	79.01	79.17	80.24
$LSD_{0.05}$	2.40				

4.4. Application Efficiency

In order to evaluate FFI, AFI and CFI systems in terms of application efficiency, soil moisture data was taken from all plots before and after irrigation and computed using equation 11 which was used as input data for equation 18 and 19 for computation of application efficiency and the obtained results were presented in Appendix Table 15.

From the results presented in analysis of variance (Appendix Table 16), application efficiencies of irrigation systems were highly significant at ($P<0.01$). As it can be clearly seen from Table 9, both of AFI and FFI systems were significantly different from CFI system, but no significant difference between AFI and FFI systems. This is consistent with the significant improvements in application efficiency that have been associated with AFI (Feyen and Zerihun 1999; Kassa, 2001; Woldesanbet, 2005).

Table 9. Effect of irrigation systems on application efficiency (Ea)

Irrigation systems	Ea (%)
AFI	60.45^a
FFI	59.22^a
CFI	55.28^b
Mean	58.32
CV	3.29%
$LSD_{0.05}$	3.25
SE	1.57

* Mean of twelve treatments observation

According to the analysis of variance (Appendix Table 16), the application efficiency due to water application levels was also highly significant at (P<0.01). As indicated from Table 10, the significant difference was observed between water application levels of 85% ETc and 50% ETc, while the rest were none significant. This is due to the higher infiltration rate than lateral flow in sandy loam soil, which increases the deep percolation losses as water application levels increases rather than improving application efficiency and vice versa for low water application levels.

Table 10. Effects of water application levels on application efficiency (Ea)

Application levels	Ea (%)
100% ETc	59.56^{a}
85% ETc	56.48^{ab}
70% ETc	57.47^{abc}
50% ETc	59.78^{ac}
Mean	58.32
CV	3.29%
$LSD_{0.05}$	3.25
SE	1.57

* Mean of twelve treatments observation

Analysis of variance (Appendix Table 16) indicates that, there were highly significant interaction effect at ($P<0.01$) between irrigation systems and water application levels on application efficiency. As observed from two ways Table 11 and Appendix Figure 4, application efficiency of CFI system at 100 % ETc was significantly different from the water application levels of 85% ETc,70 ETc, 50% ETc and also between 85% ETc and 50% ETc. This indicates that, application efficiency of CFI system was affected by water application levels. As water application levels decreases the application efficiency also decreases linearly. Under FFI system application efficiency of 50% ETc was significantly different from the rest of water application levels. In AFI system, application efficiency was significantly different between 100% ETc and 85% ETc, 85% ETc and 50% ETc, 70% ETc and 50% ETc. This shows that, for AFI and FFI systems as water application levels decreases the application efficiency increases linearly except at 85% ETc. This is because of the significant improvement in application efficiency of both AFI and FFI systems.

Table 11.Two-way table of mean application efficiency (%)

Irrigation systems	Water application levels				Mean
	100%ETc	85%ETc	70%ETc	50%ETc	
FFI	57.69^{a}	55.88^{a}	59.35^{a}	63.98^{b}	59.23
AFI	61.13^{a}	57.79^{b}	59.46^{ab}	63.41^{ac}	60.45
CFI	59.85^{a}	56.14^{b}	53.62^{cb}	51.50^{dc}	55.28
Mean	59.56	56.60	57.48	59.63	58.32
$LSD_{0.05}$	3.25				

4.5. Storage Efficiency

Soil moisture before and after irrigation was taken to evaluate the effects of FFI, AFI and CFI systems on storage efficiency and then, the soil moisture content was computed using equation 11 and used as input data to compute storage efficiency using equation 22.The results were presented in Appendix Table 17.

According to the analysis of variance (Appendix Table 18), there was highly significant difference at ($P<0.01$) between the three irrigation systems in terms of storage efficiency. The recession time of CFI system was significantly different from AFI systems, while there was no significant difference between AFI and FFI systems (Table 12). This difference may be because of the irrigation technique, as all furrows was getting the opportunity of irrigated at once in CFI system, while it was turn by turn in AFI and the depth of applied water also differ.

Table 12. Effect of irrigation systems on storage efficiency (Er)

Irrigation systems	Er (%)
CFI	65.77^{a}
AFI	63.15^{b}
FFI	65.13^{ab}
Mean	64.89
CV	2.23%
$LSD_{0.05}$	2.46
SE	1.18

* Mean of twelve treatments observation

As indicated in analysis of variance (Appendix Table 18), water application levels were highly significant at ($P<0.01$) on storage efficiency. On storage efficiency, there was a significant difference among all water application levels expect between 70% ETc and 50% ETc (Table 13). These results indicates that, as a water application levels become decreases under deficit irrigation, the storage efficiency is also decreases, as storage efficiency is a measure of adequacy when the desired depth of irrigation fills the soil to field capacity (James, 1988).

Table 13. Effect of water application levels on storage efficiency (Er)

Application levels	Er (%)
100% ETc	70.75^{a}
85% ETc	65.77^{b}
70% ETc	62.05^{c}
50% ETc	61.00^{c}
Mean	64.89
CV	2.23%
$LSD_{0.05}$	2.46
SE	1.18

* Mean of twelve treatments observations

As clearly indicated on analysis of variance Appendix Table 18, there was no significant interaction between irrigation systems and water application levels on storage efficiency.

4.6. Irrigation Water Losses

Surface irrigation losses include runoff, deep percolation, ground evaporation and surface water evaporation, but in this experiment only deep percolation loss was considered. While the tail water lost as runoff is prevented by blocking the tail end furrow with a locally available blockage materials to maintain the required depth of irrigation water in the furrow and the remaining two losses were neglected. Then, D_f was computed by the formula discussed in section 3.9.3 and equation 21 and results obtained were presented in Appendix Table 19.

From the analysis of variance (Appendix Table 20), irrigation systems were highly significant at ($P<0.01$) on deep percolation losses. As indicated on Table 14, deep percolation losses of CFI system was significantly different from both of AFI and FFI systems, but there was no significant difference between AFI and FFI systems. This is consistent with the significant water loss that has been associated with CFI (Graterol *et al.*, 1993). The result of present study was below the range of irrigation water losses reported by Kassa (2001) and also not consistent with the report of Feyen and Zerihun (1999).

Table 14. Effect of irrigation systems on deep percolation (Df)

Irrigation systems	Df (%)
CFI	44.73^a
FFI	40.78^b
AFI	39.55^b
Mean	41.69
CV	4.34%
$LSD_{0.05}$	3.09
SE	1.49

* Mean of twelve treatments observation

According to the analysis of variance (Appendix Table 20), water application levels were also highly significant at ($P<0.01$) interms of deep percolation losses. As depicted from Table 15, deep percolation losse of 85% ETc was significantly different from 50% ETc, while the rest of application levels were not significantly different.

Table 15. Effect of water application levels on deep percolation (Df)

Application levels	Df (%)
100% ETc	40.44^{a}
85% ETc	43.40^{ab}
70% ETc	42.53^{abc}
50% ETc	40.30^{ac}
Mean	41.69
CV	4.34%
$LSD_{0.05}$	3.09
SE	1.49

* Mean of twelve treatments observations

An observed from analysis of variance (Appendix Table 20), the interaction effects between irrigation systems and water application levels were highly significant at ($P<0.01$) on deep percolation losses. As indicated on two ways Table 16 and Appendix Figure 5, deep percolation losses under CFI system at 100% ETc was significantly different from 85% ETc, 70% ETc, and 50% ETc and also between 85% ETc and 50% ETc water application levels. This shows that, a deep percolation loss in CFI system was not affected by water application levels, because as water application levels decreases deep percolation losses increases. Deep percolation losses in FFI system at 50% ETc was significantly different from 100% ETc, 85% ETc, 70% ETc and also between 85 % ETc and 70% ETc water application levels. In AFI system there was a significant difference between 100% ETc and 85% ETc, 85% ETc and 50% ETc, 70% ETc and50% ETc on deep percolation losses. For both AFI and FFI systems, deep percolation losses decreases as water application levels decreases except at 85% ETc.

Table 16.Two-way mean of deep percolation (%)

Irrigation systems	Water application level				Mean
	100%ETc	85%ETc	70%ETc	50%ETc	
FFI	42.31^{a}	44.12^{ac}	40.65^{ad}	36.02^{b}	40.78
AFI	38.87^{a}	42.22^{b}	40.53^{ab}	36.76^{ac}	39.55
CFI	40.15^{a}	43.86^{b}	46.39^{cb}	48.50^{dc}	44.72
Mean	40.44	43.40	42.52	40.37	41.68
$LSD_{0.05}$	3.09				

4.7. Performance Evaluation on Crop Yield and Water Use Efficiency

Water use efficiency is usually a seasonal value defined as yield in an area per water used to produce the yield (Gregory, 1988). So, under this experiment, to evaluate AFI, FFI and CFI systems and water application levels in terms of yield and water use performances, yield and water use efficiencies were considered. As the objectives of doing this experiment was to assess how much water could be saved by alternate and fixed furrow irrigation systems without compromising the anticipated yield as compared to conventional irrigation system. To see these effects, different irrigation variables affected by furrow irrigation systems such as net irrigation, CWUE, gross irrigation (ET), FWUE and yield were considered. The results of gross irrigation and yield were presented in Appendix Tables 5 and 21 respectively.

These results showed that, water consumption was low in the treatments irrigated from one side (AFI and FFI) in comparison with the treatments irrigated from two sides (CFI), which were naturally predictable. At a time, when the experiment was conducted there was no rainfall which causes runoff or tail water lost as runoff. Because of this, gross irrigation was used for computation of both CWUE and FWUE.

As clearly observed from Table 17, the trend of decrease in yield is directly related with the decreases in water application levels. This indicates the effects of applied irrigation water levels on yield more or less. But, the degree of variation in yield may differ between the irrigation systems and applied water levels.

Table 17. Tomato yield and irrigation variables affected by furrow irrigation systems

Irrigation systems	Water application levels	Yield (kg/ha)	Gross irrigation (mm)	CWUE ($Kgha^{-1}mm^{-1}$)	FWUE ($Kgha^{-1}mm^{-1}$)
		a	b	a/b	a/b
FFI	100% ETc	25,500.00	123.45	206.56	206.56
	85% ETc	22,055.56	104.93	210.19	210.19
	70% ETc	18,000.00	86.42	208.30	208.30
	50% ETc	14,444.45	61.73	234.01	234.01
AFI	100% ETc	31,444.44	123.45	254.71	254.71
	85% ETc	25,611.114	104.93	244.08	244.08
	70% ETc	22,527.78	86.42	260.68	260.68
	50% ETc	16,500.00	61.73	267.29	267.29
CFI	100% ETc	38,694.44	246.90	156.72	156.72
	85% ETc	26,055.56	209.87	124.15	124.15
	70% ETc	21,861.11	172.83	126.49	126.49
	50% ETc	14,166.67	123.45	114.76	114.76

* Mean of twelve observations

4.7.1. Yield performance

Tomato yield was collected from the central ridges of each treatment plots, weighed and converted to hectare basis with intention of comparing the yield performance of the three irrigation systems with different levels of water application. The obtained yield results were presented in Appendix Table 21.

As depicted from analysis of variance (Appendix Table 22), there were highly significant yield difference at ($P<0.01$) between irrigation systems. As observed from Table 18, yield obtained from CFI (25194.45 kg/ha) and AFI (24020.83 kg/ha) systems were significantly different from FFI (20000 kg/ha) system. But, there was no significant difference between the yield obtained from CFI and AFI systems. As already known, there was a significant reduction (50%) in the volume of water applied to the AFI treatments. This means 2465.8 m^3 volume of water is needed to irrigate 1 hectare area in CFI system which is enough to irrigate 2 hectare area of land in AFI system. So, when the area to be irrigated becomes double in AFI system using the saved volume of water, the yield obtained also becomes double. In both AFI and FFI systems labour (4050.93 birr/ha), time (19:22'48" hrs/ha) and fuel (5457.18 birr/ha) needed for pumping irrigation water from the source were saved, which is half of CFI system. The reason why the yield result is well performing as compared to CFI system is probably because of a better application efficiency and physiological response associated with AFI (Franandez, 1994; Kang, 2000; Zhang *et al*., 2000) and less evapotranspiration associated with AFI (Stone *et al*., 1979).

Table 18. Effects of irrigation systems on yield performance

Irrigation systems	Yield (kg/ha)
CFI	25,194.45[a]
AFI	24,020.83[a]
FFI	20,000.00[b]
Mean	23071.76
CV	8.68%
$LSD_{0.05}$	3,393
SE	1,636.08

* Mean of twelve treatments observation

As clearly indicated in analysis of variance (Appendix Table 22), there were highly significant difference at ($P<0.01$) among the yield obtained from different levels of applied water. As shown on Table 19, the yields obtained from all water application levels were significantly different. This is consistent with the report of continuous water stress during the period of fruit set and fruit development can results significantly reduced fresh fruit yield and blossom-end rot (Sahasrabudhe, 1996).

Table 19. Effect of water application levels on yield performance

Application levels	(Yield kg/ha)
100%ETc	31879.63^{a}
85%ETc	24,574.08^{b}
70%ETc	20,796.30^{c}
50%ETc	15,037.04^{d}
Mean	23071.76
CV	8.68%
$LSD_{0.05}$	3,393
SE	1,636.08

* Mean of twelve treatments observations

Another inference from analysis of variance (Appendix Table 22) was the interaction effects between irrigation systems and water application levels which is highly significant at ($P<0.01$) on yield. From two ways Table 20 and Appendix Figure 6, yield obtained from CFI at all levels of applied water was significantly different. This shows that, yield was significantly affected as water application levels decreases, because of the low application efficiency associated with CFI system. Under AFI systems, there was a significant yield difference between 100% ETc and 85% ETc, 70% ETc, 50% ETc and also between 85% ETc and 50% ETc water application levels. For FFI system the yield result of 50% ETc was significantly different from water application levels of 100% ETc, 85% ETc and 50% ETc. But, in all of the three irrigation systems the yield decreases were low between water application levels of 85% ETc and 70% ETc. And when we compare the three irrigation systems in terms of yield obtained and the total irrigation water used, AFI system has best yield performance than the remaining irrigation systems.

Table 20. Two-way table of mean of yield (Kg/ha)

Irrigation systems	Water application level				Mean
	100%ETc	85%ETc	70%ETc	50%ETc	
FFI	22,500.00^{a}	22,527.78^{a}	20,777.78^{a}	15,277.78^{b}	20,270.84
AFI	31,444.44^{a}	24,777.78^{b}	21,694.44^{cb}	15,944.44^{d}	23,465.28
CFI	38,694.44^{a}	25,500.00^{b}	21,861.11^{c}	15,555.56^{d}	25,402.78
Mean	30,879.63	24,268.52	21,444.44	15,592.59	23,046.30
$LSD_{0.05}$	3,393				

4.7.2. Evaluation of water use efficiency

The two types of water use efficiency namely crop water use efficiency (CWUE) and field water use efficiency (FWUE) were estimated to evaluate AFI, FFI and CFI systems. In this experiment, the water lost as runoff or tail water does not exist, due to this, the values of both efficiencies were considered as equal.

4.7.2.1. Crop water use efficiency (CWUE) and Field water use (FWUE)

With the intention of comparing CWUE and FWUE of the three irrigation systems, both efficiencies were calculated by the equations 23 and 24 as discussed in section 3.9.6.1 and 3.9.6.2 respectively, the obtained mean results were presented in Appendix Table 23.

From the results of analysis of variance (Appendix Table 24), there were highly significant difference at ($P<0.01$) between the three irrigation systems both in CWUE and FWUE. As clearly indicated on Table 21, both CWUE and FWUE of the irrigation systems were significantly different from each other. 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).

Table 21. Effect of irrigation systems on CWUE and FWUE

Irrigation systems	CWUE and FWUE (kg $ha^{-1}mm^{-1}$)
AFI	256.69^{a}
FFI	214.77^{b}
CFI	130.53^{c}
Mean	200.66
CV	11.12%
$LSD_{0.05}$	37.79
SE	18.22

* Mean of twelve treatments observations

As observed from analysis of variance (Appendix Table 24), there were no significant difference among the water application levels on CWUE and FWUE.

As shown on analysis of variance (Appendix Table 24), there were no significant interaction between irrigation systems and water application levels on both CWUE and FWUE. However, the maximum and minimum mean values were observed from AFI (256.69 $kgha^{-1}mm^{-1}$) and CFI (130.53 $kgha^{-1}mm^{-1}$), while the maximum and minimum mean values for irrigation water application levels 100% ETc (206.00 $kgha^{-1}mm^{-1}$) and 85% ETc (192.81 $kgha^{-1}mm^{-1}$) respectively.

5. SUMMARY, CONCLUSIONS AND RECOMMANDATIONS

5.1. Summary

In arid and semi-arid regions of the tropics, the amount of rainfall is low and its distribution is highly erratic to meet the daily crop evapotranspiration requirement. To overcome this problem, using irrigation is one of the means for improving and sustaining food production. The study area is known by intensive irrigation with problems of over application and high frequency irrigation in addition to irrigation water sodicity which reduces the land production and productivity. Now, the question is how to achieve the most economic use of available water so as to get the optimum benefits per unit of available water.

Considering the above problems, the experiment was designed in RCBD with two factorial combination having twelve treatments and replicated three times. The aim of this study was to evaluate the effects of deficit irrigation on soil properties, yield and water use efficiency of tomato under three furrow irrigation systems and four water application levels for tomato production. These different irrigation systems were AFI, FFI and CFI and four water application levels were 100% ETc, 85% ETc, 70% ETc and 50% ETc.

Evaluation of the performance of AFI, FFI and CFI systems in terms of application efficiency, Storage efficiency, UCC of applied water, advance rate, recession time, CWUE and FWUE and yield were considered as an important parameters in evaluating their performance. Then, on farm measurements were carried out to identify field parameters such as infiltration characteristics of the soil, advance and recession times, yields and soil moisture before and after irrigation. ANOVA and LSD were used to separate mean difference statistically.

The results were compared at $P<0.01$ and generally indicate that, maximum depth of irrigation water was applied during the mid developmental stage of a crop at the time when the crop needs high amount of water, the mean pH value of the soil before irrigation was nearly neutral and changed to moderately alkaline for AFI system and 50% ETc water application level, while it was changed to strongly alkaline for CFI and FFI systems and water application levels of 100% ETc, 85% ETc and 70% ETc. Soil organic matter, total nitrogen and available phosphorus contents were increases after irrigation while it was decreases for available potassium.

Advance rate was not significant between irrigation systems and water application levels and their interaction was also. Recession time of the AFI system was highly significant from CFI and FFI systems, but not significant between AFI and FFI systems. Water application levels of 100% ETc was highly significant from all application levels but no significant between 85% ETc and 70% ETc and interaction was significant. Christian's distribution uniformity obtained from CFI system was highly significant from AFI system, but no significant difference between CFI and FFI and interaction was also highly significant. 100% ETc of water application level was highly significant from the remaining three application levels on Christian's distribution uniformity.

Application efficiency in AFI and FFI systems were highly significant from CFI, but no significant difference between AFI and FFI systems. Water application levels on application efficiency were highly significant between 85% ETc and 50% ETc, but not significant between the rest levels and their interaction was also highly significant. Storage efficiency were highly significant among all water application levels except between 70% ETc and 50%ETc. CFI system was highly significant difference from AFI system, but no significant difference between AFI and FFI systems and interaction were not significant. Deep percolation loss of CFI system was highly significant difference from AFI and CFI systems. While, there were no significant difference between AFI and FFI systems. A water application level of 85% ETc was highly significant difference from 50% ETc on deep percolation losses, while the remaining was not significant and their interaction was also highly significant.

The yield obtained from CFI and AFI systems were not significantly different under 50% reduction of applied water for AFI, but there were highly significant difference between the yield obtained from FFI and CFI systems. For water application levels the yield obtained at all levels of water application and their interactions with irrigation systems were highly significant.

For both CWUE and FWUE, there were highly significant differences between the three irrigation systems, while water application levels and their interaction with irrigation systems were not significant.

5.2. Conclusion

The conclusions drawn from this study are:

1. Results obtained from this study show that, in AFI system the total water used was 50% of CFI system, but the tomato yield obtained was similar. Significant amount of water (1232.9m^3/ha) was saved by AFI system while it also maintains an acceptable tomato yield and quality. AFI and FFI systems saved labour (4050.93 birr/ha), time (19:22'48" hr/ha) and fuel (5457.18birr/ha) used for irrigation water pumping which is 50% of CFI system. Because in CFI system four furrows irrigated at same time while in AFI and FFI only two furrows out of four furrows. This may improves working conditions as technology allows irrigator moving on the dry furrows. This reduction in applied water is also important to minimize the risks of soil sodicity development in irrigated area, especially when the quality of irrigation water deteriorated. Rather than using 2465.8m^3 of water for 1 hectare in CFI system, it is possible to double the irrigated area to 2 hectares in AFI system.

2. Tomato needs high amount of irrigation water during the flowering stage, but in FFI system as half of the root stay dry throughout the growth period, continuous stress significantly reduces fresh fruit yield.

5.3. Recommendation

Based on the scope of the study and findings, the following recommendations have been made.

1. As intensive irrigation practice is already common in the study area, giving a training and advisory service for communities as to how to use crop water requirement based irrigation system is a basic, as over application and high frequency irrigation causes water logging, aggravate soil sadicity, water losses as runoff or tail water, increases cost of labour and fuel for pumping irrigation water.
2. As the experiment is carried out for one season and in one place, repeating the experiment in space and time is important to improve the validity of the finding.

3. The experiment was carried out by constant inflow rate with different application time to manage water application levels. So, future research work should be needed with different inflow rate and irrigation interval.

4. Alternative furrow irrigation system is the best technology among the tested technologies to be recommended for the communities of the study area, because of its high water application efficiency both (CWUE and FWUE), yield performance, in addition to time, labour and irrigation cost saving.

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7. APPENDICES

7.1. Appendix A Tables

Appendix Table 1. Average meteorological data and ETo of the experimental area

Months	Rainfall (mm/month)	Temperature (^{0}C) Max.	Min.	Humidity %	Wind speed (km/hr)	Sunshine (hr)	ETo (mm/month)
January	13.9	27.31	2.52	49.0	1.6	9.8	105.1
February	10.3	28.97	13.50	45.4	1.7	9.5	107.3
March	43.0	29.43	15.18	41.0	1.6	9.6	121.5
April	67.0	29.55	15.89	57.0	1.6	8.8	125.1
May	77.3	29.41	6.18	58.4	1.8	8.0	121.5
June	86.7	28.13	15.78	59.8	2.4	8.4	114.3
July	163.3	25.59	15.31	66.7	2.2	6.3	104.5
August	122.9	25.72	15.18	73.6	1.9	6.1	106.3
September	77.6	26.86	14.67	72.6	1.4	6.4	106.2
October	34.7	27.75	13.24	69.2	1.5	9.2	123.4
November	19.4	27.25	12.17	63.0	1.7	9.8	110.4
December	26.9	26.64	11.34	55.3	1.7	9.8	102.6
Total	719.0						1348.0

*The experimental site does not have meteorological station; these data were obtained from the nearest station (Ziway) which located at 70^0 9'N latitude, and 38^{0}07'E longitude with altitude 1650 m asl and about 12 km from the site.

Appendix Table 2. Tomato crop data used for CWR

Crop characteristics	Unit	Growth stage Initial	Development	Mid	Late	Total
Stage length	day	15.00	21.00	23.00	16.00	75
Crop coefficient	Kc	0.6	0.76	1.15	0.80	
Rooting depth	m	0.4	0.40	1.00	1.00	
Depletion level	p	0.3	0.30	0.40	0.50	
Yield response factor	Kv	0.5	0.60	1.00	0.80	1.05

Appendix Table 3. Soil data used for CWR determination

Soil description	Unit	Value
Soil type	Texture	Sandy loam
Total available soil moisture	mm/m depth	99.0
Initial soil moisture depletion	%	0
Initial available soil moisture	mm/m depth	99.0
Maximum infiltration rate	mm/hr	28.2
Depth of root restricting layer	m	1.5

Appendix Table 4. Irrigation events and CWR

Date of irrigation	ETo (mm/period)	Crop Kc	CWR (mm/period)	Irrigation Requirement(mm/period)
04/02/2016	35.14	0.60	21.08	21.08
15/02/2016	40.70	0.68	27.68	27.68
01/03/2016	55.50	1.14	63.27	63.27
15/03/2016	58.80	1.15	67.62	67.62
31/03/2016	62.55	1.07	66.93	66.93
Total	252.69			246.58

*ETo, Kc, CRW is potential evapotranspiration, crop coefficient and crop water requirement respectively.

Appendix Table 5. Irrigation interval and depth of water applied to each treatment

Irrigation systems	Water application levels	Irrigation period (26, January-31, March 2016) & depth of applied water (mm)				
		4th February	15th February	1st March	15th March	31st March
FFI	100% ETc	21.08	27.68	63.27	67.62	66.93
	85% ETc	17.92	23.53	53.78	57.48	56.89
	70% ETc	14.78	19.34	44.29	47.33	46.85
	50% ETc	10.54	13.84	31.64	33.81	33.47
AFI	100% ETc	21.08	27.68	63.27	67.62	65.93
	85% ETc	17.92	23.53	53.78	57.48	56.89
	70% ETc	14.78	19.34	44.29	47.33	46.85
	50% ETc	10.54	13.84	31.64	33.81	33.47
CFI	100% ETc	21.08	27.68	63.27	67.62	65.93
	85% ETc	17.92	23.53	53.78	57.48	56.89
	70% ETc	14.78	19.34	44.29	47.33	46.85
	50% ETc	10.54	13.84	31.64	33.81	33.47

Appendix Table 6. Soil infiltration test data of the experimental area

	Test point 1			Test point 2			Test point 3			Test point 4			Test point 5						
Cumulative time (min)	Reading (cm)	Difference Intake (cm)	Cumulative intake(cm)	Reading (cm)	Difference Intake (cm)	Cumulative intake(cm)	Reading (cm)	Difference Intake (cm)	Cumulative intake(cm)	Reading (cm)	Difference Intake (cm)	Cumulative intake(cm)	Reading (cm)	Difference Intake (cm)	Cumulative intake(cm)	Aver. differ. .intake (cm)	Aver. differ. intake (mm)	Aver. Infiltration rate (mm/hr)	Aver. cumulative intake (mm)
0	18	0	0	18	0	0	18	0	0	18	0	0	18	0	0	0	0	0	0
1	17.2	0.8	0.8	17.1	0.9	0.9	17.1	0.9	0.9	17.1	0.9	0.9	17.1	0.9	0.9	0.88	8.8	528.0	528.0
3	16.3	0.9	1.7	16.1	1.0	1.9	16.1	1.0	1.9	16.0	1.1	2.0	16.0	1.1	2.0	1.02	10.2	306.0	834.0
6	15.4	0.9	2.6	15.0	1.1	3.0	15.0	1.1	3.0	14.8	1.2	3.2	14.8	1.2	3.2	1.10	11.0	220.0	1054.0
11	14.4	1.0	3.6	13.8	1.2	4.2	13.8	1.2	4.2	13.5	1.3	4.5	13.5	1.3	4.5	1.20	12.0	144.0	1198.0
16	13.6	0.8	4.4	12.7	1.1	5.3	12.7	1.1	5.3	12.4	1.1	5.6	12.4	1.1	5.6	1.04	10.4	124.8	1322.8
21	12.8	0.8	5.2	11.8	0.9	6.2	11.7	1.0	6.3	11.4	1.0	6.6	11.4	1.0	6.6	0.94	9.4	112.8	1435.6
26	12.1	0.7	5.9	11.0	0.8	7.0	10.9	0.8	7.1	10.5	0.9	7.5	10.5	0.9	7.5	0.82	8.2	98.4	1534.0
36	10.9	1.2	7.1	9.7	1.3	8.3	9.6	1.3	8.4	9.2	1.3	8.8	9.2	1.3	8.8	1.28	12.8	76.8	1610.8
46	9.8	1.1	8.2	8.6	1.1	9.4	8.4	1.2	9.6	8.0	1.2	10	8.0	1.2	10.0	1.16	11.6	69.6	1680.4
56	8.8	1.0	9.2	7.7	0.9	10.3	7.4	1.0	10.6	7.0	1.0	11.0	7.0	1.0	11.0	0.98	9.8	58.8	1739.2
66	7.9	0.9	10.1	6.9	0.8	11.1	6.5	0.9	11.5	6.2	0.8	11.8	6.2	0.8	11.8	0.84	8.4	50.4	1789.6
76	7.1	0.8	10.9	6.2	0.7	11.8	5.8	0.7	12.2	5.5	0.7	12.5	5.5	0.7	12.5	0.72	7.2	43.2	1832.8
86	6.4	0.7	11.6	5.6	0.6	12.4	5.2	0.6	12.8	4.9	0.6	13.1	4.9	0.6	13.1	0.62	6.2	37.2	1870.0
106	5.2	1.2	12.8	4.3	1.2	13.6	3.9	1.3	14.1	3.7	1.2	14.3	3.7	1.2	14.3	1.22	12.2	36.6	1906.6
126	4.3	0.9	13.7	3.3	1.0	14.6	3.0	0.9	15.0	2.7	1.0	15.3	2.8	0.9	15.2	0.94	9.4	28.2	1934.8
146	3.4	0.9	14.6	2.3	1.0	15.6	2.1	0.9	15.9	1.7	1.0	16.3	1.9	0.9	16.1	0.94	9.4	28.2	1963.0
166	2.5	0.9	15.5	1.4	1.0	16.6	1.2	0.9	16.8	0.7	1.0	17.3	1.0	0.9	17.0	0.94	9.4	28.2	1991.2

Appendix Table 7. Soil laboratory analysis result before irrigation

Depth(cm)	pH in water	OM (%)	FC (%) by vol.	PWP (%) by vol.	Total N (%)	Available P_2O_5 (mg/kg soil)	Available K_2O (mg/kg soil)	Bd (g/cm^3)	Sand %	Silt %	Clay %	Textural class
0-20	7.15	1.24	23.77	12.28	0.09	46.32	311.41	1.32	71	8	21	Sandy loam
20-40	7.55	1.05	20.10	11.89	0.12	44.05	309.16	1.34	69	14	17	Sandy loam
Average	7.35	1.15	21.94	12.09	0.11	45.19	310.29	1.33	70	11	19	Sandy loam

Appendix Table 8. Soil analysis result after irrigation

Irrigation systems	Water application levels	Sampling depth (cm)	pH in water	OM (%)	Total N (%)	Available P_2O_5 (mg/kg soil)	Available K_2O (mg/kg soil)
FFI	100% ETc	0-20	8.20	1.12	0.09	47.69	239.98
		20-40	8.32	1.07	0.12	45.67	236.67
		Average	8.26	1.10	0.11	46.68	238.33
	85% ETc	0-20	8.02	1.46	0.11	47.04	228.36
		20-40	8.13	1.39	0.13	46.34	222.47
		Average	8.08	1.43	0.12	46.69	225.42
	70% ETc	0-20	8.10	1.12	0.09	49.20	282.13
		20-40	8.18	1.09	0.11	47.34	277.79
		Average	8.14	1.11	0.10	48.27	279.96
	50% ETc	0-20	7.85	1.19	0.09	46.97	290.24
		20-40	7.88	1.12	0.11	44.89	285.26
		Average	7.87	1.16	0.10	45.93	287.75
AFI	100% ETc	0-20	7.71	1.25	0.10	48.72	237.87
		20-40	7.75	1.14	0.12	46.89	230.69
		Average	7.73	1.20	0.11	47.81	234.28
	85% ETc	0-20	8.15	1.35	0.11	47.28	294.06
		20-40	8.10	1.31	0.12	45.73	289.43
		Average	8.13	1.33	0.12	44.79	291.75
	70% ETc	0-20	8.00	1.39	0.12	45.73	269.18
		20-40	7.98	1.29	0.13	44.35	262.51
		Average	7.99	1.34	0.13	45.04	265.85
	50% ETc	0-20	7.20	1.18	0.09	47.09	312.01
		20-40	7.11	1.05	0.10	45.67	303.27
		Average	7.17	1.12	0.10	46.38	307.64
	100% ETc	0-20	8.20	1.40	0.10	45.47	293.89
		20-40	8.45	1.29	0.11	44.47	286.41
		Average	8.33	1.35	0.11	44.85	290.15
	85% ETc	0-20	7.67	1.43	0.11	47.04	339.81
		20-40	7.73	1.37	0.12	45.57	339.77

		Average	7.70	1.40	0.12	46.31	335.29
CFI	70% ETc	0-20	8.07	1.55	0.10	48.80	313.12
		20-40	8.11	1.45	0.10	46.97	304.12
		Average	8.09	1.50	0.10	47.89	308.62
	50% ETc	0-20	8.10	1.29	0.10	49.66	289.79
		20-40	8.12	1.20	0.10	47.89	278.99
		Average	8.11	1.25	0.10	48.78	284.39

*OM-organic matter, FC- field capacity, PWP- permanent wilting point, Bd- bulk density, N-nitrogen, P_2O_5-phosphoruspenta oxide, K-Potassium

Appendix Table 9. Parshiall flume head and discharge relationship

	Throught width (inches)				
	1	2	3	6	9
Head (cm)	Discharge (L/sec)				
2	0.140	0.281			
3	0.263	0.526	0.772	1.496	2.504
4	0.411	0.822	1.206	3.889	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	25.380	38.837

Appendix Table 10. Advance rate (m/s)

Irrigation systems	Water application levels	Advance rate across replication			Mean
		I	II	III	
FFI	100% ETc	0.349	0.414	0.371	0.126
	85% ETc	0.367	0.353	0.357	0.120
	70% ETc	0.324	0.371	0.383	0.120
	50% ETc	0.387	0.409	0.300	0.122
AFI	100% ETc	0.357	0.419	0.367	0.127
	85% ETc	0.290	0.33	0.324	0.105
	70% ETc	0.391	0.367	0.310	0.119
	50% ETc	0.409	0.419	0.379	0.125
CFI	100% ETc	0.389	0.369	0.396	0.126
	85% ETc	0.355	0.398	0.386	0.128
	70% ETc	0.400	0.377	0.389	0.130
	50% ETc	0.030	0.330	0.407	0.119
Mean		0.030	0.032	0.030	

Appendix Table 11. Recession time (min)

Irrigation systems	Water application levels	Recession time across replication			Mean
		I	II	III	
FFI	100%ETc	88.00	85.33	87.00	86.78
	85%ETc	75.50	73.00	86.30	78.27
	70%ETc	74.34	70.00	76.00	73.44
	50%ETc	69.33	67.67	72.67	69.89
AFI	100%ETc	78.67	76.67	73.00	76.11
	85%ETc	76.33	75.33	70.33	74.00
	70%ETc	72.00	74.67	67.00	71.22
	50%ETc	61.00	59.00	61.33	60.44
CFI	100%ETc	99.67	97.67	100.00	99.11
	85%ETc	83.33	81.67	88.00	84.33
	70%ETc	80.67	73.67	80.67	78.34
	50%ETc	70.00	72.67	72.33	71.67
Mean		77.74	75.86	77.89	

Appendix Table 12. Analysis of variance for recession time

Source of variation	SS	df	MS	F computed	F-tab (0.05)	F-tab (0.01)
Blocks	30.55	2	15.27	1.07	3.44	5.72
Treatments	7,716,395.10	11				
Systems	1,014.34	2	507.17	35.52	3.44	5.72**
Levels	2,030.31	3	676.77	47.39	3.05	4.82**
System x levels	282.65	6	47.11	3.30	2.55*	3.76
Error	314.16	22	14.28			
Total	7,720,067.10	46				

*-significant **-highly significant

Appendix Table 13. UCC computed from gravimetric moisture content (%)

Irrigation systems	Water application levels	UCC across replication I	II	III	Mean
FFI	100% ETc	83.03	82.22	81.70	82.32
	85% ETc	82.13	79.28	78.71	80.04
	70% ETc	80.31	81.07	81.35	80.91
	50% ETc	76.06	78.41	78.25	77.57
AFI	100% ETc	80.45	81.67	79.94	80.67
	85% ETc	80.32	78.99	79.48	79.60
	70% ETc	74.56	77.57	76.03	76.05
	50% ETc	75.69	81.78	81.61	79.69
CFI	100% ETc	84.63	86.32	84.18	85.04
	85% ETc	81.25	80.55	80.05	80.62
	70% ETc	81.52	81.85	79.83	80.07
	50% ETc	79.70	80.23	80.86	80.26
Mean		79.97	80.83	80.17	

Appendix Table 14. Analysis of variance for UCC

Source of variation	SS	df	MS	F computed	F-tab	
					(0.05)	(0.01)
Blocks	4.19	2	2.41	1.20	3.44	5.72
Treatments	8,361,269.60	11				
Systems	45.23	2	22.62	11.27	3.44	5.72**
Levels	71.14	3	23.72	11.81	3.05	4.82**
System x levels	46.19	6	7.70	3.84	2.55	3.76**
Error	44.16	22	2.01			
Total	8,361,481.12	46				

**- highly significant

Appendix Table 15. Gravimetric moisture content for Ea computation

Irrigation systems	Water application levels	Ea across replication			Mean
		I	II	III	
FFI	100%ETc	60.68	52.85	59.35	57.69
	85%ETc	56.00	56.75	54.80	55.85
	70%ETc	61.04	59.69	57.32	59.35
	50%ETc	62.71	66.13	63.09	63.98
AFI	100%ETc	60.25	62.05	61.10	61.13
	85%ETc	59.82	59.69	53.85	57.79
	70%ETc	60.09	59.62	58.67	59.46
	50%ETc	61.95	63.95	64.33	63.41
CFI	100%ETc	60.06	59.35	60.15	59.85
	85%ETc	56.42	56.53	55.47	56.14
	70%ETc	53.52	54.95	52.38	53.61
	50%ETc	50.60	51.61	52.28	51.50
Mean		58.62	58.60	57.73	

Appendix Table 16. Analysis of variance for application efficiency (Ea)

Source of variation	SS	df	MS	F computed	F-tab (0.05)	F-tab (0.01)
Blocks	6.12	2	3.10	0.83	3.44	5.72
Treatments	4,407,396.00	11				
Systems	175.23	2	87.62	23.74	3.44	5.72**
Levels	62.19	3	20.73	5.62	3.05	4.82**
System x levels	214.44	6	35.74	9.68	2.55	3.76**
Error	81.19	22	3.69			
Total	4,407,935.55	46				

**- highly significant

Appendix Table 17. Storage efficiency (%)

Irrigation systems	Water application levels	Er across replication I	II	III	Mean
FFI	100%ETc	71.49	71.49	71.17	71.23
	85%ETc	66.77	65.48	62.07	64.77
	70%ETc	65.86	61.86	59.40	62.37
	50%ETc	60.29	64.74	61.43	62.15
AFI	100%ETc	67.85	66.50	67.81	67.39
	85%ETc	64.60	65.63	63.53	64.59
	70%ETc	61.08	61.22	61.58	61.29
	50%ETc	59.19	58.95	59.85	59.33
CFI	100%ETc	72.06	73.55	71.78	72.46
	85%ETc	68.17	65.97	65.68	66.61
	70%ETc	63.98	61.58	61.88	62.48
	50%ETc	61.88	61.10	61.56	61.51
Mean		65.40	65.05	64.23	

Appendix Table 18. Analysis of variance for storage efficiency

Source of variation	SS	df	MS	F computed	F-tab (0.05)	F-tab (0.01)
Blocks	8.62	2	4.31	2.05	3.44	5.72
Treatments	5,842,275.73	11				
Systems	24.85	2	12.42	5.91	3.44	5.72**
Levels	524.65	3	174.88	83.16	3.05	4.82**
System x levels	20.00	6	3.33	1.58	2.55	3.76^{NS}
Error	46.27	22	2.10			
Total	5,842,900.00	46				

**- highly significant, NS-non significant

Appendix Table 19. Effect of treatments on irrigation water loss indicators

		Deep percolation % across replications			
Irrigation systems	Water application levels	I	II	III	Mean
FFI	100% ETc	39.14	47.15	40.65	42.31
	85% ETc	43.92	43.25	45.20	44.12
	70% ETc	38.96	40.31	42.68	40.65
	50% ETc	37.29	33.87	36.91	36.03
AFI	100% ETc	39.75	37.95	38.90	38.87
	85% ETc	43.19	40.18	43.29	42.22
	70% ETc	39.91	40.38	41.33	40.54
	50% ETc	38.05	36.05	35.67	36.37
CFI	100% ETc	39.94	40.65	39.85	40.15
	85% ETc	43.58	43.47	44.53	43.86
	70% ETc	46.48	45.05	47.63	46.39
	50% ETc	49.40	48.39	47.72	48.50

Appendix Table 20. Analysis of variance for deep percolation (Df)

Source of variation	SS	df	MS	F computed	F-tab	
					(0.05)	(0.01)
Blocks	5.56	2	2.78	0.83	3.44	5.72
Treatments	2,292,801.64	11				
Systems	127.71	2	63.85	19.12	3.44	5.72**
Levels	52.54	3	17.51	5.24	3.05	4.82**
System x levels	201.64	6	33.61	10.06	2.55	3.76**
Error	73.46	22	3.34			
Total	2,293,262.55	46				

**-highly significant

Appendix Table 21.Tomato harvested yield (Kg/ha)

Irrigation systems	Water application levels	Replication			Mean
		I	II	III	
FFI	100%ETc	24,500.00	26,500.00	25,500.00	25,500.00
	85%ETc	20,166.67	23,416.67	22,583.33	22,055.56
	70%ETc	17,083.33	19,083.33	17,833.33	18,000.00
	50%ETc	16,166.67	13,166.67	14,000.00	14,444.45
AFI	100%ETc	32,333.33	31,250.00	30,750.00	31,444.44
	85%ETc	27,166.67	25,083.33	24,583.33	25,611.11
	70%ETc	28,833.33	21,500.00	17,250.00	22,527.78
	50%ETc	17,583.33	16,416.67	15,500.00	16,500.00
CFI	100%ETc	39,500.00	38,833.33	37,750.00	38,694.44
	85%ETc	26,916.67	26,166.67	25,083.33	26,055.56
	70%ETc	22,333.33	22,666.67	20,583.33	21,861.11
	50%ETc	16,666.67	11,250.00	14,583.33	14,166.67
Mean		24,104.17	22,944.44	22,166.67	

Appendix Table 22. Analysis of variance for yield

Source of variation	SS	df	MS	F computed	F-tab (0.05)	F-tab (0.01)
Blocks	22,815,235	2	11,407,618	2.84	3.44	5.72
Treatments	$6.8987*10^{11}$	11				
Systems	178,106,834	2	89,053,417	22.18	3.44	5.72**
Levels	1,346,130,070	3	448,710,023	111.75	3.05	4.82**
System x levels	158,325,238	6	26,387,540	6.57	2.55	3.76**
Error	88,332,911	22	4,015,132			
Total	$6.8988*10^{11}$	46				

**-highly significant

Appendix Table 23. CWUE and FWUE (kgha^{-1}mm^{-1})

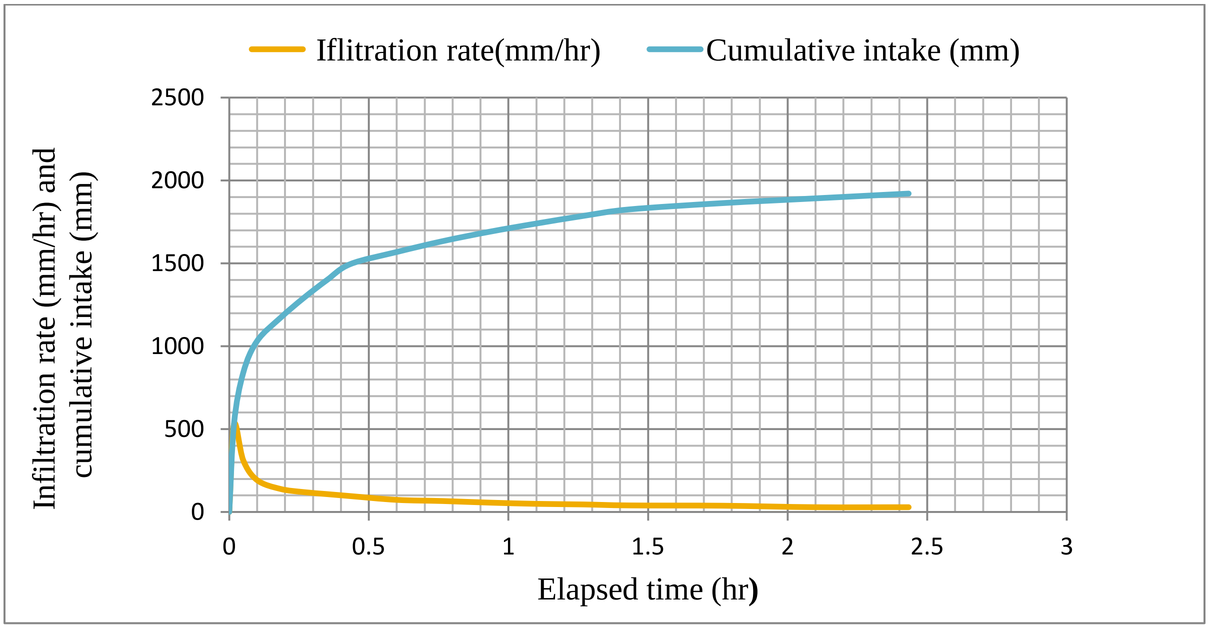
Irrigation systems	Water application levels	Replication I	Replication II	Replication III	Mean
FFI	100%ETc	198.46	214.66	206.56	206.56
	85%ETc	192.19	223.16	215.22	210.19
	70%ETc	197.69	220.83	206.37	208.30
	50%ETc	261.91	213.31	226.81	234.01
AFI	100%ETc	261.91	253.14	249.09	254.71
	85%ETc	258.90	239.05	234.28	244.08
	70%ETc	333.64	248.79	199.61	260.68
	50%ETc	284.84	265.94	251.09	267.29
CFI	100%ETc	159.98	157.28	152.90	156.72
	85%ETc	128.26	124.68	119.52	124.15
	70%ETc	129.22	131.15	119.10	126.49
	50%ETc	135.01	91.13	118.13	114.76
Mean		198.18	186.52	180.36	

Appendix Table 24. Analysis of variance for CWUE and FWUE

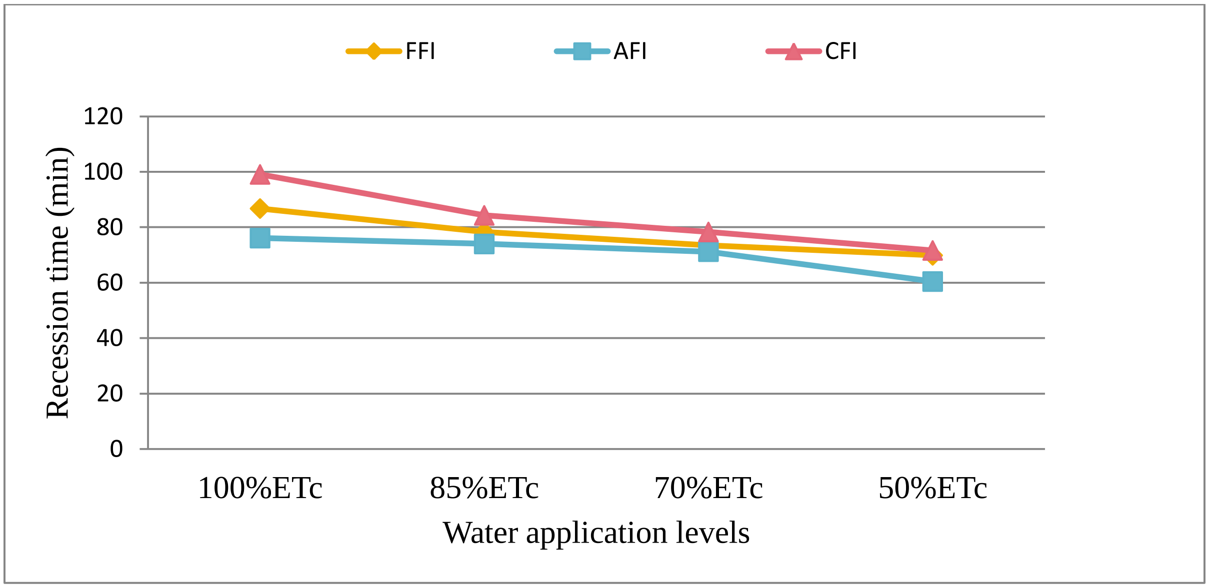
Source of Variation	SS	df	MS	F computed	F-tab (0.05)	F-tab (0.01)
Blocks	2544.09	2	1272.04	2.55	3.44	5.72
Treatments	4,7123,964.21	11				
Systems	99076.94	2	49538.47	99.46	3.44	5.72**
Levels	1051.97	3	350.66	0.70	3.05	4.82^{NS}
System x levels	4298.40	6	716.40	1.44	2.55	3.76^{NS}
Error	10957.00	22	498.08			
Total	117928.4	46				

**-highly significant NS-non significant

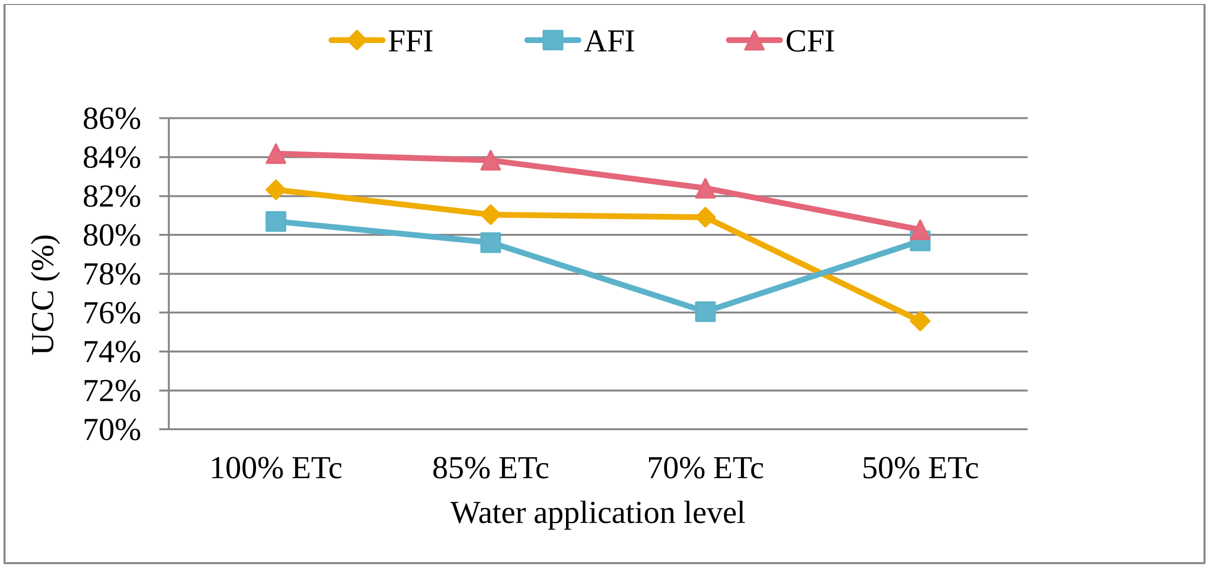
7.2. Appendix B Figures



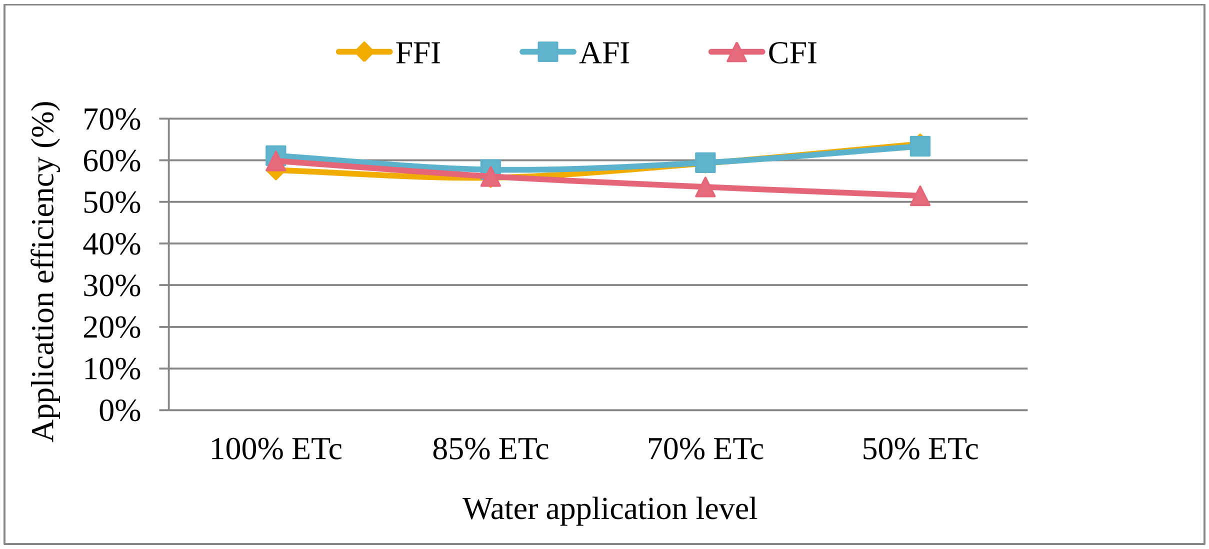
Appendix Figure 1. Cumulative and infiltration rate curve



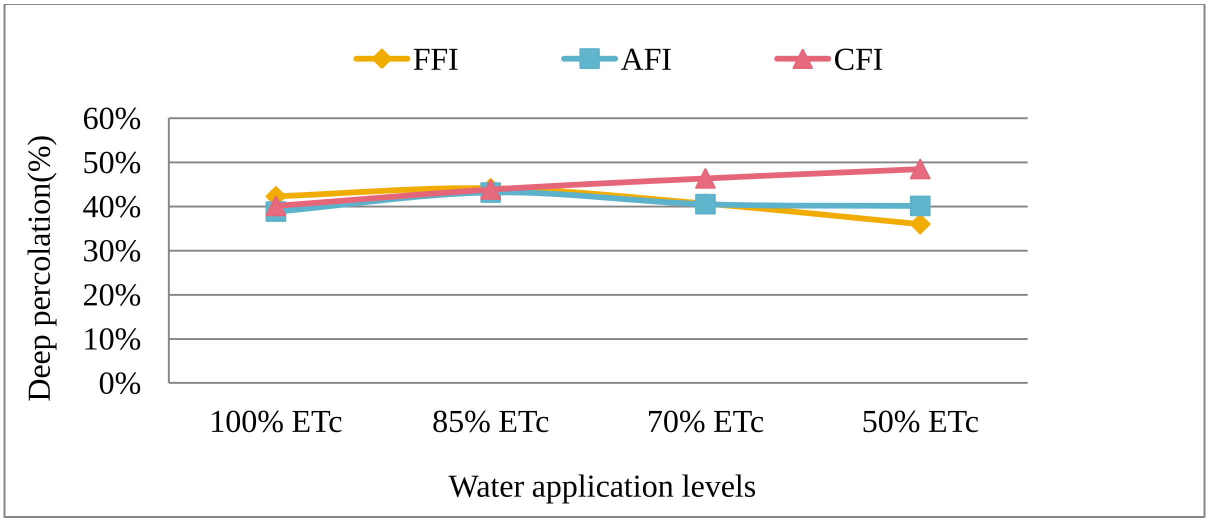
Appendix Figure 2. Effect of irrigation systems and water application levels on RT



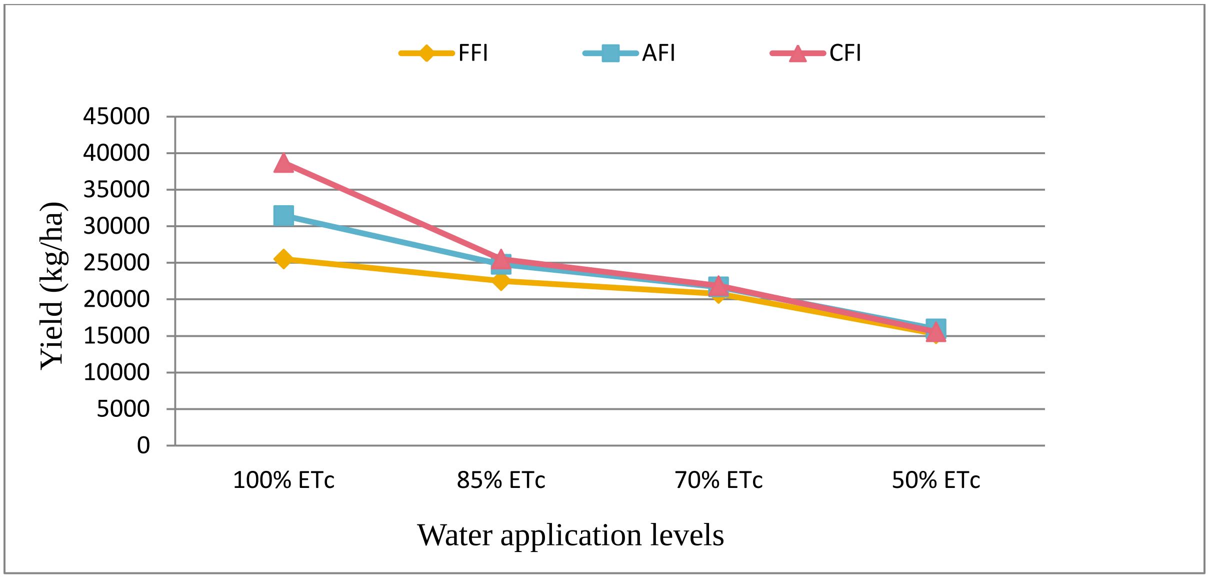
Appendix Figure 3. Effect of irrigation systems and water application levels on UCC



Appendix Figure 4. Effect of irrigation systems and water application levels on Ea



Appendix Figure 5. Effect of irrigation systems and water application levels on Dp losses



Appendix Figure 6. Effect of irrigation systems and water application levels on yield

Appendix Figure 7. Infiltration measurement

Appendix Figure 8. Land Preparation

Appendix Figure 9. Parshall flume installed for discharge measurement

Appendix Figure 10. Tensiometer installed for moisture monitoring at field condition

Appendix Figure 11. Training of FRG on how to manage irrigation water

Appendix Figure 12. Field visit for monitoring and Evaluation (M & E)

Appendix Figure 13. Soil sample analysis